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An evaluation of the effects of deltamethrin on two non-target lizard species in the Karoo, South Africa

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We measured the effects of deltamethrin, a pyrethroid insecticide, on individuals of two lizard species, *Meroles suborbitalis* and *Pedioplanis namaquensis*, in enclosures under controlled conditions, and under field conditions. We found significant effects on lizard mortality rates in the enclosure experiments, with most lizards dying within two months of treatment. Our field-based investigation, conducted over a five-month period, revealed significant reductions in abundance of *M. suborbitalis* (reduced by 52%) and *P. namaquensis*, (reduced by 72%) one and four weeks after spraying with deltamethrin. At 18 weeks after spraying there was no longer a significant difference in abundance measures between treatment and control plots, due to the invasion of the plots by juveniles.

Keywords: pesticide; Karoo; locust; non-target reptiles; pyrethroid insecticide; *Meroles suborbitalis*; *Pedioplanis namaquensis*

Introduction

The pyrethroid pesticide deltamethrin has been used extensively in South Africa for the control of brown locust, *Locustana pardalina* (Walker) (Stewart & Seesink, 1996), which forms swarms of plague proportions in the southern parts of Africa (de Villiers, 1988). In arid parts of the country, such as in the Karoo, *L. pardalina* constitutes the single most economically important pest species. Swarming, which occurs with a periodicity of approximately 7–11 years (de Villiers, 1988), may result in plagues of locusts that spread into the agricultural areas of the Free State and north-west provinces of South Africa, and into the southern regions of Namibia and Botswana. Currently, trends are towards more frequent and severe swarming (de Villiers, 1988), and since chemical methods of control are currently the only practical means of combating locust outbreaks, increasing amounts of pesticides are being released into the environment (Ledger, 1987). In South Africa, locust control programmes involve the spraying of areas where

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there are hopper bands or adult swarms. Pesticides are applied either by hand-held equipment or sprayed from the back of moving vehicles. As yet, little has been applied by aerial spraying. However, even current methods of application result in the exposure of plants and non-target animals in the vicinity of the applications (de Villiers, 1988).

Although deltamethrin has only a moderate effect on mammals (Brown *et al.*, 1996), it is known to be highly toxic to a variety of invertebrates. It acts on the nervous system to cause prolonged opening of sodium channels, causing facilitation and then blocking of synaptic transmission (Narahashi, 1985). It has a relatively short lifespan, with a half-life of between 11 and 19 days under aerobic conditions (Lhoste & L'Hotellier, 1982) and only 96 hours in aquatic environments (Caquet *et al.*, 1992). Several authors have reported that less than 10% of the applied deltamethrin remains on crops or straw two to three weeks after application (Johnson *et al.*, 1986; Hill & Johnson, 1987; Hill *et al.* 1987).

Few studies have measured the effects of deltamethrin on reptiles and empirical data are desperately needed, both from a 'conservation of reptiles' viewpoint (Hall, 1980) and because lizards have been proposed as ideal candidates for bioindicating, as they are plentiful and obvious in many environments (Lambert, 1999). Lhoste & L'Hotellier (1982) reported 'effects on some reptiles', but provide no evidence for this assertion. Lambert (1994) investigated the effects of deltamethrin on non-target reptiles in Zimbabwe and found no significant effects on lizard populations. Stewart & Seesink (1996) investigated the effect of deltamethrin in two species of lizards indirectly, *Pedioplanis* (formerly *Eremias*) *lineoocellata* Dumeril & Bibron and *P. namaquensis* Dumeril & Bibron, demonstrating the potential for deltamethrin uptake through food ingestion. Walker & Ronis (1989) have suggested that reptiles may be more susceptible to pesticides than are birds or mammals on account of their low metabolic rates and simple enzyme systems, which results in a slow breakdown of deltamethrin in the body.

Our study was conducted on a farm, La-de-da, (32° 24′ 30″ S; 22°25′ 30″ E), which is adjacent to the Karoo National Park, Beaufort West, in the south-western region of South Africa. Our interest in the effect of deltamethrin on non-target reptiles was generated in response to a possible need to spray deltamethrin within the park for the control of locust swarms. We chose La-de-da due to its similarity in habitat to the Karoo National Park, the compliance of the owner and the fact the little insecticide had been used on the farm during the previous 10 years.

The vegetation of the Karoo comprises arid and semi-arid dwarf shrublands and open grasslands, and is generally an area of low rainfall (100–600 mm per annum), with poor, shallow and stony soils (Cowling & Roux, 1987). Our study site was typical of the Karoo biome, which is rich in herpetofauna. Sixty-eight species of reptiles and amphibians having been recorded within the boundaries of the Karoo National Park (Branch & Braack, 1987).

We measured the effects of deltamethrin on two lacertid lizard species, *Meroles suborbitalis* (Peters) and *P. namaquensis*, since these lizards were by far the most abundant species in the study area. Both species are limited to the arid parts of southern Africa and are small (max. snout-to-vent length 70 mm), diurnal insectivores. *Pedioplanis namaquensis* is an active forager (Pianka, 1971; Cooper & Whiting, 1999), while *M. suborbitalis* uses a sit and wait strategy (Pianka, 1971; Huey & Pianka, 1981). Individuals of both species take refuge from predators and adverse climatic conditions in their burrows, which they dig at the base of bushes and shrubs. Burrows also appear to be focal points in the home ranges of individual lizards. In our study area, both species breed in summer, when small clutches of eggs are laid in burrows (Branch, 1998). Huey *et al.* (1977) reported that while *P. namaquensis* brumates during the winter months, *M. suborbitalis* remains active throughout the year, changing from a bimodal activity pattern in summer, to a unimodal pattern in winter. They also report that *P. namaquensis* selects slightly higher body temperatures (37·4°C ± 0·23) than does *M. suborbitalis* (36·8°C ± 0·18) while active.

Methods

We conducted two types of experiments; in the first type, captured lizards were exposed to two concentrations of deltamethrin, either directly or indirectly, under controlled conditions in enclosures (from here on referred to as Enclosure Trials). The second type involved spraying demarcated areas in the field with deltamethrin, where the abundances of lizards were measured before and after treatment (from here on referred to as Field Trials).

Enclosure trials

Initial investigations were conducted to measure direct effects of deltamethrin on individual lizards treated under controlled conditions. Deltamethrin was applied at two dilutions, 17·5 g (recommended dosage) and 25 g active ingredient (a.i.) ha^{-1}, directly or indirectly to individuals of each species. For direct spraying, lizards were cooled until they lost mobility and they were then sprayed using an ultra low volume (ULV) formulation applied with a Micron ULVA + applicator (battery operated spinning disk applicator—Micron Sprayers Limited, Bromyard HR7 4HU, U.K.) using standard field spraying methods (backpack reservoir; applicator held at waist height). Lizards were then placed in 1-M glass tanks for observation after treatment.

For the indirect spraying treatment, lizards were placed in 1-M tanks on soil that had been sprayed with deltamethrin as described above. Observations of the effects of deltamethrin on the lizards were made following treatment, with special attention being paid to the occurrence of any of the typical reactions of pyrethroid poisoning, such as the loss of co-ordination, loss of righting response, sensitivity to bright light, muscle spasms and panic. The lizards were observed every 15 min on the day of spraying (treatment was conducted at 0700 h) and then four times per day for the following two days. After this, survival was monitored on a daily basis for two months. During this time, lizards were kept under a natural lighting regime and supplied with a radiant heat source and rocks, under which they could retreat, for thermoregulation. They were provided with water and were fed on a diet of termites and mealworms, *ad libitum*.

We compared mortality rates of the lizards treated with deltamethrin to control groups of lizards that were not exposed to insecticide. The controls were treated in an identical way to the test lizards, apart from not being sprayed (i.e. controls for direct spraying treatment were cooled in the same way as treatment lizards). Unfortunately, we could not spray controls with water (to simulate the effects of application) since our limited budget only allowed for only a single applicator, and we could not be certain of flushing all insecticide residue from the instrument, which had previously been used for the application of deltamethrin. However, we are confident that this minor difference between treatment and control lizards had little material effect on our results.

Field trials

Three plots (each 100 × 100 m = 1 ha), situated within 500 m of one another, were demarcated. These were chosen on the basis of the apparent similarity in vegetation structure, soil type and geomorphology. The similarity of the vegetation structure between plots was then measured, since we assumed this to be the single most important attribute determining lizard abundance in the area and the probability of sighting a lizard during a census.

Vegetation surveys were conducted using the line intercept method outlined by Smith (1996). The position and direction of a 50-m line was determined using a table of random numbers. Plants that were touched by the line were identified according to Shearing & van Heerden (1994) and le Roux *et al.* (1994). Measures of only the six most abundant species (each of these were represented by a minimum of three intercepts) were used in the analysis since their abundance far exceeded the abundance of all other species, which only occurred sporadically. Relative density, dominance, relative dominance, frequency and relative frequency of each species were assessed as described by Smith (1996).

Two of the 1-ha plots (treatment plots) were sprayed with deltamethrin before 0700 h at a dilution of 17·5 g a.i. ha^{-1} (recommended dosage) using a Micron ULVA + applicator held waist high. To ensure that the edges of the treatment plots received the correct concentration of deltamethrin, spraying was extended for five meters over each perimeter. The control plot was chosen according to the wind direction on the day of spraying, thus preventing contamination of this plot with deltamethrin spray drift. Spraying was conducted on 6 November 1995 prior to the breeding season of both *M. suborbitalis* and *P. namaquensis* in the Karoo (Branch, 1998).

Relative lizard abundance was assessed by census. Censuses were made on each plot in the week immediately prior to spraying, during the week immediately after spraying, during the fourth week after spraying and during the 18th week after spraying. Census intervals were based on the reported rates of deltamethrin breakdown and logistical considerations. Each census was made up of a number of sub-samples: each plot was sampled during each hour of the day (between 0800 h and 1700 h, spanning the entire activity period for the two lizard species), on three different, but not necessarily consecutive days (depending on weather conditions). Thus, each census consisted of 27 sub-samples (nine per day for three days). Without exception, censuses were conducted on days of fine weather, since overcast weather can result in erratic activity levels in lizards since basking opportunities on overcast days are reduced. All census data were collected by one person (DH), thus avoiding any bias due to variation in observer ability.

A single sub-sample of a census consisted of walking in the plot for 20 minutes along a predefined path (ten 100-m transects, each 10 m apart). During this time, all observed lizards were identified to species and counted. In addition, we recorded whether lizards were juvenile or adult. Lizards were easily assigned to these two age categories on the basis of size. Air temperature (T_a) was measured with a digital thermometer (APPA51) one meter above the ground in the shade, at the end of each census sub-sample. In order to make census counts comparable between plots, all counts were converted to percentages of the number of lizards recorded during pre-treatment censuses for each plot.

We factored out the influence of temperature on the census counts by regressing census counts for each plot against T_a. In this way, differences in regression slopes, analysed using ANCOVA, were used as a temperature-independent measure of relative abundance. Sequential Bonferroni adjustments for multiple paired comparisons (Rice, 1989) were applied where appropriate.

In order to ascertain if lizard abundance was affected more dramatically in the centre of the treatment plots, we defined a border of 15 m around the inside edge of the perimeter of each plot (approximately half the area). The number of lizards counted within this border was compared to the number within the remainder of each respective plot. We also tested for differences in relative proportions of juveniles in each plot.

Results

Enclosure trials

Mortality rates in both *P. namaquensis* and *M. suborbitalis* were significantly higher in all treatment categories (Table 1) in comparison to controls. In the direct application experiments, reactions typical of pyrethroid poisoning were usually shown within an hour of treatment. Symptoms included loss of co-ordination, loss of righting response, sensitivity to bright light, muscle spasms and panic, and these symptoms appeared to increase in intensity and regularity as the cooled lizards warmed to ambient temperature. In the indirect application experiments, symptoms were similar, but were not as severe and took approximately twice as long to manifest. One individual of *P. namaquensis* in the 25 g a.i. ha^{-1} direct application experiment died within seven hours of treatment. All remaining lizards in all treatment categories appeared to have recovered by the following day, as symptoms of poisoning were no longer evident. However, the mortality rates of lizards in all treatment categories increased significantly and the majority of these lizards were dead within two months of treatment.

Field trials

The measured attributes of the vegetation in the three study plots were similar. Of the six species included in the analysis (*Tetragonia sarcophylla* Fenzl, *Malephora crocea* (Jacq.) Schwant., *Delosperma* spp, *Lycium cinereum* Thunb. (Sens. Lat.), *Stipagrostis obtusa* (Del.) Nees and *Salsola calluna* Fenzl ex C. H. Wr.), Kolmogorov-Smirnov two-sample tests revealed that only one species differed between plots. *Salsola calluna* was less common in the control plot in comparison to the treatment plots. Thus, we considered the habitat available to the lizards in the three plots to be sufficiently similar to each other for the purposes of our study.

On average, we counted 18·1 ± 3·1 (mean ± S.D.) *M. suborbitalis* and 32·7 ± 4·7 *P. namaquensis* per day, in each of the plots before treatment with deltamethrin (Table 2). All regressions between census measures and T_a were significant (Table 3). Generally, ANCOVA revealed significant differences in measures of abundance (slopes of the regressions), in both treatment plots, between censuses taken pre-treatment and one week after spraying, and pre-treatment and four weeks after spraying with deltamethrin (Table 4). The only exception to this was the comparison between pre-treatment and one week post-treatment for *M. suborbitalis* in one of the treatment plots, where the measured decrease was not large enough to be significant. In all cases where there were significant differences in lizard counts, this was due to a reduction in the post-treatment counts. On average, census counts of *M. suborbitalis* decreased by 29% one week after spraying, and by 52% four weeks after spraying. Census counts of *P. namaquensis* decreased by 58% and 72% for the one and four week censuses respectively. No significant differences in abundance were evident between the pre-treatment censuses and 18 weeks after treatment. In some cases, there were also significant differences in abundance measures between the censuses at one, four and 18 weeks after spraying, as the lizard counts returned to pre-spraying levels by the week 18 census. No significant changes in abundances were recorded in the control plot. In all plots, juvenile lizards were only observed during the week 18 post-treatment censuses.

Table 1. *Numbers of lizards per experimental class treated (A) and alive (B) two months after deltamethrin application in laboratory trials*

	Direct application						Indirect application					
	Meroles suborbitalis			Pedioplanis namaquensis			Meroles suborbitalis			Pedioplanis namaquensis		
Treatment	A	B	*p*	A	B	*p*	A	B	*p*	A	B	*p*
17·5 g a.i. ha^{-1}	10	0	< 0·001★	5	0	< 0·001★	10	4	< 0·001★	—	—	—
25 g a.i. ha^{-1}	—	—	—	8	0	< 0·001★	—	—	—	8	0	< 0·001★
Control	8	6	1	8	7	1	8	6	1	8	8	0

The *p* values are for χ^2 comparisons using control values as the expected values. Significant comparisons are shown by★.

Table 2. *Average daily census counts (mean ± S.D.) of Meroles suborbitalis and Pedioplanis namaquensis recorded before and after treatment with deltamethrin*

Plot and sample	*Meroles suborbitalis*	*Pedioplanis namaquensis*
Treat. plot 1		
Before	21·7 ± 4·0	32·0 ± 10·0
1 week after	13·7 ± 4·0	10·3 ± 0·58
4 weeks after	12·0 ± 1·73	8·67 ± 0·58
18 weeks after	21·0 ± 1·34	26·3 ± 1·34
Treat. plot 2		
Before	16·3 ± 2·9	28·3 ± 7·5
1 week after	13·3 ± 7·5	15·0 ± 2·9
4 weeks after	6·3 ± 0·58	8·0 ± 0·58
18 weeks after	14·3 ± 1·24	24·0 ± 1·87
Control plot		
Before	16·3 ± 5·8	37·7 ± 6·3
1 week after	19·0 ± 1·15	24·3 ± 2·3
4 weeks after	24·7 ± 1·15	26·7 ± 1·15
18 weeks after	13·7 ± 1·10	33·7 ± 1·75

Table 3. *r^2 values for the regression analysis between relative lizard abundances and temperature. All regression lines were significant at* $p \leqslant 0·05$

	Meroles suborbitalis			*Pedioplanis namaquensis*		
Plot and sample	r^2	b	a	r^2	b	a
Treat. Plot 1						
Before	0·63	– 11·4	382·1	0·60	– 6·5	241·9
1 week after	0·54	– 8·0	280·2	0·91	– 3·8	142·2
4 weeks after	0·66	– 8·1	273·1	0·51	– 3·6	119·5
18 weeks after	0·85	– 10·4	353·8	0·88	– 7·2	250·6
Treat. Plot 2						
Before	0·52	– 9·7	346·6	0·81	– 14·0	473·5
1 week after	0·74	– 9·8	386·9	0·70	– 5·2	201·0
4 weeks after	0·68	– 6·6	215·7	0·65	– 2·9	100·3
18 weeks after	0·76	– 12·34	407·8	0·93	– 12·9	431·5
Control Plot						
Before	0·69	– 15·8	522·6	0·98	– 13·1	444·0
1 week after	0·94	– 9·7	310·4	0·46	– 6·9	231·7
4 weeks after	0·66	– 15·0	527·1	0·75	– 8·9	307·1
18 weeks after	0·84	– 10·83	370·8	0·96	– 9·4	334·6

a and b denote the y intercept and slope of the regression lines respectively.
The 18-weeks after treatment sample includes both adult and juvenile individuals.

Edge effects

We found significant differences between abundance measures recorded at the edge and the centre of our treatment plots for the one and week four censuses after spraying (Table 5). In all cases of significance, the centre of the plot contained fewer lizards than the edge. This 'edge effect' was not evident before spraying in the treatment plots,

Table 4. p *values for comparisons of regressions (using ANCOVA) between activity and temperature*

		Sample	
Plot	Before treatment— 1 week after treatment	Before treatment— 4 weeks after treatment	Before treatment— 18 weeks after treatment
Meroles suborbitalis			
Treat. plot 1	0·028★	0·021★	0·5
Treat. plot 2	0·92	0·047★	0·96
Control plot	0·25	0·33	0·82
Pedioplanis namaquensis			
Treat. plot 1	0·042★	0·007★	0·57
Treat. plot 2	0·0001★	0·0001★	0·46
Control plot	0·062	0·99	0·46

The week 18 samples include both adult and juvenile individuals. Significant comparisons are shown by★.

Table 5. p *values for* χ^2 *comparisons of* Pedioplanis namaquensis and Meroles suborbitalis *sighted during walking samples within the perimeter and inner sections of the three experimental plots*

Sample	*Pedioplanis namaquensis*	*Meroles suborbitalis*
Treat. plot 1		
Before	0·11	0·064
1 week after	0·036★	< 0·00★
4 weeks after	< 0·0001★	< 0·0001★
18 weeks after	0·55	0·28
Treat. plot 2		
Before	0·40	0·40
1 week after	0·036★	< 0·0001★
4 weeks after	< 0·0001★	< 0·0001★
18 weeks after	0·40	0·98
Control plot		
Before	0·18	0·62
1 week after	0·32	0·40
4 weeks after	0·18	0·68
18 weeks after	0·98	0·17

The week 18 samples include both adult and juvenile individuals. Significant comparisons are shown by★.

nor was it evident at the week 18 post-treatment censuses. The control plot did not show any edge effects during any of our censuses.

Age structure

Since juveniles were first observed during the week 18 census, we assumed that young hatched between the weeks 4 and 18 censuses. This is in agreement with the breeding data from Branch (1998). We found significant differences in the proportion of juveniles in the population in three of the four comparisons (two plots; two species)

Table 6. p *values for* χ^2 *comparisons between control and treatment plots of the proportion of the population made up by juveniles for the week 18 census using* χ^2

	Meroles suborbitalis	*Pedioplanis namaquensis*
Plot 1	0·0005*	0·005*
Plot 2	0·10	0·050*

between treatment plots when compared to the control (Table 6). In the three cases of significance, juveniles comprised a greater proportion of the populations of lizards in the treatment plots in comparison to the control.

Discussion

We have demonstrated that deltamethrin, applied at recommended dosages, significantly and obviously increased mortality rates in the two non-target lizard species that we studied. These effects were present regardless of whether the lizards were exposed to deltamethrin through direct exposure, or indirectly through contact with contaminated vegetation and ground. However, the effects appear to be more marked when the lizards were exposed directly. We have also demonstrated that application of deltamethrin, as routinely applied in the control of locust swarms, can have an effect on populations of the two lizard species we studied, reducing local abundance in the short-term. We found that lizard abundance was most affected in the centre of sprayed patches, and recovery of populations appeared to be through immigration of lizards from untreated areas. In our study, this immigration resulted in a change in the age structure of the population since the recovery period spanned the breeding season, and juveniles appeared to be the predominant immigrants.

Both our laboratory and field experiments suggest that the effects of deltamethrin are not always immediate, since mortality rates of lizards remained significantly higher for an extended time period, long after most of the residue should have disappeared from the environment. In our field experiments, the greatest reductions in lizard abundance were recorded four weeks after spraying, at which time, both of the sprayed plots had significantly and drastically reduced populations for both the species that we monitored. These trends are in close agreement with the results of our enclosure experiments. The delayed response of the lizard populations and the short residue period of deltamethrin (Lhoste & L'Hotellier, 1982) imply that pesticide is taken up by the lizards on initial exposure, causing continued physiological damage through time, eventually leading to death. Our results also clearly highlight the necessity for monitoring lizard populations for at least a month after the application of deltamethrin, if the full response to the pesticide is to be revealed.

Our measures of relative lizard abundance during field trials were made using walked censuses. This is an indirect measure of abundance in that abundance is inferred by the activity level (number of active lizards; lizards not sequestered in their burrows) of the population. However, the activity level may also be influenced by factors other than population size. For example, it is well known that ambient temperature has a profound effect on the level of activity in reptiles (Gibbons & Semlitsch, 1987). We factored out temperature effects in our analysis by using ANCOVA. However, the effects of some other influencing factors are not so easily negated: spraying pesticide in our treatment plots is likely to have reduced food abundance for both of the species of lizards that we studied, since both are insectivorous. In fact, reduced food availability in the treatment plots may well have caused the significant decrease in our census counts (three significant comparisons out of a possible four; Table 4) in the week immediately after spraying.

We are, however, confident that decreases in our census measures four weeks after treatment reflect real decreases in lizard populations. We base this confidence on several facts: First, our laboratory trials clearly showed an increased chance of mortality, which was most marked about one month after treatment, and are thus in close agreement with the trends shown in our field experiments. Second, since deltamethrin has a short residual time (Hill *et al.*, 1987), it is unlikely to affect insect populations, and thus the lizards' food availability, in the area one month after application. Insect abundance certainly appeared to be normal in our treatment plots at the time of our week four censuses. Johnson *et al.* (1986) reported 'considerable immigration' of grasshoppers into 20-ha plots from 15 days after treatment with deltamethrin. Immigration rates into our much smaller 1-ha plots should have been faster than this. Third, the significantly higher proportion of juvenile lizards in the populations in the treatment plots at the week 18 census, is strong circumstantial evidence that the original adult lizard population had been decimated, providing vacant space for juveniles that either hatched in the plot or immigrated from outside of it. Massot *et al.* (1992) have shown that juvenile mortality is positively related to density in lizards, and that immigration rates into an area increase when density is reduced. Juveniles may also be chased out of territorial areas already established by other lizards (Stamps & Krishnan, 1995). Thus our findings are in keeping with reduced adult numbers in our treatment plots at the time of hatching.

Reductions in abundance of *P. namaquensis* were greater than in *M. suborbitalis* in our treatment plots. In one of the censuses taken during the week after spraying, the reduction of *M. suborbitalis* was not large enough to be significant. We have considered four possible explanations for differences in the magnitude of the population reductions: (1) differences in the foraging modes of *P. namaquensis* and *M. suborbitalis* result in differences in the amount of deltamethrin ingested. Stewart & Seesink (1996) have demonstrated that *P. namaquensis* will ingest dead hoppers under laboratory conditions and argued that this is a potential route for poisoning in this species. Huey & Pianka (1981) recorded differences in the diet of *P. namaquensis* and *M. suborbitalis*; in *P. namaquensis* termites formed a larger proportion of the diet than in *M. suborbitalis* because *M. suborbitalis* is an ambush forager and thus feeds mainly on more mobile prey. We argue that *P. namaquensis* is more likely to feed on dead, poisoned insects than is *M. suborbitalis*, resulting in increased deltamethrin ingestion. (2) *Pedioplanis namaquensis* was exposed to more deltamethrin through contact, because it moves greater distances than *M. suborbitalis* while foraging (Huey & Pianka, 1981) and is thus exposed to more deltamethrin. *Meroles suborbitalis* spends more time under the shelter of bushes while ambushing prey. (3) Differences in selected body temperatures of the lizards result in differences in the effectiveness of deltamethrin and the lizards' ability to detoxify deltamethrin. Johnson (1990) has shown that deltamethrin is more effective at higher body temperatures in two species of grasshoppers, *Camnula pellucida* (Scudder) and *Melanophus bivittatus* (Say), but this relationship may be reversed in other species (e.g. Riskallah, 1984; Grafius, 1986). However, since the selected body temperatures of the two lizards species that we investigated differ by less than 1°C (Huey *et al.*, 1977), it is unlikely that temperature difference is the main cause of the difference in the decrease in abundance. (4) *Pedioplanis namaquensis* simply has a lower tolerance of the deltamethrin.

We found significantly fewer lizards at the centre of our treatment plots in comparison to the edge in our week one and week four post-treatment censuses. This trend was not evident before spraying or 18 weeks after treatment. We can counter the argument that these edge effects were due to less insecticide being applied to the edge of our test plots, as was found in a study by Hill *et al.* (1987), since we were careful to apply insecticide evenly, and extended the area of application to between five and ten meters outside the perimeter of our treatment plots. The observed pattern could result from lizards with home ranges located on the periphery of the treatment plots spending less time in the treated area, as their home ranges extended beyond the plot's boundaries. These individuals would thus be exposed to less insecticide and consequently, have reduced chance of mortality compared to lizards with home ranges totally surrounded by the boundaries of the treatment plot. The edge effects that we observed in our study highlight the possibility that the dosage of deltamethrin may be an important factor in influencing the effect of the insecticide on non-target reptiles.

Our conclusion that deltamethrin has a detrimental effect on non-target reptiles differs from Lambert's (1994) conclusion of minimal effect on lizard populations. Lambert conducted his study in Mopane woodland (*Colophospermum mopane* (Kirk ex Benth.)) in Zimbabwe, where deltamethrin is used in the control of tsetse fly. He applied a 0·05% aqueous solution of deltamethrin selectively to tree trunks and monitored subsequent changes in a population of the common skink, *Mabuya wahlbergii* (Peters) (formerly *Mabuya striata wahlbergii*), using a census method that recorded the number of lizards on tree trunks. He found no significant changes in the population size in the 40 days following spraying. Differences in the results of the two studies could be due to differences in the method of deltamethrin application or in the species studied. However, we believe that Lambert's finding of no significant difference may be due to the effect that ambient temperature had on the activity levels of the lizards and thus abundance measures, resulting in a high noise to signal ratio in his data: census measures were also affected by temperature effects on lizard activity and so temperature masked the effects of poisoning.

Our study allows us to make several recommendations regarding the use and management of deltamethrin for the control of locust swarms in the Karoo: (1) since we have shown that deltamethrin does have obvious negative effects, at least for populations of some species of non-target reptiles, it should be used sparingly and should never be applied at levels above recommended dosages; (2) since even indirect contact with deltamethrin appears to increase rates of mortality, there is no safe time-window during the day or night when spraying could be conducted with less detrimental effect on non-target species; (3) we also recommend that sprayed areas be as small as possible since recovery of the reptile populations appears to be primarily through immigration from unaffected areas. Thus, we favour the current trend of localised spraying on hopper bands and predict a much greater and prolonged depression of reptile populations in the event of aerial spraying; (4) we recommend also, that future studies into the effects of deltamethrin on reptiles take into account the delayed nature of the response and design their research protocols accordingly; (5) in light of the negative effects related to the use of deltamethrin, we recommend intensive investigation into the use of microbial control agents that are highly specific to the target organism. Price *et al.* (1997) and Arthurs & Thomas (2000) have recently shown a mycoinsecticide, *Metarhizium anisopliae* (= flavoviride) Gams & Rozsypal to be effective in reducing feeding rates and increasing mortality rates of *L. pardalina.*

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