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The Dangers of Life in the City: Patterns of Activity, Injury and Mortality in Suburban Lizards (*Tiliqua scincoides*)

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ABSTRACT.—**Human activities affect animal populations whenever animals and humans live in close proximity, but patterns of mortality in urban wildlife remain poorly known. We analyzed rates of injury and mortality of bluetongue lizards (*Tiliqua scincoides*) in Sydney, Australia, using a Wildlife Information and Rescue Service database that contained more than 2000 reported "rescues" of this species over a three-year period. Motor vehicles and dogs killed many adult lizards in springtime (the mating season) when adult males move about more frequently. Domestic cats killed mainly juvenile lizards, especially just after parturition in midsummer. Weather conditions affected rescue rates, presumably because lizards were more active on hot dry days. Habitat loss was the most important cause for lizard rescue in highly urbanized areas, whereas domestic pets were a major threat in outlying suburbs. Such datasets are subject to many biases but allow meaningful comparisons at some levels of analysis. The large datasets of wildlife rescue groups have considerable potential to illuminate the nature and frequency of interactions between humans and wildlife.**

Wild animals in urban environments face different hazards from those experienced by their counterparts in natural habitats, and human activities can affect survival in many ways. The most obvious impact involves direct killing. Such killing may be motivated by commerce (Boeadi et al., 1998; Shine et al., 1998a,c), harvesting for food or medicinal purposes (Klemens and Thorbjarnarson, 1995; Shine, 1986), or by fear (Dodd, 1993). Some anthropogenic mortality occurs purely by accident (Mallick et al., 1998; Bonnet et al., 1999): collisions between animals and motor vehicles fall into this category (Holbrook and Vaughan, 1985; Davies et al., 1987; Andrews, 1990; Bernardino and Dalrymple, 1992; Rosen and Lowe, 1994; Fahrig et al., 1995; Mallick et al., 1998; Bonnet et al., 1999). Nonetheless, road accidents may be frequent enough to threaten the viability of some animal populations (Davies et al., 1987; Rosen and Lowe, 1994; Groot Bruinderink and Hazebroek, 1996).

Urban development also degrades and fragments natural habitats. Loss of habitat directly affects some species, whereas fragmentation may reduce an animal's access to critical resources such as food and reproductive partners

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(Andren, 1994; Shine et al., 1998b). Conversion from native habitat to urban development also tends to favor exotic species (Green, 1984; Munyenyembe et al., 1989; Sewell and Catteral, 1998), which may pose an additional threat. In Australia, three main introduced predators (cats, dogs, and foxes) compete for resources with, and prey upon, local wildlife (Barratt, 1995), and numbers of domestic dogs and cats may be higher in urban areas than in natural habitats.

To understand the hazards experienced by urban wildlife, we need to document patterns of mortality associated with each hazard. The effect of anthropogenic mortality will depend not simply on the numbers killed but also on the kinds of animals killed (male vs. female, adult vs. juvenile, reproductive vs. nonreproductive) as well as the timing of mortality (e.g., before or after the reproductive season; Bonnet et al., 1999). Because the study of such patterns is difficult and often hampered by small sample sizes and limited spatial scales (Quinn, 1995), we need alternative techniques. The databases of community-based ''wildlife rescue'' groups offer such opportunity (Kaplan, 1999; Shine and Koenig, 2001) but may be subject to bias (Harris, 1981; Saunders, 1993; Quinn, 1995). The utility of these data depend upon the researchers' objectives and their ability to identify bias. We analyze an extensive database on bluetongue lizards (*Tiliqua scincoides*) rescued in Sydney by a community group, so that we can explore patterns of activity, injury and mortality in these suburban reptiles.

Materials and Methods

Study Species.—The eastern bluetongue lizard (*Tiliqua scincoides*) is a large (adult snout–vent length $\sim$ 400 mm, mass to 700 g), heavy-bodied, terrestrial lizard with small limbs (Cogger, 1992). These animals are long-lived ($>$ 30 years in captivity; P. Harlow pers. comm.), diurnal and omnivorous (Cogger, 1992), and viviparous with high fecundity (up to 18 in a litter; Shea, 1992). The species is widely distributed in eastern Australia, including the area around Sydney (a city of more than four million people, and growing rapidly). Unlike other large reptiles in the Sydney area, *T. scincoides* continues to be common in suburban gardens (Griffiths, 1987; Weigel, 1988; Swan, 1990; Cogger, 1992). Indeed, bluetongue lizards are one of the few large native vertebrates directly associated with urban dwellings in Sydney (Koenig et al., 2001). Thus, these lizards provide an opportunity to investigate ongoing anthropogenic impacts on a native vertebrate living in close proximity to humans.

Wildlife Rescue Data.—The New South Wales Wildlife Information and Rescue Service (WIRES) is a volunteer-based organization that rescues injured and abandoned native wildlife (Shine and Koenig, 2001). We obtained WIRES records of bluetongue lizards collected in the Sydney area from January 1989 to December 1998. Most of our analyses, however, are based on a more detailed and complete subset of those data (July 1994 to March 1998). Each record during this latter period contained: date; rescue location; injury; cause of injury; fate (i.e., died or released), and life phase (i.e., adult or juvenile). These data enabled us to investigate (1) causes of injury and mortality; (2) short-term survival rates of rescued lizards; (3) annual and monthly variations in the total number of records; (4) reasons for and seasonality of rescues, including patterns within each area of Sydney; and (5) relationships between weather conditions and the numbers of lizards brought in for rescue.

Data Analysis.—Contingency tables were used to compare frequencies of variables in the WIRES database. We used Spearman Rank Correlation to examine the influence of weather conditions on the numbers of reported rescues. All data were tested for significance at the P = 0.05 level and checked for relevant assumptions prior to analysis. We assumed all records to be independent, although it is possible (albeit unlikely) that a few individuals appear in the database more than once. That is, a lizard may have been rescued, released, and rescued again. This sequence of events should be rare, however, given the low number of individual rescues in each suburb, the high rate of mortality among rescued animals and WIRES policy to relocate most animals brought into their care.

Results

Causes of Injury and Mortality.—Between July 1994 and March 1998, information on 2004 bluetongue lizards from the Sydney area was entered into the WIRES database. Of these lizards, 757 died, 720 survived and were later released, and the fate of the remaining 527 animals was not recorded. Table 1 summarizes the cause and degree of injury associated with each rescue. Of 757 bluetongues that died, attacks by dogs were responsible for 318 (42%), attacks by cats 76 (10%), and collisions with motor vehicles 91 (12%). Twenty-nine percent of deaths (220) were from ''unknown'' causes and the remaining 52 (7%) resulted from other factors (birds, poison, weapons, traps, etc.). Locations of injuries responsible for fatalities were distributed as follows: body (42%), head (10%), limb (8%), tail (6%), nothing apparent (8%), and ''other'' (26%).

Survival Rates of Rescued Lizards.—Survival rates differed significantly for lizards allocated

TABLE 1. Summary of the cause and injury associated with each reported rescue of bluetongue lizards in the database of the Wildlife Information and Rescue Service. All data are from Sydney and were recorded between July 1994 and March 1998.

Cause	Number	Percent of total
Unknown	664	33.2
Dog	550	27.5
Unsuitable environment	247	12.3
Cat	182	9.1
Car	152	7.6
Habitat loss	85	4.3
Bird	36	1.8
Animal attack	20	1.0
Miscellaneous (<1% each)	65	3.2
Injury	**Number**	**Percent of total**
Nothing apparent	548	31.0
Body	522	29.5
Limb	168	9.5
Head	141	8.0
Tail	111	6.3
Mouth	88	5.0
Eye	68	3.9
Immobile	32	1.8
Separated from parent[a]	23	1.3
Miscellaneous (<1% each)	65	3.7

[a] We presume that members of the public finding juvenile lizards thought them abandoned and, hence, in need of assistance.

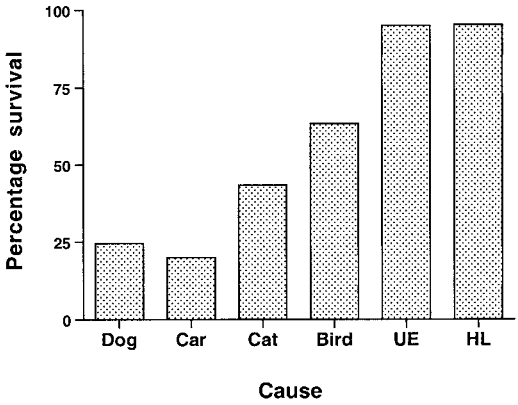

FIG. 1. Reported survivorship rates of bluetongue lizards subject to each of the six main causes for rescue by WIRES. UE = unsuitable environment, HL = habitat loss. Number of dead lizards (left to right) = 315, 90, 72, 11, 9, and 5.

to each of six main causes for rescue (dog, cat, bird, car, unsuitable environment, and habitat loss: $\chi^2 = 282.69$, df = 5, $P < 0.0001$). More animals died than survived after being run over by cars or attacked by dogs. Lizards attacked by cats or birds had an approximately 50% chance of surviving (Fig. 1), whereas bluetongues brought into WIRES because of ''unsuitable environment'' and ''habitat loss'' generally survived.

Annual and Monthly Variation in Numbers and Causes of Rescue.—To examine annual variation in the total numbers of bluetongue lizards reported to WIRES, we used a dataset that included all years between 1989 and 1998. Numbers of lizards reported each year ranged from < 200 to > 800, and increased significantly over the period examined (linear regression, $r = 0.88$, $N = 9$, $P < 0.002$). WIRES records data separately for six areas of Sydney: eastern suburbs, northern beaches, northern suburbs, northwest, southern beaches, and southwest. The rate at which lizard numbers increased through time varied significantly among the six areas ($\chi^2 = 91.22$, 40 df, $P < 0.0001$).

Between July 1994 and August 1998, lizard rescues were least frequent in winter. Two major peaks in total numbers were apparent: the first from September to October (springtime) and the second from January to February (summer). Age structure in the rescued sample also changed through time (adult vs. juvenile lizards by month: $\chi^2 = 104.00$, df = 11, $P < 0.0001$). The springtime peak involved mostly adult lizards, whereas the summer peak involved juveniles (Fig. 2). There was no significant seasonal variation in the proportion of lizards dying versus those surviving after rescue ($\chi^2 = 7.70$, df = 3, $P = 0.53$).

Number of rescues due to dog attacks, cat attacks and automobile-inflicted injuries varied significantly among seasons ($\chi^2 = 47.11$, df = 6, $P < 0.0001$) and among months ($\chi^2 = 71.05$, df = 22, $P < 0.0001$). ''Dog'' and ''car'' records peaked in springtime (Fig. 3), whereas cat attacks were concentrated in summer (January to March) and resembled the monthly distribution of juvenile lizard rescues (Figs. 2–3). Relative numbers of adult versus juvenile lizards attacked by dogs ($\chi^2 = 51.93$, df = 3, $P < 0.0001$) and cats ($\chi^2 = 15.42$, df = 3, $P < 0.0015$) differed among seasons. Over 75% of cat attacks were on juvenile lizards, whereas > 75% of dog, car and ''unsuitable environment'' records involved adult lizards (Fig. 4).

Geographic Variation in Monthly Distribution of Records and Causes.—The seasonal pattern present in total dog and car analyses (Figs. 2–3) was similar in each area (see above). The six areas did not differ significantly in monthly distributions of the total number of lizards reported ($\chi^2 = 31.24$, df = 55, $P = 0.10$). Reasons for rescue showed significant geographic variation. For example, the relative number of attacks by cats versus attacks by dogs varied among areas

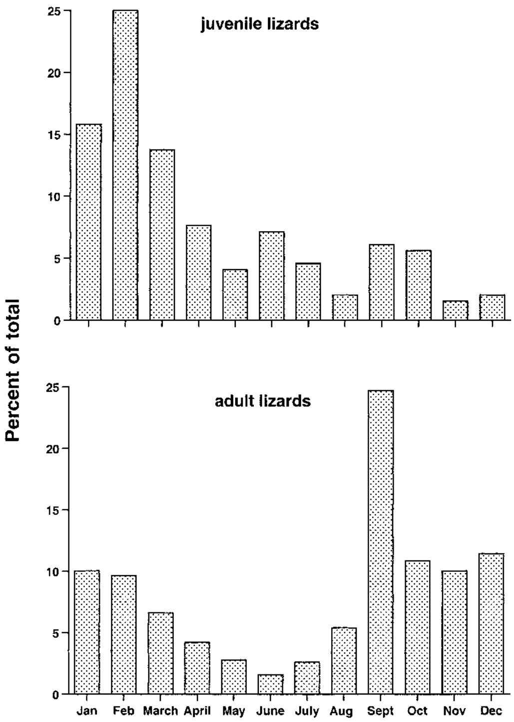

FIG. 2. Monthly distribution of adult (N = 788) and juvenile (N = 523) bluetongue lizard rescues reported to WIRES between 1995 and 1997.

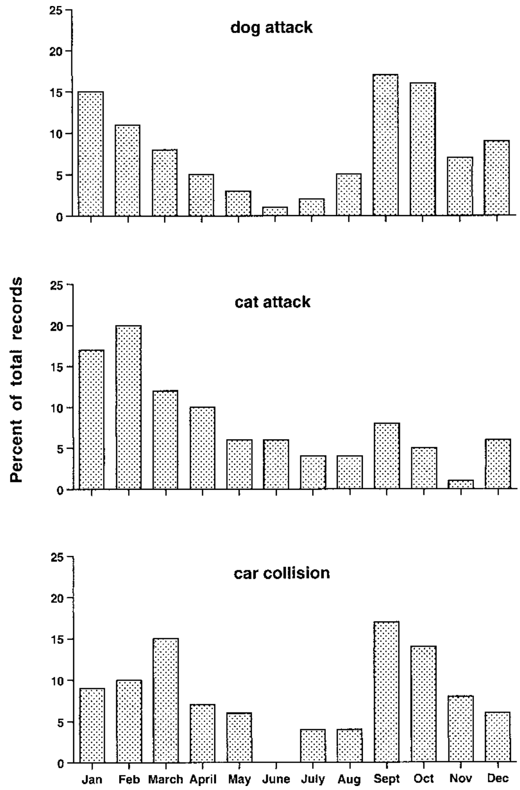

FIG. 3. Monthly distribution of bluetongue lizard rescues reported as a result of dog attack, cat attack, and car collision between 1995 and 1997. Sample sizes are 516 for dog attack, 177 for cat attack, and 129 for car collisions.

(χ^2 = 14.32, df = 5, P = 0.01), as did the relative number of rescues caused by injuries inflicted by automobiles versus domestic pets (χ^2 = 19.98, df = 5, P < 0.001). We partitioned the six areas into two categories: highly urbanized areas (southwest, northwest, eastern suburbs) versus more outlying suburbs with lower-density housing and, thus, more remaining bushland (northern beaches, southern beaches, northern suburbs). Attacks by domestic pets were more common in these garden suburbs (451 of 755 rescues, = 60%) than in the inner city (357 of 693, = 52%; χ^2 = 9.57, 1 df, P < 0.002). In contrast, habitat loss was much more common in the outlying suburbs than the inner city (165 vs. 7 cases; χ^2 = 178.6, 1 df, P < 0.0001).

Effect of Weather Conditions on the Incidence of Rescues.—More lizards were reported to WIRES on days with a higher maximum temperature (rho = 0.28, P < 0.0001) and minimum temperature (rho = 0.20, P < 0.0001). Conversely, fewer lizards were collected on days with more rain (rho = 0.07, P < 0.03; weather data from the Bureau of Meteorology). As weather conditions are highly seasonal, these significant overall results might reflect seasonal shifts in lizard activity rather than any causal effect of daily weather conditions. To evaluate this possibility, we repeated the regression analyses separately on seasonal subsets of the total dataset. Maximum temperature continued to be the highest

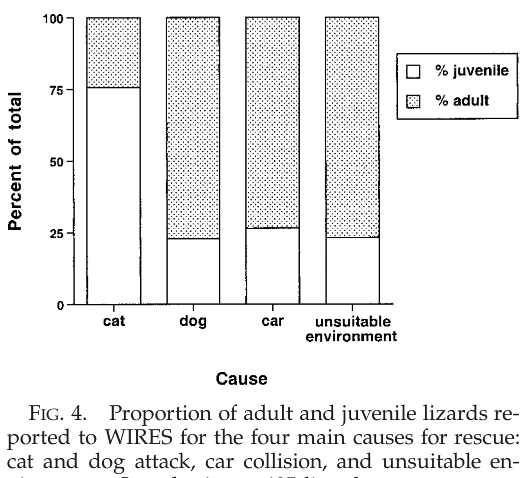

FIG. 4. Proportion of adult and juvenile lizards reported to WIRES for the four main causes for rescue: cat and dog attack, car collision, and unsuitable environment. Sample size = 495 lizards.

TABLE 2. Results from Spearman Rank Correlation tests of the number of bluetongue lizard rescues reported to WIRES and the weather conditions that day. Analyses were run separately for each season (spring = Sept–Nov, N = 296 days; summer = Dec–Feb, N = 302; autumn = March–May, N = 278; winter = June–Aug, N = 306). Data are combined for three complete years (1995–1997). Asterisks and **boldface** font indicate significant results ($P < 0.05$).

	Maximum temperature		Minimum temperature		Precipitation	
	rho	*P*-value	rho	*P*-value	rho	*P*-value
Spring	0.03	0.60	**−0.25**	**0.0001***	**−0.15**	**0.01***
Summer	**0.14**	**0.015***	−0.03	0.59	**−0.13**	**0.04**
Autumn	**0.24**	**<0.0001***	0.10	0.11	−0.13	0.05
Winter	**0.12**	**0.04***	0.06	0.28	0.05	0.46

correlate of bluetongue numbers in most seasons (Table 2).

DISCUSSION

Although it is difficult to quantify the impact of anthropogenic activities on an animal population, we may gain important insight from information on the causes and patterns of injury and mortality associated with these activities. The use of ''unconventional'' datasets, such as the WIRES database, can provide large sample sizes. Reliance on such data, however, raises questions of bias in data collection. Two such biases are important within the WIRES database. First, the probability of an animal being reported to WIRES for all causes is not equal. Animals already dead when found are unlikely to be reported, so the database will underestimate these fatalities. Second, the probability of someone reporting a rescue to WIRES may not be consistent across years, or across months within years. Rates of reporting may rise after extensive advertising by WIRES or during times of the year when people are more active outdoors (e.g., summer holidays).

More than 2000 bluetongue lizard rescues (and > 750 deaths) were recorded in the WIRES database over the three-year period, and these data presumably represent only a small subset of the total mortality of bluetongue lizards in Sydney during that time. Paradoxically, this is encouraging because it suggests that the lizards are abundant over most of the city. Although many lizards died, about 50% of lizards survived their trauma in the short term (but note that this proportion is misleading if already-dead animals are unlikely to be reported). It is difficult to invoke lizard-centered hypotheses to account for patterns such as annual variation in the number of rescues reported to WIRES; such variation may be due to other factors (i.e., related to the WIRES organization) rather than the biology of the bluetongues. Although numbers of lizard reports have increased strongly over the last decade, this increase is more likely to reflect the growing popularity of WIRES rather than a change in the frequency of interactions between humans and reptiles.

Numerical comparisons among putative causes for lizard injury are also problematical. The low number of records for car injuries may not indicate that car collisions are responsible for less injury or mortality than other causes (such as dog attacks). It merely suggests that fewer car-injured than dog-attacked lizards were reported to WIRES. Plausibly, most collision victims are killed instantly and thus not rescued. Hence, although WIRES data confirm that these causes play a role in bluetongue lizard injury and mortality, it is difficult to infer the relative importance of such factors without calibration trials to assess the probability of reporting for various kinds of injuries.

Comparisons of survivorship within each cause of rescue may be useful, but extrapolation to field conditions is problematic. WIRES records may overestimate the survivorship of bluetongues in the field injured by dogs or cars (e.g., if badly injured lizards are less likely to be brought in, or if the stress of captivity exacerbates the injury or if instantly killed lizards are not rescued). Similarly, records of survival rates after cat attacks may overestimate survivorship in the field. Cat injuries penetrate deep into the skin and often result in infection. Thus, survivorship of rescued lizards may be enhanced by antibiotics and other care provided in captivity.

Despite limitations, much can be learned from the WIRES database. The distribution of rescues reveals some interesting and biologically meaningful results. First, the seasonal trend in total numbers of records (and in the dog and car records) may reflect general lizard activity. In other studies, seasonal peaks in the numbers of road-killed animals reflected increased activity of animals, such as during the mating period (Davies et al., 1987; Groot Bruinderink and Hazebroek, 1996; Coulson, 1997). Low numbers of bluetongue rescues occur over the winter months when lizards are hibernating, whereas the two major peaks coincide with the period when lizards search for reproductive partners (September to October) and when they give birth (January to February; Shea, 1992). Thus, the spring peak involved mostly adult lizards, whereas the summer peak involved juveniles (Fig. 3).

Second, seasonal patterns in the causes for rescue may also be informative. Attacks by domestic cats were concentrated ($> 75\%$) on juvenile lizards rather than on the more formidable adults. Thus, cat-attack records (unlike other causes) occurred mainly in the season of parturition (January to March). For a long-lived and highly fecund species (Shea, 1981, 1992), high mortality rates for juvenile lizards at this time may be of less significance to population viability than the peak of mortality seen in adult lizards during springtime.

Third, within-season patterns may also be informative. Weather variables (especially temperature) often strongly influence reptile activity (e.g., Gibbons and Semlitsch, 1987), and we found a significant (albeit weak) increase in the number of records on hotter days. Radio-tracked bluetongue lizards remained inactive during wet, cold days (Koenig et al., 2001), possibly explaining why fewer lizards were rescued on wetter days. However, these weather conditions may also reduce activity by humans and their pets. Rainfall may increase food availability (i.e., abundance of snails) and, thus, promote bluetongue activity, but this influence is probably minor in irrigated suburban gardens.

Finally, geographic differences in causes for rescue may provide insight into the relative magnitude of different threats to bluetongue populations. Our analyses suggest that pets (especially cats) are a primary concern in outlying suburbs, whereas habitat loss resulting from construction activity is a more significant threat to bluetongue populations in inner-city areas. This kind of information could be used in developing management strategies to mitigate lizard mortality in different parts of the city.

Despite some difficulties with interpretation, information from the WIRES database provides a valuable insight into broad patterns of activity, injury, and mortality to bluetongue lizards in Sydney. To improve the usefulness of such data, it would be helpful for wildlife rescue organizations to record additional information on date, time of day, place, sex, body size, reproductive condition, and weather conditions. Given the large numbers of people in wildlife rescue groups, and the broad geographic distribution of such groups, there exists an exciting potential for scientists to make more extensive use of the resulting data. The first step is to communicate with community groups and explain the potential conservation advantages of rigorous and extensive data collection.

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