

- Hayes, M.P. 1994. The Spotted Frog (*Rana pretiosa*) in Western Oregon. Part I. Technical Report 94-1-01. Oregon Department of Fish and Wildlife, Salem.
- Kelley, D.B. 2004. Vocal communication in frogs. *Current Opinion in Neurobiology* 14:751-757.
- Ladich, F. and A.H. Bass. 2003. Underwater sound generation and acoustic reception in fishes with some notes on frogs. In: S.P. Collin and N.J. Marshall (eds.), *Sensory Processing in Aquatic Environments*. Springer, New York.
- Leonard, W.P., L. Hallock, and K.R. McAllister. 1997. *Rana pretiosa* (Oregon Spotted Frog). Behavior and reproduction. *Herpetological Review* 28:28.
- Licht, L.E. 1969. Comparative breeding behavior of the Red-legged Frog (*Rana aurora aurora*) and the Western Spotted Frog (*Rana pretiosa pretiosa*) in southwestern British Columbia. *Canadian Journal of Zoology* 47:1287-1299.
- MacTague, L. and P.T. Northern. 1993. Underwater vocalization by the Foothill Yellow-legged Frog (*Rana boylei*). *Transactions of the Western Section of the Wildlife Society* 29:1-7.
- Platz, J.E. 1993. *Rana subaquavocalis*, a new species of Leopard Frog (*Rana pipiens* complex) from southeastern Arizona. *Journal of Herpetology* 27:154-162.
- Rosen, M. and R.E. Lemon. 1974. The vocal behavior of Spring Peepers, *Hyla crucifer*. *Copeia* 1974:940-950.
- Schiötz, A. 1973. Evolution of anuran mating calls: Ecological aspects, pp. 311-319. In: J.L. Vial (ed.), *Evolutionary Biology of the Anurans*. University of Missouri Press, Columbia.
- Storm, R.M. 1960. Notes on the breeding biology of the Red-legged Frog (*Rana aurora*). *Herpetologica* 16:251-259.
- Wells, K.D. 1977. The social behavior of anuran amphibians. *Animal Behaviour* 25:666-693.

Suburbanization of a Central Texas Herpetofauna

Frederick R. Gehlbach

Department of Biology, Baylor University, Waco, TX 76798

Photographs by the author. All were taken at the study site.

Reptiles and amphibians were surveyed on the Balcones Escarpment in central Texas as the area was transformed into suburbia. Of four habitats, oak-juniper savanna was totally destroyed and a quarter of the adjacent oak-juniper woodland was eliminated, but two creeks and most deciduous riparian forest remained. Extirpation of 12 of 30 species (40%) included 55% of nine amphibian species, 50% of two turtles, 33% of six lizards, and 30% of 13 snakes. Herpetofaunal richness declined exponentially from 1965 to 1990 with increased house building, then stabilized through 2005 as building slowed and stopped. Species survival was related to use of cultural and remaining natural habitats, secretive behavior, and human interest.

Suburban development in Woodway (a suburb of Waco), McLennan County, Texas had begun in 1964, when I started a 46-year project to record the area's natural and unnatural herpetofaunal history (Gehlbach 2002). The 80-ha savanna was part of a ranch totally erased by suburbia during the study, and about 20% of adjacent woodland was lost. One earth-dammed stock pond was kept for fishing; the other was demolished by floods. Habitat protection was inadvertently affected by city building codes that saved forested ravines with steep slopes, creeks and their terraces,

and by a planned-unit development's 6-ha private nature preserve of creek, forest, and woodland in 1984.

This study presents features of extirpation, survival, and general abundance of each species of amphibian and reptile and describes herpetofaunal change during the study site's suburban development. I hope it will stimulate other studies that support conservation and educational use of nature preserves in our ever-growing U.S. cities.



A mating pair of Cope's Gray Treefrogs (*Hyla chrysoscelis*).



Strecker's Chorus Frog (*Pseudacris streckeri*).

Methods

Fieldwork covered the 120-ha study site (elevation 165–196 m) on the Balcones Escarpment in all months in 1964–2009. Original habitats were mature evergreen oak-juniper savanna, a livestock pasture with tree “islands” (locally called motts), two permanent creeks (each with a stock pond in a 12-m deep ravine with deciduous riparian forest), and deciduous oak-juniper woodland on limestone slopes with rock outcrops above the forested ravines. Observational and catch and release surveys in March–October included a 3.3-km transect (gradually reduced by house building to 1.2 km) in all habitats 2–4 times/week, 20 covered pitfall traps arranged

randomly in 200 m² of protected riparian forest and checked daily in April–June 1984–1989, and daily dead-on-road (DOR) records on 3–5 km of city streets bordering natural habitats and among houses in the study site and 1 km beyond it on all sides.

Species are grouped as follows: (1) Extirpated (no evidence for five consecutive years), (2) uncommon surviving (noted less frequently than weekly), or (3) common surviving (noted daily to weekly). Proportional herpetofaunal changes were analyzed, as was the cumulative number of extirpated species per five-year period in 1965–2005 relative to the concurrent rate of house building.



Great Plains Narrowmouth Toad (*Gastrophryne olivacea*).



Smallmouth Salamander (*Ambystoma texanum*).



Texas Spotted Whiptail (*Aspidoscelis* [*Cnemidophorus*] *gularis gularis*).

Scientific names follow Collins and Taggart (2009) or subsequent updates on the website of the Center for North American Herpetology (www.cnah.org); if recently changed, previous names are in brackets to assist recognition.

RESULTS

Extirpated Species:

Woodhouse’s Toad (*Anaxyrus* [*Bufo*] *woodhousii woodhousii*). Uncommon; disappeared by 1970 without evidence of local reproduction.

Cope’s Gray Treefrog (*Hyla chrysoscelis*). Uncommon March–April breeder in a stock pond and adjacent creek pools in riparian forest until game fish were stocked in the pond and some escaped into the creek in 1980; this frog disappeared in 1982.

Strecker’s Chorus Frog (*Pseudacris streckeri*). Common November–February breeder in the savanna’s rain pools further formed as livestock wallows in natural depressions until eliminated by 1975.

Great Plains Narrowmouth Toad (*Gastrophryne olivacea*). Uncommon breeder in savanna rain pools during April–June until 1975, but did not disappear until 1979.

Smallmouth Salamander (*Ambystoma texanum*). Common in the riparian forest; bred during October–December rains in creek pools and the stock pond that became a fishing pond. The second-most frequent DOR amphibian; gone by 1982.

Ornate Box Turtle (*Terrapene ornata*). Only two records in the savanna; none after 1975.

Texas Horned Lizard (*Phrynosoma cornutum*). Common in the savanna until 1975; subsequently uncommon in suburban vacant lots



Ground Snake (*Sonora semiannulata*).



An adult Yellowbelly Racer (*Coluber constrictor flaviventris*).



Texas Patchnose Snake (*Salvadora grahamiae lineata*).



A juvenile Yellowbelly Racer (*Coluber constrictor flaviventris*).



Broad-banded Copperhead (*Agkistrodon contortrix laticinctus*).

until 1978. A pronounced decline throughout central and eastern Texas coincided with insecticide spraying from airplanes in the 1970s to eradicate populations of imported Fire Ants that expanded during suburbanization.

Texas Spotted Whiptail (*Aspidoscelis* [*Cnemidophorus*] *gularis gularis*). Common in the savanna until 1975 and later uncommon in vacant lots among houses; gone by 1986.

Texas Patchnose Snake (*Salvadora grahamiae lineata*). This rarest of the 13 original snake species was found only twice in oak-juniper woodland; not seen after 1988.

Broad-banded Copperhead (*Agkistrodon contortrix laticinctus*). Uncommon in the two natural wooded habitats and occasionally in wooded suburban yards until 1970. A winter den 5 m above a creek in a limestone crevice had 19 sunning adults in October 1967; the den was apparently destroyed by dynamite and later bulldozed during development of planned-unit housing; extirpated by 1971.

Lined Snake (*Tropidoclonion lineatum*). Only three individuals were found under ground surface cover in the savanna, all before 1975, making this the second rarest snake in the original herpetofauna.

Ground Snake (*Sonora semiannulata*). Uncommon; 1–2 found annually under surface cover in evergreen woodland until 1983. Both plain brown-colored individuals and snakes with black heads and neck spots on a dull orange-brown ground color were present.

Uncommon Surviving Species

Southern Leopard Frog (*Lithobates sphenoccephalus utricularius* [*Rana sphenoccephala*]). Once a common breeder in creek pools in March–May, and still common in creeks and ponds outside the study site. Gradually less abundant in the study plot; not recorded in 2007–2009, hence extirpation is possible.

Northern Cricket Frog (*Acris crepitans*). Inhabits creek sides and breeds in creek pools in April–May, but, like the other anurans, eggs and tadpoles are washed downstream by floods enhanced by street drainage. Effective reproduction seems increasingly less infrequent for this and all of the suburban creek breeders that remain common to abundant elsewhere in local rural areas.

Three-toed Box Turtle (*Terrapene carolina triunguis*). Originally uncommon in riparian forest and rare in evergreen woodland. Since 1991, only one marked adult male has been found annually (but not in 2009), so the present status is unknown. A few liberated pets from outside the region were known before 2000, but extirpation is now quite possible.

Yellowbelly Racer (*Coluber constrictor flaviventris*). Moderately abundant in the original savanna and woodland, but gradually more uncommon in remaining woodland and woodland-yard edges, where it hunts lizards such as Northern Green Anoles and Texas Spiny Lizards. Originally 1–3 DOR records per year, but only one since 2000, reflecting reduced numbers.

Flathead Snake (*Tantilla gracilis*). This fossorial species is secretive but persists in remaining forest and woodland. Equal to Rough Earth Snakes, Flathead Snakes were the least frequent catch in pitfall traps and are the only surviving snake not yet found on developed property. This is the third



Coastal Plain Toad (*Ollotis nebulifer* [*Bufo valliceps*]).



Mediterranean Gecko (*Hemidactylus turcicus*) on the brick wall of a house.



An adult Eastern Hognose Snake (*Heterodon platirhinos*) exhibiting a defensive display against a predator.

most frequent DOR snake, most often on roads bordering or less than 75 m from remaining natural habitat.

Texas Garter Snake (*Thamnophis sirtalis annectens*). Always uncommon, although it persists in riparian forest near creeks and occasionally appears in suburban yards and gardens that adjoin remaining natural habitat.

Eastern Hognose Snake (*Heterodon platirhinos*). Another snake originally uncommon and rare today. Because of its initial aggressive, neck-flattening, defensive behavior, it is commonly thought to be dangerous and is sometimes confused with the Copperhead, hence summarily killed. Coastal Plain Toads are known food. A 48-cm (total length) adult was active at 16 °C in early December. One DOR was recorded in 2007.



Texas Spiny Lizard (*Sceloporus olivaceus*).

Common Surviving Species:

Coastal Plain Toad (*Ollotis nebulifer* [*Bufo valliceps*]). The most abundant anuran and most frequent DOR in all years, apparently because individuals congregate on streets to feed on insects below streetlights. Lays eggs in creek pools and backyard ponds during April–August rains, the longest breeding season among anurans. It is the only amphibian that utilizes artificial ponds at suburban residences. Whether an individual breeds more than once annually is unknown. Suburbanites do not mind toads on their property.

Rio Grand Leopard Frog (*Lithobates* [*Rana*] *berlandieri*). Breeds in creek pools during August–October. Increasingly less common, although, as noted for other anurans, abundant in ponds outside the study area. Street and yard water drains into creeks, so flooded eggs and tadpoles and/or dissolved toxins may be detriments to continued existence.

Mediterranean Gecko (*Hemidactylus turcicus*). Introduced to Waco, Texas in the early 1950s (B. Brown, pers. comm.) and to the study site by 1982. Lives on brick and stone walls and inside houses and other buildings; hatchlings appear anytime except December–February. Adults are active



Northern Green Anole (*Anolis carolinensis carolinensis*) on a potted porch plant.



Western Rat Snakes (*Scotophis obsoletus* [*Elaphe obsoleta*]) readily climb trees.



Rough Green Snake (*Opheodrys aestivus*).

throughout the year during nights with temperatures above -15°C , but in winter only if bricks have been sun-heated. One DOR.

Texas Spiny Lizard (*Sceloporus olivaceus*). In open forest, woodland, and wooded suburban yards on the ground and rocks and in trees (see also Blair 1960). Rarely climbs herbaceous vegetation. Gardens and backyard refuse piles are nest sites, also for Green Anoles, Ground Skinks, Western Rat Snakes, and probably other species. The most frequent DOR lizard.

Northern Green Anole (*Anolis carolinensis carolinensis*). Common around houses, less so in forest and woodland edges. Lives in planted herbaceous vegetation, shrubs, and trees in gardens, and climbs potted patio and porch plants and house walls. This species increased dramatically during suburbanization, benefiting from human interest and plantings that attract its insect food. Two–three broods per year in June–September. Adults are active throughout the year in sunny weather at temperatures above -15°C . The third most frequent DOR lizard.

Ground Skink (*Scincella lateralis [Lygosoma laterale]*). Only slightly less abundant than the Green Anole, but rarely noticed by suburbanites because of its secretive terrestrial habits in and under ground cover in wooded yards and gardens, especially at forest and woodland edges; 2–3 broods per year in July–September (see also Fitch and Greene 1965). This is the most frequent reptile in pitfall traps, and the only abundant species without a DOR record.

Rough Green Snake (*Opheodrys aestivus*). Moderately common in open riparian forest and brushy edges along creeks and in yards and gardens, where it is unnoticed lying lengthwise on low foliage while sit-and-wait foraging for insects. Its green coloration and behavior hide it so effectively that I never heard of one killed by people. One DOR record.

Western Rat Snake (*Scotophis obsoletus [Elaphe obsoleta]*). This largest of local snakes (to 2 m total length) is common in forest and woodland, less so on wooded suburban property. It is the snake I am most frequently asked to remove; for example, a 1.5-m adult coiled inside a cooking pot in a kitchen cabinet. Active in March–November; eggs hatch in August–September. Hatchlings and adults eat lizards, including Mediterranean Geckos on brick-walled houses to second-floor heights. A nest predator



Rough Earth Snake (*Virginia striatula*) in pre-shedding condition (note the “cloudy” eye).



Texas Blind Snake (*Rena [Leptotyphlops] dulcis*) emerging from the soil.

of open and cavity-nesting birds, including small owls (Gehlbach 1994). Fourth most frequent DOR snake.

Texas Blind Snake (*Rena [Leptotyphlops] dulcis*). Abundant in suburbia, mostly during April–June under flat ground cover objects such as pathway stepping stones; also dug up in flower beds, found alive in swimming pools, on garage floors, in Eastern Screech-Owl nests (Gehlbach and Baldrige 1987) and Fire Ant mounds (Baldrige and Wivagg 1992). The second most frequently recorded DOR snake, and tied with the Texas Brown Snake for second most frequent pitfall catch.

Texas Brown Snake (*Storeria dekayi texana*). Like other small invertebrate-eating snakes, encountered mostly during the spring under ground cover after rains. Lives largely in riparian forest but also in suburban yards, although less commonly than Blind and Rough Earth snakes. It is the second most frequent pitfall catch and third most abundant DOR snake.

Rough Earth Snake (*Virginia striatula*). The most abundant suburban snake and DOR reptile of any species. Lawn and garden watering might promote its earthworm food, while small size, burrowing behavior, brown coloration, and use of ground-surface cover contribute to its existence in suburbia. Active in March–November.

Discussion

Survival was nil for species that depended mostly on the erased savanna. Strecker's Chorus Frogs, Great Plains Narrowmouth Toads, and Ornate Box Turtles did not survive, while Texas Horned Lizards and Texas Spotted Whiptails remained only temporarily on large vacant grassy suburban lots in the former savanna area. Other amphibians bred in declining numbers in creek pools or were extirpated by stocked game fish. However, one toad, three lizards, and four snakes began to live partly in suburban yards and gardens. Most people did not mind toads, but two of the lizards and all of the snakes survived in suburban habitats by being inconspicuous.

Native species most commonly encountered in suburbia were, in order of frequency, Northern Green Anole, Coastal Plain Toad, Rough Earth Snake, Texas Spiny Lizard, Ground Skink, Texas Blind Snake, and Rough Green Snake. They and other survivors benefited from the study site's heat-island (Landsberg 1981), which averaged 1.5 °C higher than a corresponding rural value in March–October (Gehlbach 1994), and suburb-forest edge habitat that supplied 40% more potential insect prey than 12 m away in the forest interior in September–October (D. Quigley, pers. comm.).

Human attitudes were negative toward the largest snakes and contributed to the extirpation of Copperheads and declines in Yellowbelly Racers and Eastern Hognose Snakes. Homeowners sometimes asked me to remove

large snakes, but not those less than ~15 cm in total length, which many believed were “worms.” Small size, brown color, soil or ground-litter habitat, and green color combined with sit-and-wait foraging hid some lizards and snakes in suburbia. Conversely, the Northern Green Anole's red dewlap displays, body color changes coordinated with perch color, and prominent use of cultivated plants drew human interest and protection that might have enhanced the obvious increase in the numbers of this species in suburbia.

Creek-breeding anurans were negatively affected by water runoff from city streets and private properties. These unnatural sources probably contain petroleum and pesticide toxins, and street drains concentrate rain into flash floods that wash eggs and tadpoles out of the creeks. Thus, Southern Leopard, Rio Grande Leopard, and Northern Cricket frogs declined — but not Coastal Plain Toads, perhaps because their breeding season is 1.7 times longer than those of the other anurans, and hence are more likely to avoid floods. Also, only this toad bred in and might have benefited from artificial ponds in suburban yards.

Twelve (40%) of the study site's 30 original species of amphibians and reptiles disappeared during suburbanization. This fraction is significantly less than the 67% extirpation of 21 species surveyed by Minton (1968) in an older suburb of Indianapolis, Indiana ($\chi^2 = 7.2$, $P = 0.007$). Amphibian losses were coincident with degraded aquatic habitats in both suburbs and proportionately higher than those of reptiles: 75% versus 61% of species in Indiana and 55% versus 38% in Texas without intra- or inter-site differences ($\chi^2 < 0.23$, $P > 0.63$).

The rate of herpetofaunal decline in this Texas study was 1–5 species per five-year period of exponentially increasing suburban growth during 1965–1995. Subsequently, no additional species were lost as suburban growth became progressively slower through 2005. During nine five-year periods through 2005, the changing and then stable herpetofauna was strongly correlated with the cumulative number of city building permits for the study site and surrounding 1-km wide suburban area (3° polynomial regression, $r^2 = 0.95$, $P = 0.001$).

Acknowledgements

Colleagues, family, friends, and students joined hunts; Nancy Gehlbach was present most frequently and made helpful comments on the manuscript. Dena Quigley provided insect abundance data from Malaise traps. Henry S. Fitch participated in a transect survey in the 1970s, and I am honored to dedicate this study to his memory in recognition of his friendship and exemplary professional career in herpetology and ecology.

Literature Cited

- Baldrige, R.S. and D.W. Wivagg. 1992. Predation on imported fire ants by blind snakes. *Texas Journal of Science* 44:250–252.
- Blair, W.F. 1960. *The Rusty Lizard: A Population Study*. University of Texas Press, Austin, Texas.
- Collins, J.T. and T.W. Taggart. 2009. *Standard Common and Current Scientific Names for North American Amphibians, Turtles, Reptiles, and Crocodylians*. 6th ed. Center For North American Herpetology, Lawrence, Kansas.
- Fitch, H.S. and H.W. Greene. 1965. Breeding cycle of the Ground Skink, *Lygosoma laterale*. *University of Kansas Publications, Museum of Natural History* 15:565–575.
- Gehlbach, F.R. 1994. *The Eastern Screech Owl: Life History, Ecology, and Behavior in the Suburbs and Countryside* (2nd ed. 2008). Texas A&M University Press, College Station.
- Gehlbach, F.R. 2002. *Messages from the Wild: An Almanac of Suburban Natural and Unnatural History*. University of Texas Press, Austin.
- Gehlbach, F.R. and R.S. Baldrige. 1987. Live Blind Snakes (*Leptotyphlops dulcis*) in Eastern Screech Owl (*Otus asio*) nests: A novel commensalism. *Oecologia* 71:560–563.
- Landsberg, H.E. 1981. *The Urban Heat Island*. Academic Press, New York.
- Minton, S.A., Jr. 1968. The fate of amphibians and reptiles in a suburban area. *Journal of Herpetology* 2:113–116.