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Spadefoot Toads (*Scaphiopus holbrookii holbrookii*) in an Urban Landscape: Effects of Nonnatural Substrates on Burrowing in Adults and Juveniles

KEVIN P. JANSEN[1], *Department of Biology, University of South Florida, Tampa, Florida 33620 USA*

ADAM P. SUMMERS, *Museum of Vertebrate Zoology, University of California, Berkeley, California 94720 USA*

PABLO R. DELIS, *Science Department, Hillsborough Community College, Tampa, Florida 33630 USA*

Urban development is a form of habitat loss or alteration that can reduce the size and extent of local amphibian populations (Minton, 1968; Wilson and Porras, 1983; Cochrane, 1989). Community development (Sjögren, 1991; Vos and Stumpel, 1995) and road construction (Fahrig et al., 1995; Vos and Chardon, 1998) both splinter anuran habitat. Proximate causes of anuran decline are sometimes apparent (e.g., road mortality) but often are not well understood (see Delis et al., 1996). A 500% increase in urban land use over the last 50 years in Florida (Kautz, 1993) and approximately three million people relocating to the state per decade (Bureau of Economic and Business Research, 1998) force us to identify specific characteristics of urban developments that precipitate anuran declines.

Anurans seem particularly susceptible to urbanization because of their biphasic life history. Many anuran species depend upon uplands, which often are located away from the aquatic habitats used for reproduction (e.g., Pearson, 1955; Dodd and Cade, 1998). Because urbanization in Florida often severely alters terrestrial habitats, the biological requirements of resident species may be degraded enough to reduce population sizes (Wilson and Porras, 1983) or cause local extirpations (Cochrane, 1989; Delis et al., 1996). *Scaphiopus holbrookii holbrookii* (Harlan) is an anuran species that is dramatically affected by urban development (Delis et al., 1996). A terrestrial frog found throughout southeastern North America, *S. h. holbrookii* is a mesic-dwelling representative of a desert-adapted clade. Adult *S. h. holbrookii* inhabit predominantly loose, friable soils typically derived from surficial sands and excavate burrows that are 5–30 cm deep, remaining underground much of the year except when heavy rainfall stimulates reproduction in shallow, temporary ponds (Pearson, 1955; Hansen, 1958).

In Florida, developers alter upland habitats in stereotypical ways, including the creation of retention ponds, construction of roads, and erection of buildings. Well-drained sand and soils of natural uplands are replaced with asphalt, sod, and ornamental plantings, which reduce the available burrowing habitat for both newly metamorphosed and adult *S. h. holbrookii*. Habitat alteration may exclude toads from developed areas. We address two main questions in this study: (1) Can toads burrow in substrates typical of developed areas? and (2) Do toadlets prefer naturally occurring substrates over those common in developed areas? The first question asks whether toads are excluded from developed habitats because proper burrowing substrates are lacking. The second question asks whether toadlets prefer natural substrates. Although providing less direct evidence of the fate of spadefoot toads in urban areas, we hypothesize that if toadlets prefer natural substrates they will disperse further from the breeding ponds in search of such substrates and likely suffer increased mortality.

Treatment Substrates.—Treatment substrates chosen according to available substrates in urban areas and the dominant substrate used by *S. h. holbrookii* in Florida (Pearson, 1955) included sand taken from areas with known toad populations and three substrates commonly used for landscaping in Florida: an organic soil mixture, decorative gravel (3–8 mm diameter), and St. Augustine sod. All substrates were dried to constant weight at 95°C except for the sod and then divided into one of three moisture regimes. Substrates were dry, maintained with 6–8% water (referred to as "moist" hereafter) or saturated with water. All substrates used in the adult burrowing experiment were moist, and because no toadlets attempted to burrow in any saturated substrate, we only compared the dry and moist substrates in the toadlet preference experiment. It is possible that two substrates with identical water content will present very different moisture tension to the toads. We tested the soil moisture tension for the sand and soil mixture by the ceramic plate extraction method (Slatyer, 1967), providing a measure of the soil matric potential (sensu Kramer et al., 1966). Over the range of experimental moistures, the moist sand and soil mixture substrates had similar water potentials (see box in Fig. 1), so soil moisture was not a factor in the toadlet preference trials.

Adult Burrowing Experiment.—Adult toads were captured during the rainy season in Pine Flatwoods Wilderness Park, Hillsborough County, Florida. Twelve individuals [>35 mm snout–urostyle length (SUL)] were housed separately in one-liter containers with 4

[1] Corresponding Author/Present Address: Department of Natural Sciences, University of Virginia's College at Wise, Wise, Virginia 24293 USA; E-mail: kpj6n@uvawise.edu.

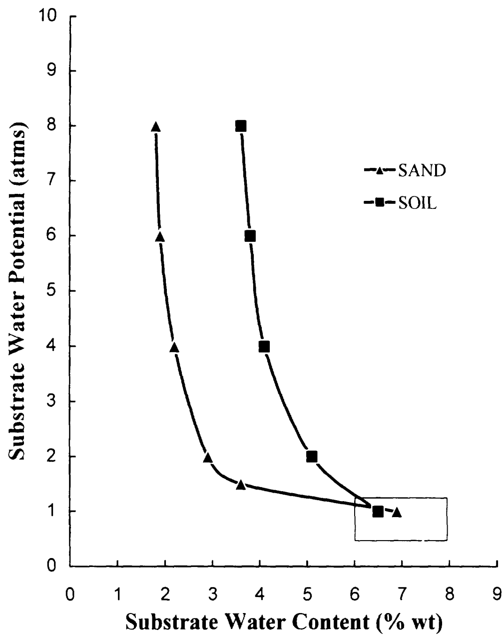

FIG. 1. Moisture tension curves for substrate samples used in the burrowing preference experiments. The box represents values for treatment substrates used during trials. Tension curves were constructed only for substrates used by juvenile *Scaphiopus holbrookii holbrookii.*

cm of damp sand, maintained at 23–25°C and fed crickets ad libitum.

Trials were conducted in five-liter aquaria with 10 cm of substrate. Each of the 12 adult toads was randomly assigned a schedule of substrates and was given three chances to burrow in each of the treatment substrates. A trial consisted of gently transferring a toad into the burrowing aquarium and starting a timer when the toad began to burrow. When a toad had covered itself, it was considered to have burrowed, and the elapsed time was recorded. If a toad did not burrow within 10 min, the trial was terminated and scored as "did not burrow." Sod was the only substrate in which no toads burrowed, so these trials were extended to 24 h. Because no toad successfully burrowed in sod within 24 h, this substrate was removed from subsequent data analysis concerning burrowing times. All successful burrowing attempts in the other three substrates took less than 5 min; however, each toad was tested on only one substrate in any 24-h period.

The fastest burrowing time in each substrate was used to rank the substrates from 1 (easy) to 3 (difficult) for each toad. If a toad did not burrow in a substrate, it was given the highest rank. A Pearson's rank correlation was used to detect an effect of substrate on burrowing success.

Toadlet Preference Experiment.—Toadlets were collected as they dispersed from the same temporary pool where the adults were collected. Individuals (mean SUL = 16.2 mm, SD = 1.1, N = 104) were kept in 25-liter aquaria containing moist paper towels at 23–25°C. All toadlets were maintained in these aquaria unless engaged in a burrowing experiment.

Each testing arena consisted of a 20-liter aquarium (800 cm^2 base) filled with two distinct treatment substrates. Individual treatment substrates occupied equal halves of an aquarium and were 4 cm deep. The surface of each substrate was flattened when necessary to reduce the possibility of instinctive burrowing near perceived crevices (Creusere and Whitford, 1976; Weintraub, 1980) and/or conspecifics (Creusere and Whitford, 1976). To examine whether juvenile *S. h. holbrookii* selected substrates based on moisture content, we gave them a choice of dry sand or moist soil in one testing arena and wet sand or dry soil in another arena. Toadlets were also given a choice between dry sand and dry soil to see whether there was a preference in the absence of adequate moisture. After several trials, it was clear that toadlets preferred moist substrates. A fourth choice, between wet gravel and dry sand was used to determine the strength of this preference. Two testing arenas with a single uniform substrate (one with moist sand and one with moist soil) were used to control for possible side bias.

Five trials were performed for each substrate pair. A trial consisted of placing 20 individuals haphazardly chosen from the pool of approximately 100 at the juncture of the two substrates. Trials ran 24 h, and then the substrate was carefully searched with a blunt probe to locate the burrowed toadlets. An individual "selected" a substrate if it was fully covered by the substrate or located in a cavity with more than half its body covered. Alternatively, an individual on the surface or with half or more of its body uncovered was considered "undecided" and was not used in subsequent calculations. A G-test with Williams' (1976) correction factor was used for all burrowing preference experiments to compare the observed distribution of selected toadlets with the null hypothesis that burrowed individuals were equally distributed between the treatment substrates.

Results of Adult Burrowing Experiment.—Adult toads usually began burrowing within 15 sec of placement in the test arena. Toads burrowed into the substrate rear first using their hind limbs. The burrowing motion was repetitive and stereotyped. With the hip, knee, and ankle joint fully flexed, the leg was drawn up against the side of the body, at which time the femur was rotated laterally, causing the foot to move from a ventral position to a lateral position. The keratinous spade on the medial aspect of the foot as well as the toes and associated webbing scraped substrate from under the posterior part of the body and shoveled it laterally and dorsally. The two legs were used alternately rather than simultaneously during this operation. In this manner, the toad excavated a burrow while piling the removed material on top of itself, a behavior that seems to explain the structuring of burrows previously reported by Ruibal et al. (1969) for *Scaphiopus.* The alternating pattern led to a rotation of the toad during burrowing ranging from 0° to 720°. There was no detectable handedness to this rotation (G = 1.364, df = 1, P = 0.24), nor did there appear to be a correlation with rotation and substrate type.

Adult toads burrowed in all substrates except St. Augustine sod. No toad penetrated the surface running root system of this drought resistant grass. There

TABLE 1. Burrowing times of adult *Scaphiopus holbrookii holbrookii* in three substrates. Mean and range values were calculated from the fastest of three attempts by each of 12 individuals. The fastest time for each substrate determined the relative difficulty of burrowing in that substrate for an individual toad. Rank is the average difficulty among individuals for that substrate.

Substrate type	Mean (s)	Range (s)	Rank
Sand	36	15–192	1.1
Soil mixture	51	34–77	1.9
Gravel	274	225–505	3.0

were detectable differences in burrowing ability among the other substrates (Table 1), with sand being the easiest in which to burrow and gravel the most difficult.

Results of Toadlet Preference Experiment.—Toadlets hopped around the test arena for several minutes to several hours before burrowing. On many occasions a toadlet started burrowing then stopped but eventually resumed burrowing in another location. We do not know whether toadlets burrowed completely into the substrate then abandoned the burrow within the 24 h test period, although we never observed such an event. There was no detectable side bias because toadlets were distributed evenly throughout the test arenas containing a single uniform substrate ($G = 0.708$, df $= 1$, $P = 0.40$).

When substrate moisture was relatively constant (6–8%), significantly more toadlets burrowed in sand than in soil, gravel, or sod (Fig. 2). No individual burrowed in gravel or sod when sand was an option (Fig. 2). When substrates that differed in moisture content were used, moist substrates were chosen significantly more often than dry ones (Fig. 3). Only 32% of toadlets burrowed when both treatment substrates were dry (Fig. 3), whereas 90% of toadlets burrowed during trials where moist sand or soil mixture substrates were available. When presented with a choice between moist gravel and dry sand, only 40% of toadlets burrowed, and no individual burrowed in the moist gravel (Fig. 3).

Discussion.—Adult spadefoot toads could not burrow in grass sod, suggesting that developed areas provide fewer refugia in which toads can shelter. The drought-resistant grasses typical of Florida have a system of stiff, springy surface roots that deform when the toad burrows but snap back to their original position as the foot scoops. Toads attempt to burrow several times in sod before giving up. Although adult toads could burrow in gravel, it was difficult for them to do so. It took toads 7.6 times longer to burrow in gravel than in sand. We suggest that toads suffer additional energetic costs, increased exposure to predators, and risk injury when attempting to burrow in gravel instead of sand. Adult spadefoot toads burrowed most efficiently in sand. Consequently, if spadefoot populations are to persist in urban developments, sand must be available as a surface substrate for burrowing.

Scaphiopus selected loose, friable soils for burrowing in previous field experiments. This result was interpreted as a preference for substrates that were mechanically accessible for burrowing (Ruibal et al., 1969). If this hypothesis is correct, juvenile *S. h. holbrookii* could be excluded from developed areas containing extensive sod and gravel. Toadlets did not burrow in sod or moist gravel, even when the alternatives were to burrow in completely dry sand or remain on the surface. Toadlets also remained on the surface when confronted with water-saturated substrates, which are typical of the humic soils bordering retention ponds in urban developments. Given the low availability of suitable burrowing habitat, and the importance of adequate soil moisture (Whitford and Meltzer, 1976) and subsurface daytime retreats (Creusere and Whitford, 1976), toadlet survival likely is low in such developed areas.

The inability of adults to burrow in sod and toadlet avoidance of sod, gravel, and saturated substrates jeopardizes populations of *S. h. holbrookii* in several ways. First, adults would be forced to find scattered soil refugia within a developed site. Soils within developed areas may be contaminated from surface runoff (see Boyd and Gardiner, 1990) and landscape management practices, and anurans are susceptible to toxins throughout ontogeny (Sanders, 1970; Judd, 1977; Beattie et al., 1991; Herkovits and Perez-Coll, 1991; Pradham and Dasgupta, 1991). Second, newly transformed toadlets would have difficulty finding a place to burrow and it is unlikely that they could remain adequately hydrated during the day outside of refugia. High mortality in a range of life-history stages of *S. h. holbrookii* makes it difficult for populations to survive or become reestablished in urban areas. These circumstances also may isolate spadefoot populations.

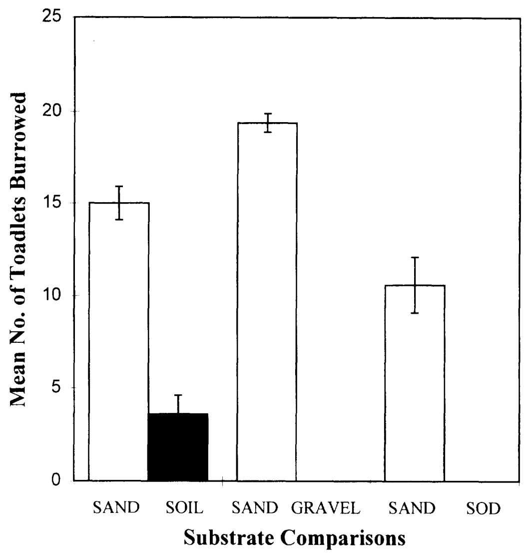

FIG. 2. Influence of substrate type during burrowing preference experiments with newly metamorphosed *Scaphiopus holbrookii holbrookii*. Substrates were maintained at 6–8% water content and sand was preferred over soil ($G = 37.338$, df $= 1$, $P \ll 0.001$), gravel ($G = 124.06$, df $= 1$, $P \ll 0.001$), and sod ($G = 64.305$, df $= 1$, $P \ll 0.001$). Bars represent one standard deviation.

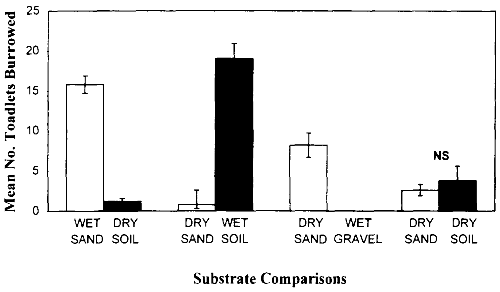

FIG. 3. Influence of soil moisture during burrowing preference experiments with newly metamorphosed *Scaphiopus holbrookii holbrookii.* Moist surfaces were preferred and overrode the toadlets' preference for sand except when compared to gravel. Moist sand was preferred over dry soil ($G = 74.023$, df = 1, $P \ll 0.001$), but dry sand was selected less often than moist soil ($G = 103.22$, df = 1, $P \ll 0.001$). However, toadlets preferred dry sand to moist gravel ($G = 48.199$, df = 1, $P \ll 0.001$). Toadlets did not show a preference when presented with dry sand and dry soil ($G = 1.114$, df = 1, $P = 0.29$). Bars represent one standard deviation.

Because the risk of extirpation of anuran populations increases with increasing fragmentation (Sjögren, 1991; Vos and Stumpel, 1995), both established and founder populations in developed areas become more susceptible to extinction.

A recent study has suggested that the pervasive loss of natural habitats at the local scale is of a greater detriment to amphibian species than commonly acknowledged (Delis et al., 1996). Indeed, *S. h. holbrookii* disappeared from urban settings where critical habitats (both wetland and upland) were destroyed or degraded (Delis et al., 1996). Recent studies have focused on the value of temporary wetlands in maintaining vegetative (e.g., Kirkman et al., 1998), invertebrate (e.g., Collinson et al., 1995), and vertebrate (e.g., Dodd, 1992) diversity as well as providing flood control and water quality enhancement (Robinson, 1995). In addition, many anuran populations depend on temporary breeding pools (e.g., Woodward, 1983; Brönmark and Edenhamn, 1994). Temporary wetlands are important, and their continued legislated protection is fully warranted. However, the surrounding "life zones" (see Semlitsch, 1998) currently do not have similar protection.

Like many organisms with complex life cycles, *S. h. holbrookii* requires both wetland and upland habitat (Burke and Gibbons, 1995; Samways and Steytler, 1996; Dodd and Cade, 1998; Semlitsch, 1998). Spadefoot toad populations need wetlands for reproduction and larval development and upland habitats for feeding and burrowing. Conservation measures aimed at preserving some minimum area of aquatic and terrestrial habitat are not sufficient for some organisms; the physical characteristics of the habitat are also important. Our data suggest that specific burrowing characteristics of the upland substrate may need to be addressed if spadefoot toad populations are to persist in urbanized landscapes.

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Aspects of the Life History and Ecology of the Coal Skink, *Eumeces anthracinus*, in Georgia

Paul E. Hotchkin and Carlos D. Camp,[1] *Department of Biology, Piedmont College, Demorest, Georgia 30535*

Jeremy L. Marshall, *Department of Biology, University of Louisiana-Lafayette, Lafayette, Louisiana 70504*

The coal skink, *Eumeces anthracinus*, is a medium-sized (maximum snout–vent length approximately 65 mm) lizard that has a highly localized distribution in the midwestern and eastern United States (Walley, 1998). It is uncommonly encountered throughout its range (Mount, 1975; Collins, 1993; Trauth, 1994; Dundee and Rossman, 1996) and is listed as endangered, threatened, or a species of special concern in at least five states (Mitchell, 1994; Ramus, 1998). It is a ground-dwelling form that has a strong affinity for mesic sites and often occurs near water (Collins, 1993; Mount, 1975; Trauth, 1994; Dundee and Rossman, 1996). Other than habitat, very little is known about the ecology of this secretive species. Most information on life history and activity patterns is in the form of scattered anecdotal observations (e.g., Collins, 1974; Mount, 1975; Irwin, 1982). The single exception is Trauth's (1994) study of gonadal development in Arkansas.

Although normally rare, the abundance of coal skinks in a forested area in Habersham County, Georgia, afforded us the opportunity to investigate the ecology of this relatively unstudied species. Our specific objectives were to use nondestructive sampling to collect data on life history and activity patterns.

The study site was an area approximately 5000 m^2 located on the southern side of Lake Demorest, Habersham County, Georgia. This area is north-facing with a gentle slope (< 15°) abutting a marshy swamp on its northern edge. The area is covered by a largely deciduous forest. The most common trees are, in decreasing order of abundance, tulip poplar (*Liriodendron tulipifera*), short-leaf pine (*Pinus echinata*), red maple (*Acer rubrum*), dogwood (*Cornus florida*), beech (*Fagus grandifolia*), and southern red oak (*Quercus falcata*). The area is bisected by a north-flowing swampy stream, whose associated bottoms are dominated by Chinese privet (*Lugustrum sinense*). Much of the forest floor is densely covered with English ivy (*Hedera helix*). The southern end terminates at a south-facing roadbank, which is approximately 45° and has a substrate of mowed grass and exposed soil.

We captured lizards using a drift fence similar to that described by Gibbons and Semlitsch (1981). The fence was 25 cm high with regularly spaced (approximately 5-m intervals) bucket stations. Each bucket station consisted of a pair of four-liter buckets, each of which was placed on the opposite side of the fence from the other. The longest part (100 m) of the fence paralleled the roadbank approximately 10 m inside

[1] Corresponding Author.