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ECOLOGY OF GEORGETOWN SALAMANDERS (*EURYCEA NAUFRAGIA*) WITHIN THE FLOW OF A SPRING

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Abstract—The Georgetown salamander, *Eurycea naufragia*, is a permanently neotenic salamander known only from about a dozen surface springs and caves in Williamson County, Texas. Rapid urbanization places all known populations at risk and conservation strategies are hindered by a lack of information on the ecology of the species. To better understand requirements of microhabitat and spatial distribution of *E. naufragia* within flows of surface springs, we conducted counts of salamanders on the surface at one locality over a 12-month period. Numbers of salamanders and percentage of cover objects occupied by salamanders varied among months, with a general trend of higher abundance in spring and summer. Few juveniles were observed, and there was no strong seasonal trend in distribution of size of salamanders. Within the flow of the spring, abundance of salamanders decreased linearly with distance from origin of the spring. Salamanders were more likely to be under rocks than under other types of cover objects and they selected larger rocks. Larger salamanders occupied larger cover objects; rocks covering multiple salamanders were larger than those covering single salamanders.

Resumen—La salamandra *Eurycea naufragia* es una salamandra permanentemente neoténica conocida solamente de una docena de manantiales superficiales y cuevas en el condado de Williamson de Texas. La rápida urbanización que ocurre en las áreas donde habita la especie pone a todas las poblaciones conocidas en riesgo, pero las estrategias de conservación son impedidas por falta de información básica sobre su ecología. Para entender mejor las necesidades del microhábitat y la distribución espacial de *E. naufragia* dentro de los flujos de los manantiales superficiales, contamos el número de salamandras en la superficie de una localidad por un período de doce meses. La cantidad de salamandras y el porcentaje de objetos de cubierta utilizados por las salamandras variaron de mes en mes, con una tendencia general de más abundancia durante los meses de la primavera y del verano. Observamos muy pocos juveniles, y no hubo ninguna fuerte tendencia estacional en las distribuciones del tamaño de las salamandras. Dentro del flujo del manantial, la abundancia de las salamandras disminuyó linealmente con la distancia del nacimiento del manantial. Fue más probable encontrar salamandras debajo de piedras que debajo de otros tipos de objetos de cubierta y las salamandras eligieron piedras más grandes. Las salamandras más grandes ocuparon objetos de cubierta más grandes; las piedras cubriendo múltiples salamandras fueron más grandes que las que cubrieron salamandras individuales.

The Georgetown salamander, *Eurycea naufragia*, is an endemic, spring-dwelling and cave-dwelling salamander restricted to the San Gabriel River drainage in central Texas. The species occurs at ca. 12 sites and its entire range is within the vicinity of Georgetown, Texas, an area that is undergoing rapid growth and urbanization. The population of Georgetown was 9,468 in 1980 but had increased to 44,398 in 2007 and is projected to reach 84,000 by 2015. Published research on *E. naufragia* is limited to the original description of its genetic and morphological characteristics (Chippindale et al., 2000) and general treatments of *Eurycea* in central Texas (e.g., Chippindale and Price, 2005). *Eurycea naufragia* has been included as a candidate for listing as endangered (Jones, 2001), but currently is not protected by federal or state regulation. Because of its conservation status, basic information on distribution and ecology is critical for management of the species.

Populations of *E. naufragia* originally were assigned to the wide-ranging species *E. neotenes* (Bishop and Wright, 1937; Sweet, 1977, 1984), but analysis of molecular data (Chippindale et al., 1993, 1998, 2000; Hillis et al., 2001) demonstrated numerous evolutionarily distinct lineages within *Eurycea* from central Texas. Chippindale et al. (2000) determined that populations of *Eurycea* in Texas north of the Colorado River were monophyletic and exhibited considerable genetic divergence from other populations of *Eurycea* on the Edwards Plateau. Based on allozymes, sequences of mitochondrial DNA, morphology, and osteology, they described three species in Texas north of the Colorado River: *E. tonkawae* from the Jollyville Plateau in Travis and Williamson counties, *E. naufragia* from the San Gabriel River drainage in Williamson County, and *E. chisholmensis* from Salado Creek in Bell County. Chippindale et al. (2000) listed seven populations of *E. naufragia.* They suggested that additional populations might occur west of Georgetown and, indeed, we and others have located salamanders at several additional sites. Currently, we are aware of past collections, observations, or both, of *E. naufragia* at 14 locations in Williamson County, Texas; some of these were 20–30 years ago and we have not been able to confirm presence of salamanders at several previously reported sites.

In spring 2007, we initiated a low-impact ecological study of *E. naufragia* with the goal of better understanding the ecology of salamanders within flows of surface springs. Counts of *E. naufragia* on the surface were made monthly or bimonthly at Swinbank Spring near Georgetown, Williamson County, Texas, over a period of 1 year. Counts of salamanders on the surface were conducted 4 April, 7 June, 24 August, 21 September, 26 October, 30 November, and 31 December in 2007, and 1 February, 29 February, and 28 March in 2008. For analysis of selection of microhabitat, we also included results of one count conducted at Taylor Ray Hollow Spring on 20 April 2007.

All counts were conducted during 0800–1700 h. For each count, we established a transect along the flow of the spring, beginning at the origin and extending 25 m downstream. Starting at the bottom of the transect and working upstream, we overturned objects that were submerged in the flow and potentially capable of covering a salamander. For each potential cover object, we recorded location along the transect (in m), classified it to type (rock, stick, leaf litter, gravel, or other), recorded its two broadest dimensions (in cm), and recorded the aquatic habitat in which it occurred (riffle, pool, or bedrock glide). We recorded presence of *E. naufragia* and crayfish (*Procambarus clarkii*) under cover objects. Each salamander was assigned to one of three size classes (<2.5, 2.5–5.1, or >5.1 cm) based on a visual estimate of its total length from tip of snout to tip of tail. To minimize disturbance to the population, we did not attempt to capture or handle salamanders during surveys, and we returned all potential cover objects examined to their original location after observation. At the conclusion of each count, we measured temperature (°C) and specific conductivity ($\mu S\ cm^{-1}$) of the water at 1-m intervals along the transect.

To standardize counts for sampling effort, we calculated percentage of cover objects exam-

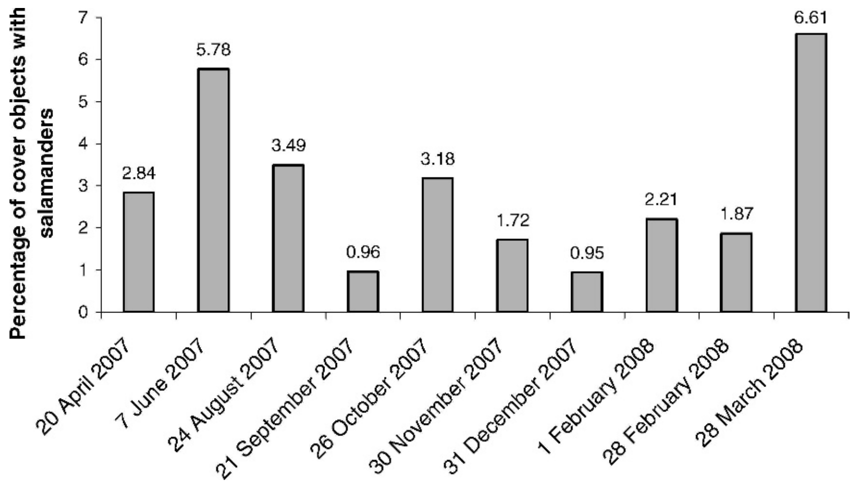

FIG. 1—Percentage of cover objects occupied by Georgetown salamanders (*Eurycea naufragia*) at Swinbank Spring, Williamson County, Texas, April 2007–March 2008.

ined that were occupied by salamanders. Because counts and surface areas of cover objects were not distributed normally, we used nonparametric statistics for analyses. Statistical tests were conducted using SPSS statistical software (SPSS 13.0 for Windows, release 13.01, SPSS, Inc., Chicago, Illinois). This study complied with all applicable institutional animal-care guidelines.

Numbers of salamanders observed at Swinbank Spring during surface counts were relatively small (range, 5–43). Percentage of cover objects occupied by salamanders at this site varied significantly among months (Fig. 1, $\chi^2 = 80.54$, $df = 9$, $P < 0.001$), ranging from ca. 1% in December to >6% in March. Similar temporal variation has been observed in counts of another species of *Eurycea* in central Texas (Bowles et al., 2006). In the one survey at Taylor Ray Hollow Spring, we observed 24 salamanders occupying 5.23% of cover objects.

Although percentage of cover objects occupied by salamanders varied considerably among months, there was a general trend of higher abundance in summer and spring and lower abundance in winter. Similarly, Bowles et al. (2006) observed highest counts of *E. tonkawae* during spring and summer. The cause of monthly variation in counts at Swinbank Spring is not known. However, monthly variation in counts is not directly explained by recruitment of new salamanders via reproduction, as almost all salamanders were >2.5 cm; a size class considered to be adult (Bruce, 1976; Najvar et al., 2007). We suspect that monthly differences in abundance of salamanders are influenced by variation in distribution of salamanders on the surface within the flow of the spring; during certain months, more salamanders may be near the surface of the flow, where they are more likely to be observed in our counts. Differences in abundance of food, chemistry of the water, or flow may influence abundance of salamanders on the surface and contribute to variation in abundance among months.

Percentage of cover objects occupied by crayfish also varied among months ($\chi^2 = 29.01$, $df = 9$, $P = 0.001$), but there was no significant correlation between percentage of cover objects occupied by salamanders each month and percentage of cover objects occupied by crayfish (Spearman's rho = 0.294, $P = 0.410$). In their study of *E. tonkawae*, Bowles et al. (2006) also detected no correlation between abundance of salamanders and abundance of crayfish. Abundance of crayfish also may be influenced by factors that affect their presence near the surface, but those factors appear to be different and uncorrelated from factors influencing abundance of salamanders at the surface.

We observed only five salamanders in the smallest, juvenile (Bruce, 1976; Najvar et al., 2007) size class. There was no strong seasonal trend in distribution of sizes of salamanders (Fig. 2) in our counts. Juveniles appeared only during autumn and winter, and there was a general

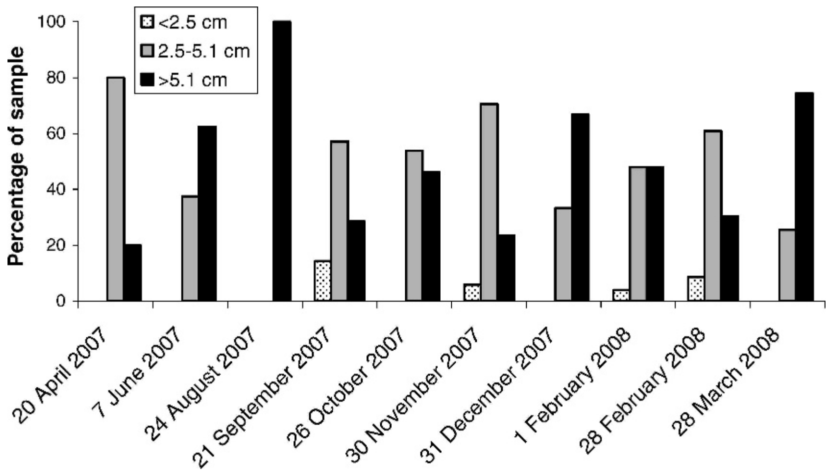

FIG. 2—Frequency of three size classes of Georgetown salamanders (*Eurycea naufragia*) at Swinbank Spring, Williamson County, Texas, April 2007–March 2008.

trend of a higher percentage of the largest salamanders (>5.1 cm) in spring and summer.

We never observed eggs and we observed few salamanders <2.5 cm in total length. Rarity of juveniles could result from low reproductive recruitment or from juveniles using microenvironments (e.g., subsurface gravel) that were not assessed in our counts. Bowles et al. (2006) also observed relatively few small *E. tonkawae*; the juveniles they observed occurred in highest numbers during March–August. In contrast, the only juveniles we observed occurred in autumn and winter, but, given the small numbers we observed, their absence in other months may be due to sampling error. Observations by Bowles et al. (2006) are consistent with *E. tonkawae* reproducing in spring and summer, but *E. nana* appears to reproduce during all months (Tupa and Davis, 1976; Najvar et al., 2007). We cannot speculate about the timing of reproduction in *E. naufragia* without data on gravid females, eggs, or more juvenile individuals.

Temperature of water along the upper 25 m of flow at Swinbank Spring varied a maximum of 0.1°C on any given day of our survey, except for the sample on 1 February when it varied 0.6°C. Range of temperature over the entire year was 20.2–21.0°C. Conductivity likewise showed relatively little variation along the transect on a given day, typically varying <10 μS cm^{-1}. Conductivity was 604–721 μS cm^{-1} during our year-long study.

To analyze spatial distribution of salamanders within the flow of Swinbank Spring, we divided the flow into 5-m segments and calculated percentage of cover objects occupied by salamanders, including all salamanders observed in our 10 surveys. Percentage of cover objects occupied by salamanders varied significantly among these 5-m segments ($\chi^2 = 187.57$, $df = 4$, $P < 0.001$). There was a strong negative correlation (Spearman's rho $= -1.000$, $P = 0.014$) between distance from origin of the spring and percentage of cover objects occupied by salamanders (Fig. 3).

Our informal observations at other springs suggest that *E. naufragia* at these sites also are most abundant within a few meters of the origin of the spring, consistent with observations of other *Eurycea* in central Texas (Sweet, 1982; Bowles et al., 2006). Sweet (1982) suggested that thermal stability of springs was critical for survival of *Eurycea* in central Texas, especially during summer when temperatures of water in shallow streambeds may exceed 30°C. However, at Swinbank Spring, there was no correlation between temperature of water and abundance of salamanders, as temperature of water varied little over the 25-m transect, even in summer. Yet, most salamanders were concentrated within 5 m of the origin of the spring. A requirement for thermal stability may indeed prevent salamanders from occupying habitat further downstream, but it does not appear to be responsible for spatial distribution of salamanders within the reach of the flow we examined at Swinbank Spring.

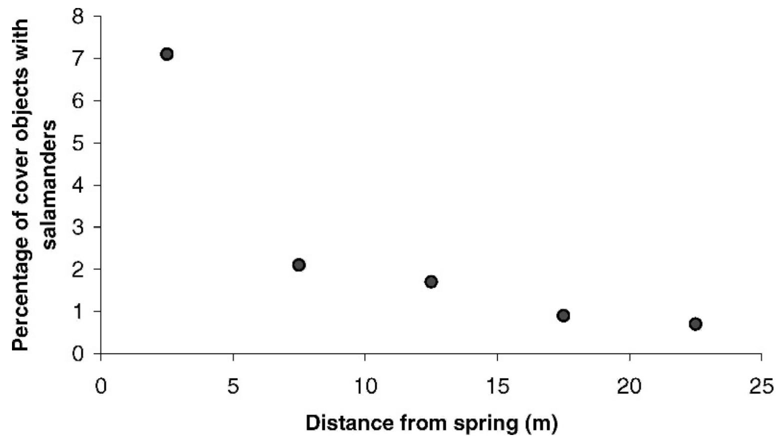

FIG. 3—Relationship between percentage of cover objects occupied by Georgetown salamanders (*Eurycea naufragia*) and linear distance from the origin of Swinbank Spring, Williamson County, Texas, April 2007–March 2008.

In our monthly counts at Swinbank Spring and the one survey at Taylor Ray Hollow Spring, we examined and measured a total of 8,318 potential cover objects and made 233 observations of salamanders. Most salamanders were under rocks (91.85%); others were in the open (6.44%) or under leaf litter (0.86%), sticks (0.43%), and other structural cover (0.43%). Rocks were the majority (90.8%) of potential cover objects that occurred within flows. Nevertheless, a chi-square analysis demonstrated that salamanders were under a significantly higher proportion of rocks than other cover objects ($\chi^2 = 11.73$, $df = 1$, $P = 0.001$). For example, salamanders were under 2.7% of all rocks examined, but were under only 0.7% of other cover objects.

Surface area of rocks occupied by salamanders (314.17 ± 28.50 cm^2, mean $\pm$ *SE*) was significantly larger than surface area of rocks without salamanders (122.06 ± 2.35 cm^2, Mann-Whitney $U = 399{,}791$, $P < 0.001$). Even when all rocks smaller than the minimum size occupied by salamanders (12 cm^2) were removed from the analysis, salamanders still occurred under significantly larger rocks (Mann-Whitney $U = 399{,}791$, $P < 0.001$). We observed two salamanders under the same rock on nine occasions and observed three salamanders under the same rock once. Average surface area of rocks occupied by ≥ 2 salamanders (726.85 ± 120.61 cm^2) was greater than surface area of rocks occupied by single salamanders (290.20 ± 28.31 cm^2; Mann-Whitney $U = 300$, $P < 0.001$). Salamanders in the largest size class (>5.1 cm total length) occurred under larger rocks than salamanders of the two smaller size classes (Mann-Whitney $U = 4038$, $P < 0.001$). Crayfish also occurred under larger rocks (Mann-Whitney $U = 385{,}851$, $P < 0.001$). A chi-square test of independence demonstrated that presences of salamanders and crayfish were not independent ($\chi^2 = 7.46$, $df = 1$, $P = 0.006$); significantly more salamanders and crayfish co-occurred under the same rocks than expected by chance. This co-occurrence is likely the result of both salamanders and crayfish selecting large rocks for cover objects. We never observed crayfish feeding on salamanders.

Bowles et al. (2006) reported that *E. tonkawae* preferred rock substrates to leaf litter and vegetation and that larger adults used larger-sized rocks as cover objects. They detected a strong relationship between available rock cover and density of salamanders among populations of *E. tonkawae*. However, we detected no significant correlation between average number of rocks in a 5-m segment of the flow and average number of salamanders observed in that segment during monthly counts (Spearman's rho = 0.1, $P = 0.870$). There were considerably more large rocks (>300 cm^2) in the first 5-m segment of the flow, where most salamanders were observed, but correlation between number of large rocks and average number of salamanders observed during monthly counts was not significant (Spearman's rho = 0.3, $P = 0.624$).

Our observations and those of others (Bowles et al., 2006) on cover objects that were occupied by salamanders suggest that salamanders are more likely to be under rocks than other cover objects and that they select rocks with larger surface areas. This suggests that presence of large rocks within flows is an important habitat requirement for *E. naufragia* and other *Eurycea* in central Texas that occupy surface flows of springs, an observation with implications for habitat management of these animals.

Habitat along the 25-m transect at Swinbank Spring consisted almost entirely of riffles; only 0.4% of cover objects we examined occurred in pools, and we observed no salamander in pools at Swinbank Spring. In contrast, pools with slow-moving water were a larger fraction of habitat at Taylor Ray Hollow Spring; 30.5% of cover objects examined at Taylor Ray Hollow Spring were in pools. At Taylor Ray Hollow Spring, a higher proportion of cover objects with salamanders occurred in pools than in riffles (9.3% in pools, 2.2% in riffles; $\chi^2 = 11.74$, $df = 1$, $P = 0.001$).

Counts such as those we conducted in this study provide relative estimates of abundance of salamanders at the surface of springs, but do not provide information about absolute size of populations. Densities of other populations of *E. naufragia* we have observed appear to be similar or lower than that those at Swinbank Spring. An unexplored question is whether subsurface populations of salamanders exist within the aquifer. If so, what is the extent to which subsurface populations are connected to surface populations?

Like all brook salamanders in central Texas, *E. naufragia* is permanently neotenic and critically dependent on its aquatic habitat. The species is restricted to pristine surface springs and wet caves associated with the Edwards Aquifer. These habitats are threatened by increased pumping of groundwater from the aquifer, increases in impervious cover that reduce recharge of the aquifer, and pollution of groundwater (Chippindale and Price, 2005). Research suggests that aquatic salamanders are sensitive to urban impacts (Orser and Shure, 1972; Willson and Dorcas, 2003; Bowles et al., 2006). The restricted distribution of *E. naufragia*, the small number of known populations, and the apparently limited abundance add to the vulnerability of this species.

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Literature Cited

Bishop, S. C., and M. R. Wright. 1937. A new neotenic salamander from Texas. Proceedings of the Biological Society of Washington 50:141–143.

Bowles, B. D., M. S. Sanders, and R. S. Hansen. 2006. Ecology of the Jollyville Plateau salamander (*Eurycea tonkawae*: Plethodontidae) with an assessment of the potential effects of urbanization. Hydrobiologia 553:111–120.

Bruce, C. 1976. Population structure, life history and evolution of paedogenesis in the salamander *Eurycea neotenes*. Copeia 1976:242–249.

Chippindale, P. T., and A. H. Price. 2005. Conservation of Texas spring and cave salamanders (*Eurycea*). Pages 193–197 in Amphibian declines: conservation status of United States species (M. Lannoo, editor). University of California Press, Berkeley.

Chippindale, P. T., A. H. Price, and D. M. Hillis. 1993. A new species of perennibranchiate salamander (*Eurycea*, Plethodontidae) from Austin, Texas. Herpetologica 49:248–259.

Chippindale, P. T., A. H. Price, and D. M. Hillis. 1998. Systematic status of the San Marcos salamander, *Eurycea nana* (Caudata: Plethodontidae). Copeia 1998:1046–1049.

Chippindale, P. T., A. H. Price, J. J. Wiens, and D. M. Hillis. 2000. Phylogenetic relationships and systematic revision of central Texas hemidactyliine plethodontid salamanders. Herpetological Monographs 14:1–80.

Hillis, D. M., D. A. Chamberlain, T. P. Wilcox, and P. T. Chippindale. 2001. A new species of subterranean blind salamander from Austin, Texas and a systematic revision of central Texas paedomorphic salamanders. Herpetologica 57:266–280.

Jones, M. P., Jr. 2001. Endangered and threatened wildlife and plants; review of plant and animal species that are candidates or proposed for listing as endangered or threatened, annual notice of findings on recycled petitions, and annual description of progress on listing actions. Federal Register 66(201):54808–54832.

Najvar, P. A., J. N. Fries, and J. T. Baccus. 2007. Fecundity of San Marcus salamanders in captivity. Southwestern Naturalist 52:145–156.

Orser, P. N., and D. J. Shure. 1972. Effects of urbanization on the salamander *Desmognathus fuscus fuscus*. Ecology 53:1148–1154.

Sweet, S. S. 1977. Natural metamorphosis in *Eurycea neotenes* and the generic allocation of the Texas *Eurycea* (Amphibia: Plethodontidae). Herpetologica 33:364–375.

Sweet, S. S. 1982. A distributional analysis of epigean populations of *Eurycea neotenes* in central Texas, with comments on the origin of troglobitic populations. Herpetologica 38:430–444.

Sweet, S. S. 1984. Secondary contact and hybridization in the Texas cave salamanders *Eurycea neotenes* and *E. tridentifera*. Copeia 1984:428–441.

Tupa, D. D., and W. K. Davis. 1976. Population dynamics of the San Marcos salamander, *Eurycea nana* Bishop. Texas Journal of Science 27:179–195.

Willson, J. D., and M. E. Dorcas. 2003. Effects of habitat disturbance on stream salamanders: implications for buffer zones and watershed management. Conservation Biology 17:763–771.

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