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The effects of aerially applied fenitrothion and chlorpyrifos on birds in the savannah of northern Senegal

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Summary

1. Studies of the effects of applications of locust insecticides on birds were conducted in the savannah of northern Senegal in 1989. The insecticides studied were fenitrothion at 485 and 825 g ha^{-1} and chlorpyrifos at 270 and 387 g ha^{-1}.
2. Total bird numbers decreased on all treated plots. Decreases in three of the most abundant species were significant on the fenitrothion plots. Some of the decrease was due to bird mortality, but apparently most of it represented movements of birds in reaction to a reduction in their arthropod food.
3. The reduction in grasshoppers was four times greater on the fenitrothion plots than on the chlorpyrifos plots, and this difference was reflected by a decrease in the insect foods eaten by birds after the treatments.

Key-words: brain cholinesterase inhibition, mortality, food habits, reproductive success, pesticide impacts.

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Introduction

An eruption of the desert locust (*Schistocerca gregaria* Forskål) occurred through the African Sahel between 1986 and 1989. Affected African countries responded by initiating surveillance and control programmes with the assistance of international donors. Between June 1988 and June 1989 alone, 12 million ha were treated with insecticides (Everts 1990). In addition, major outbreaks of the Senegalese grasshopper (*Oedaleus senegalensis* (Krauss)) occurred in 1985, 1986 and 1989. This species is at present considered to be the most destructive grasshopper pest in the Sahelian zone of West Africa (Cheke 1990). During 1986, insecticides were sprayed from aircraft and by ground applications on 3·4 million ha of grasshopper-infested zones between Senegal and Chad (FAO 1987), and in 1987 on 1·3 million ha in the same general region (US Congress 1990). A variety of insecticides was used in these programmes, few of which had been evaluated for possible effects on Sahelian environments.

When applied to wetland habitats, chlorpyrifos has consistently caused mortality and other effects in aquatic invertebrates and fishes. In contrast, when used for insect control in terrestrial habitats, chlorpyrifos has not had severe effects on resident animals (Odenkirchen & Eisler 1988).

Fenitrothion applications to forests in Canada at 300 g ha^{-1} and higher have usually had acute effects on passerine birds (Busby *et al.* 1983), while at lower rates sublethal effects are observed (Millikin & Smith 1990). Reductions in bird abundance were found at application rates of 140–280 g ha^{-1}, especially in canopy feeders (Pearce & Peakall 1977). In addition, almost all breeding attempts (84%) at 13 nests of white-throated sparrows (*Zonotrichia albicollis* Gmelin) were disrupted by a 420 g ha^{-1} spray and reproductive success in the sprayed area was only one-third of that in the control area (Busby, White & Pearce 1990). However, at an application rate of 300 g ha^{-1} in Scotland, Spray, Crick & Hart (1987) did not find effects on the size of the breeding bird populations, on bird counts immediately before and after spraying, or on reproduction in coal tits (*Parus ater* L.) although this may have been caused by a difference in exposure or by out-of-area feeding by the birds due to the relatively small plot size in the latter study. Of greater pertinence to locust control programmes are the findings of mortality and

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decreases in bird abundance following applications of 210–420 g ha^{-1} of fenitrothion to rangelands in the western United States for grasshopper control (McEwen 1982). Evidence was provided by Mineau & Peakall (1987) and by D.B. Peakall (*personal communication*) that heavily exposed birds seek sheltered locations and are less likely to be found. Therefore, they suggested that data collected thus far showed a strong collection bias, and that in fact they were only the 'tip of the iceberg'.

The information on birds we present was part of a larger FAO study to evaluate the effects of experimental applications of fenitrothion and chlorpyrifos on aquatic and terrestrial habitats in northern Senegal (Everts 1990). An experimental approach was chosen because it was impossible to predict when and where the insecticides would be applied for operational control of locusts. Thus, treatments were not made to areas containing locust swarms or bands; however, relatively high populations of grasshoppers (predominantly *Oedaleus senegalensis*) were present on studied areas.

This pilot study was conducted primarily to observe the kinds of gross effects that took place and differences in the intensity of effects associated with the different chemicals and application rates. Fenitrothion and chlorpyrifos are both widely used in locust control and the amounts applied may exceed recommended rates. Occasionally mass mortality among birds has been reported (e.g. Mullié *et al.* 1991). Treatments were not replicated. For this pilot study, it was decided to use the research capabilities to differentiate among the variables of chemicals and rates. In the future, long-term work will be needed to examine experimentally the more important effects identified in this pilot study.

Study area

PLOTS AND TREATMENTS

The study was conducted in a 400 km^2 area 15 km south of the Senegal River near Richard Toll, Senegal, between June and October 1989 (Fig. 1). Five 2 × 3-km study plots, each separated by at least 2 km, were used to evaluate the effects of four individual insecticide treatments and one control. These consisted of fenitrothion in study plot 1F at 485 g ha^{-1} (recommended rate for desert locust control is 500 g ha^{-1}); fenitrothion in study plot 2F at 825 g ha^{-1}, an untreated control (Control); chlorpyrifos in study plot 1C at 270 g ha^{-1} (recommended rate for desert locust control is 240 g ha^{-1}); and chlorpyrifos in study plot 2C at 387 g ha^{-1}. Insecticides were applied aerially to plots in ULV formulations between 5 and 12 September using an Islander aircraft fitted with electric pumps, two AU4000 Micronairs and short twisted blades (Courshee 1990).

RAINFALL

Total rainfall for the rainy season (June–October) ranged from 183·5 to 313·9 mm (average 235·5 mm, $n = 16$) in the sugar cane plantation of the Compagnie Sucrière Sénégalaise, immediately north of our study area.

Long-term rainfall in the region has averaged 319 ± 39 mm (Morel & Morel 1980). Thus, 1989 had less than average precipitation.

VEGETATION

The semi-arid thornbush savannah of the northern Sahel, which has also been termed Mimosaceae thorn scrub (Le Houérou 1989), is characterized by short trees, bushes and annual grasses, such as *Aristida* spp., *Cenchrus biflorus* Roxb., and *Schoenefeldia gracilis* Kunth. and common dominant herbs such as *Zornia glochidiata* Reichb. and *Cassia* spp..

Counts on 4–10 ha along a representative transect (see Methods) within each of our five study plots indicated *Boscia senegalensis* (Pers.) Lam. ex Poir., *Balanites aegyptiaca* (L.) Del., and *Acacia* spp. (e.g. *A. senegal* (L.) Willd., *A. tortilis* Hayne, and *A. seyal* Del.) made up 97% of the trees present. Total tree density ranged from 51 to 84 trees per ha; tree density and species richness was highest in plot 1F. Of trees counted, 57% were shorter than 2·5 m in height. Baobabs (*Adansonia digitata* L.) were widely, but thinly, distributed and occurred on all study plots (estimated density, 5–10 trees per 1000 ha). Large herds of cattle, goats, and sheep grazed the study area.

There were numerous shallow depressions scattered throughout the study area, ranging from 0·25 to 1 ha or more in size. Water and sediments tended to drain into depressions after rain storms. The higher soil moisture in depressions supported a greater diversity and biomass of vegetation and usually twice the number of trees as in the surrounding savannah (Bille & Poupon 1972). After rains began, annual and perennial herbs in depressions responded immediately and grew tall and dense, in striking contrast to the shorter grasses in the savannah.

Methods

BIRD COUNTS ON TRANSECTS

To help assess treatment effects on bird numbers, six 1-km long transects, 250 m apart, were established in each of the five study plots (Fig. 1). Along each transect a white marker was placed every 100 m. Bird counts were generally made weekly and in the same sequence between 24 July and 7 October (Table 1).

Transect counts on a single plot, each lasting 50 min, were conducted by two observers between

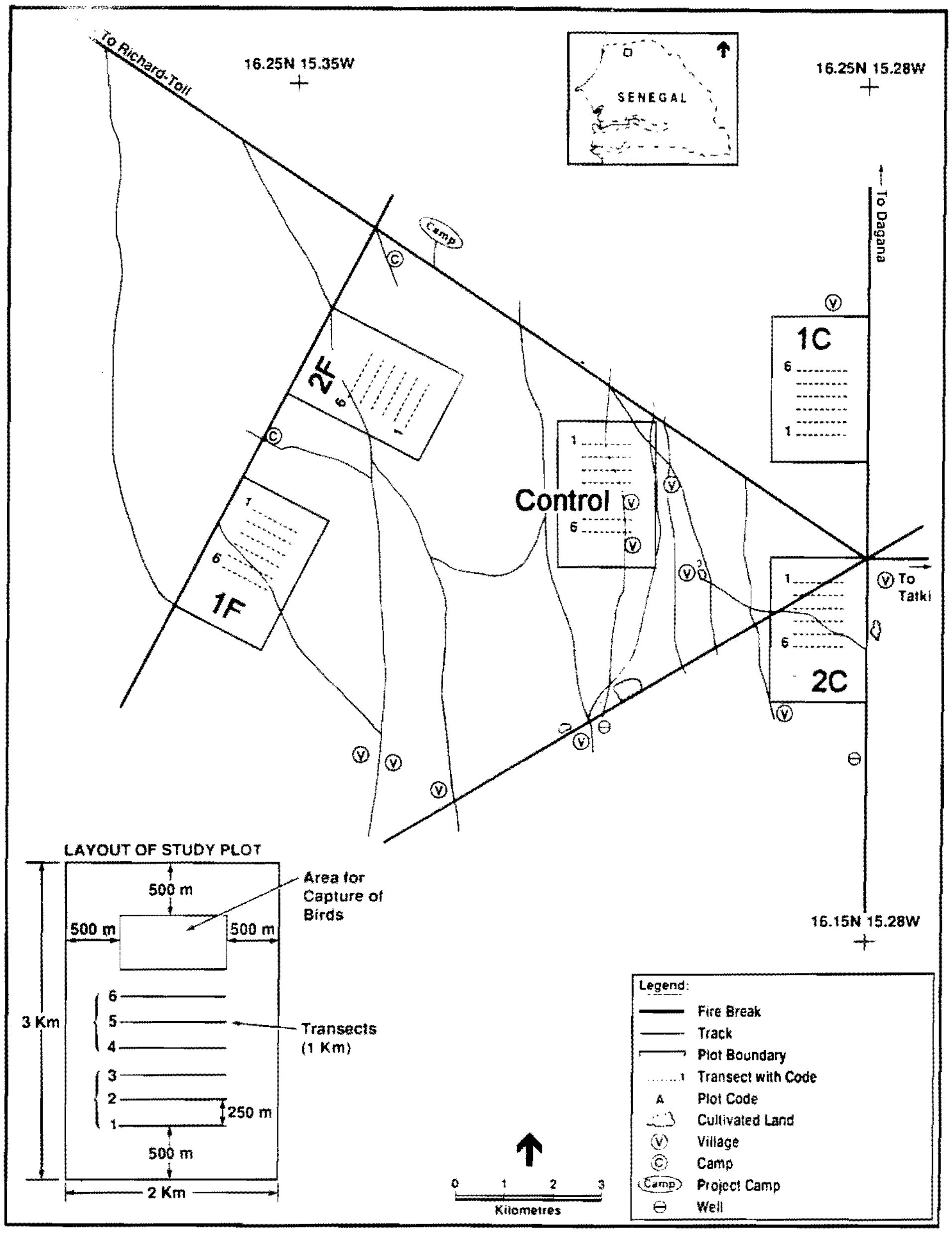

Fig. 1. Study area in northern Senegal and layout of experimental plots.

07.00 and 10.00 h. One observer visited transects 1–3, the other transects 4–6 (Fig. 1). Birds heard or seen within 50 m of the transect were tallied. A constant pace was maintained by covering each 100 m of the transect in 5 min. Our counts did not always measure actual bird densities but they provided a relative index of abundance. Secretive and nocturnal birds were seldom recorded, and counts did not evaluate treatment effects on these species.

Table 1. Timetable of transect counts

	Start of week on										
	July		August				September				October
	23	30	6	13	20	27	3	10	17	24	1
Count	1	2	3	4	5	6*	7†	8‡	9	10	11
							Treatments				

* Three transects per plot.

† Only three transects on control plot, none on other plots.

‡ Three transects on Plot 1C, six on other plots.

There was some variation in the observers' knowledge of and ability to identify birds. However, analysis of counts of common birds that were ultimately used to evaluate treatment effects showed no difference ($P > 0{\cdot}20$) between observers.

BIRD COUNTS IN DEPRESSIONS

Three to five of the depressions in each plot were selected for monitoring bird abundance. One to four 15-min counts were obtained in each depression both before and after treatments. An observer sat or walked around and through depressions while noting the birds present. Such counts were taken between 10.00 and 13.00 h, after transect counts.

EVALUATION OF BREEDING PERFORMANCE

Colonies of synchronously breeding buffalo weavers (*Bubalornis albirostris* (Vieillot)) were present throughout the study area, primarily in large baobab and acacia trees. The breeding stage of colonies was noted during bird counts before and after insecticide treatments.

Before treatments, the breeding biology of the singing bush-lark (*Mirafra javanica* Horsfield), was studied. Details are presented elsewhere (Mullié & Keith 1991).

SEARCHES FOR DEAD AND DEBILITATED BIRDS

Searches

To measure any direct mortality from treatments, special carcass searches were organized. Twelve young men were recruited from nearby camps and villages. Two searches were conducted on each of the four treated plots: one at 24 h and another at 48 h after treatments. Two searches were made on the control plot during the same period on 2 consecutive days. In each search, the 12 men spread out 20 m apart over a distance of 250 m and walked abreast for 2·0 km for a period of 2–3 h, depending on the density of vegetation. Searchers covered about 8·3% of the area within each plot and searched 1·3–1·9 ha h^{-1} $person^{-1}$. In addition to data on dead birds found, a value for search efficiency and for carcass disappearance rate was needed to calculate the proportion of the population killed (Fite *et al.* 1988).

Search efficiency

On two occasions 36 and 61 dead birds were placed respectively in an area to be searched in order to establish search efficiency. The search team was not informed of this prior to counts. Each labelled specimen was placed haphazardly in a habitat where it probably could have died. After the searches, remaining marked carcasses were not removed but were left to help evaluate subsequent searches. Separate efficiency coefficients were calculated for small birds (weight <30 g) and larger birds.

Carcass disappearance rate

Dead birds were also used to determine the disappearance rate of carcasses due to scavenger activity. In plot 1C 14 birds were placed at five locations and in plot 2F 33 birds were placed at seven locations along a transect. They were checked after 24 and 48 h. The disappearance rate was used to calculate the proportion of carcasses remaining ($R = 1 -$ disappearance rate).

BIRD COLLECTIONS FOR FOOD HABITS AND CHOLINESTERASE ANALYSES

Collections

Singing bush-larks, buffalo weavers, and golden sparrows (*Passer luteus* (Lichtenstein)) were initially chosen for monitoring changes in ChE levels and food habits following treatments. These species were abundant, widely distributed, and ranged in food habits from insectivores to granivores. Golden sparrows decreased rapidly in numbers after rains started and they were deleted from collections. Abyssinian rollers (*Coracias abyssinica* Hermann), hoopoes (*Upupa epops* L.) and woodchat shrikes (*Lanius senator* L.) proved susceptible to treatments; they were also collected. Birds were taken with mist nets, a 4·5-mm air rifle, and a 16-gauge shotgun. For each species an attempt was made to collect 10 individuals in each plot in the first and again in the third week after treatments. Birds from untreated areas were taken for controls. These untreated areas were at least 2 km from the edge of any treated plot. Birds found dead or debilitated during searches were also saved for analyses.

Specimen handling

Usually fresh specimens were dissected within 15 min of death. Weights were taken using spring scales with a precision of 0·3%. During dissection, birds were sexed and aged and relevant information was noted. Developmental stage ('age') of fledgling larks was assessed by taking wing lengths and tail lengths and adding these measurements. The gizzard and crop, if present were removed, and the contents or the complete gizzard was stored in ethanol (96%). Empty gizzards were discarded. Brains were removed and placed in 15-ml cryogenic vials, and subsequently stored in liquid nitrogen until they could be processed in the laboratory.

Food habits analysis

Gizzard contents were identified to order using a 7 × 40 × binocular microscope. Remains of some taxa, such as those of *Oedaleus senegalensis*, could be identified to the species level. The presence of grit was also noted. Bird species to be sampled could not always be obtained on all plots. Using numbers of food items as a basis for determining food habits tends to bias results in favour of the small, numerous items.

Cholinesterase analysis

Brains were transferred to storage in a laboratory freezer after fieldwork was completed. They were held in the freezer for a maximum of 14 weeks. ChE activity was determined by the colorimetric method of Ellman *et al.* (1961) as modified by Hill & Fleming (1982). Analyses were conducted at the University Cheikh Anta Diop, Dakar, Senegal (Ciss & Niane 1990). Results are expressed as μmoles of acetylthiocholine iodide hydrolysed per minute per gram (wet weight) of brain tissue (μmoles $\text{min}^{-1}\,\text{g}^{-1}$).

STATISTICAL ANALYSES

The experimental design of this study did not include replications of treatments and, therefore, it did not fulfil theoretical requirements to permit general inferences from the results. However, statistical analyses were conducted with the understanding that any differences detected could be due either to the effects of the chemicals, to inherent differences among plots, or to both factors.

Analyses of bird count data were made using a two-factor, repeated measures ANOVA with unbalanced data. Analyses were conducted for birds grouped by systematic relationships and life-history traits using a three-factor, repeated measures ANOVA with unbalanced data. Data were unbalanced because several counts on some plots were conducted by only one of the two observers.

Differences among-plots and within-plots among-weeks, in the proportion of grasshopper remains in gizzards of selected species, were tested separately in single classification ANOVAS. The same analysis was conducted to test differences among and within plots in weights of captured specimens and in development of captured fledgling larks. Means were separated with Duncan's Multiple Range test.

Results

BIRD COUNTS ON TRANSECTS

131 species of birds were documented on the study plots between June and October (Keith & Mullié 1990). Afrotropical species (both residents and intra-African migrants) dominated the avifauna in June and July, but Palaearctic migrants increased in August, September and October. Some species of local breeding birds were presumably augmented by migrants. It was sometimes unclear whether increases observed over time were the result of local movements or of an influx of Palaearctic migrants. Observations on the control plot and other untreated areas showed that normal increases and decreases in certain species occurred unrelated to insecticide treatments.

Counts on study plots were conducted during (July–September) and after the rainy season (October). Some birds had reproduced during the dry season (Abyssinian rollers), while others initiated breeding with the beginning of the rains (singing bush-larks, buffalo weavers, blue-eared glossy starlings (*Lamprocolius chalybaeus* (Hempr. & Ehrenb.)), cricket warblers (*Prinia clamans* (Temm.)), and fantailed warblers (*Cisticola juncidis* (Rafin.)).

Many of the species seen on study plots were not used in the assessment of treatment effects. Some species were wide-ranging and not known to be exposed to insecticides. All rare and incidental birds and all palaearctic migrants, most of which arrived after treatments, were not considered in evaluating treatment effects. Golden sparrows were so numerous that changes in their abundance were capable of masking effects on the less abundant species and data for this species were considered separately.

The removal of the above birds left 71 species, 21 of which were common, for consideration in assessing insecticide applications. Means and standard errors for transect counts of these 21 species and of golden sparrows on each plot are given in Keith & Mullié (1990) and are available upon request.

To determine whether life-history characteristics of the 71 species made them more or less sensitive to treatments, analyses were conducted based on systematic relationships (passerine, non-passerine), macrohabitat preferences (depression, savannah proper), feeding strategies (terrestrial, arboreal), and diet (insectivore, omnivore, vegetarian) (Keith & Mullié 1990).

The total number of birds (sum of 71 species) and the total of the most common species (sum of 21 species) decreased after treatments ($P < 0{\cdot}01$). The percentage decrease in bird numbers was greatest on plot 2F and was greater on all treated plots than on the control plot (Table 2). In general, a greater decrease in bird numbers on plot 2F was indicated by all assessments ranging from the sum of 71 species,

Table 2. Percentage change in bird numbers between periods on study plots

Data and means compared	Plot 1C	 2C	 1F	 2F	 Control
Sum of 71 species					
Pre-treatment vs. post-treatment	−26	−28	−30	−46	−8
Count 6 vs. post-treatment	−26	−26	−42	−61	−14
Sum of 21 species					
Pre-treatment vs. post-treatment	−26	−28	−32	−51	−13
Count 6 vs. post-treatment	−24	−26	−46	−63	−16

the sum of 21 species (Fig. 2), and the life-history traits of birds (Fig. 3a,b,c) to many of the individual species, such as the singing bush-lark.

Abyssinian rollers increased during the study, but by the third week after treatment (week 10), roller numbers on all treated plots were 36–40% lower than on the control plot ($P = 0{\cdot}01$). Blue-naped mousebirds (*Urocolius macrourus* (L.)) also tended to increase during the first 8 weeks of the study, especially on plots 1C and 2C, which by the eighth week had more than twice the numbers as the control plot ($P = 0{\cdot}01$). In contrast, on plots 1F and 2F, mousebirds numbers had dropped to zero 1 week after treatments. Singing bush-larks were the second

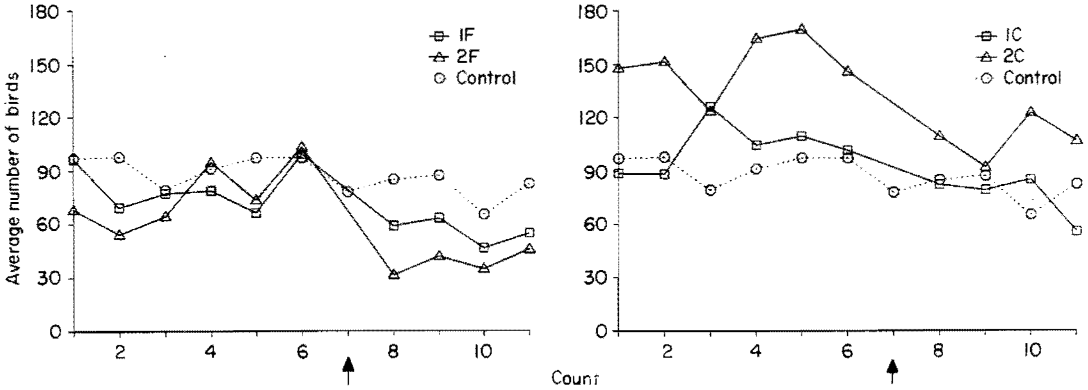

Fig. 2. Average number per transect of 21 species seen during each count on experimental plots. An arrow indicates the moment of treatment.

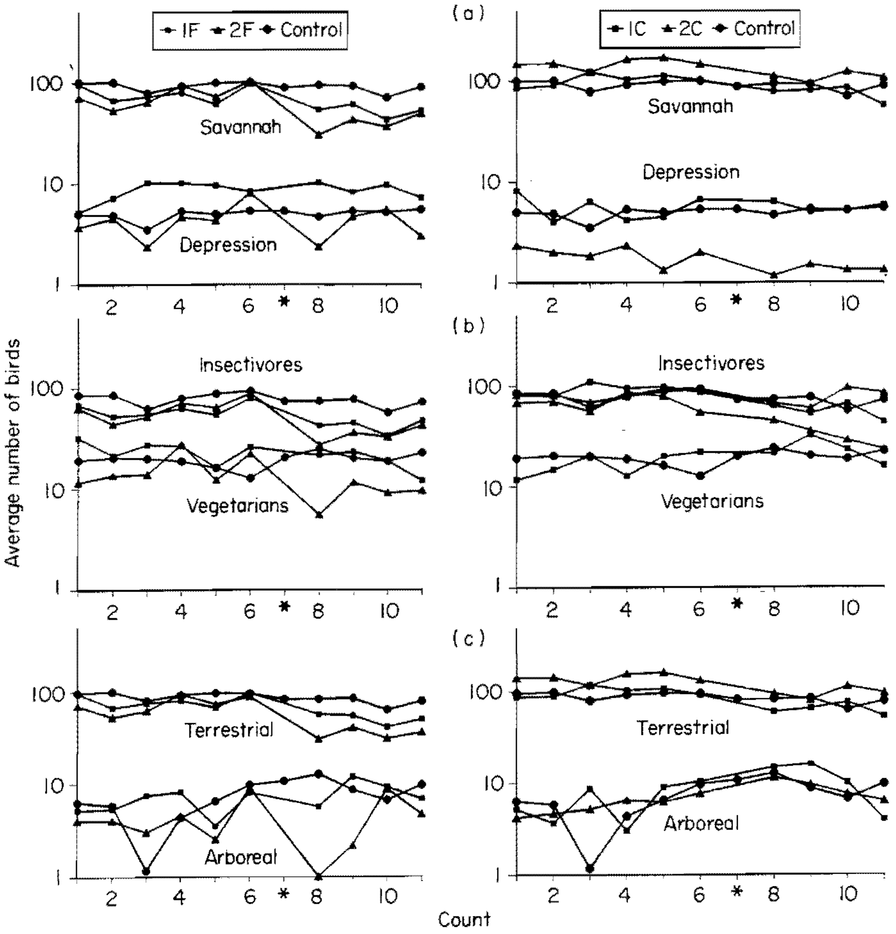

Fig. 3. Average number per transect of (a) savannah and depression birds, (b) insectivores and vegetarians, and (c) terrestrial and arboreal feeding birds seen during each count on experimental plots. An asterisk indicates the moment of treatment.

most abundant birds on plots (after golden sparrows). They were likely to be a good indicator species for treatment effects in the savannah because they were abundant, widely distributed, sedentary, and nested in the grasslands. After treatments, lark numbers decreased on all plots as young fledged and birds presumably left the area. However, decreases were greatest and occurred more rapidly on plots 1F (3·2 transect^{-1}), 2F (8·0 transect^{-1}) and 2C (10·0 transect^{-1}), all of which on the first or second week after treatment had significantly ($P < 0{\cdot}01$) fewer larks than the control plot (20·8 transect^{-1}).

Buffalo weavers decreased on treated plots immediately after insecticide applications. Although these changes were not highly significant ($P = 0{\cdot}11$), they probably were real.

Golden sparrows were apparently not affected by treatments; however, their numbers decreased significantly ($P = 0{\cdot}01$) on all plots over time. They constituted 80% of total birds seen on the control plot during the first five counts and only about 30% during the last four counts. Their decrease was correlated with breeding elsewhere in the region. Sparrows were increasing during our last counts as grasses dried and a new crop of seeds ripened. At that time flocks consisted largely of recently fledged birds.

In contrast to golden sparrows, woodchat shrikes tended to increase on plots during the study period but, like sparrows, the shrikes were not apparently affected by treatments although two individuals were found debilitated. Cricket warblers increased ($P < 0{\cdot}01$) during the study and did not appear to be affected by insecticide treatments. Increases were due partly to the appearance of young with adults: the cricket warblers bred during the period of the study.

Other afrotropical species that were widely distributed and bred during the study period did not appear to be affected by insecticide treatments. Numbers of black bush-robins (*Cercotrichas podobe* (Müller)) ($P = 0{\cdot}03$), grey-backed camaropteras (*Camaroptera brachyura* (Vieillot)) ($P < 0{\cdot}01$), and fantail warblers ($P = 0{\cdot}07$) varied among plots and over time, but not in relation to treatments. These species were considered obligate depression species, and the lack of an effect on them suggests the depression habitat was not affected by spraying to the same degree as the savannah habitat (see also Fig. 3a).

Effects of fenitrothion were indicated, especially on plot 2F, for most groups of birds, whether separated on the basis of systematic relationships, diet or feeding strategy (Table 3). This suggests that these traits did not predispose birds to fenitrothion effects. In contrast to birds on the control plot, those on fenitrothion plots tended to decrease after treatments regardless of their systematic relationships or their life-history traits (except that depression species increased). This situation probably reflects the fact that birds are somewhat opportunistic in their choice of foods. The abundance of grasshoppers on plots (Balança & De Visscher 1990) may have supported high bird populations. Reduction of that food source, therefore, could have caused some birds to leave plots.

Table 3. Percentage change in numbers of birds grouped by systematic relationships and life-history traits on control and fenitrothion plots*

	Plot		
Traits	1F	2F	Control
Systematic relationship			
Passerine	−39	−67	−12
Non-passerine	−40	−65	+91
Habitat preference			
Depression	+32	−67	+12
Savannah	−72	−81	+24
Feeding strategy			
Terrestrial	−42	−60	+10
Arboreal	−34	−78	+76
Diet			
Insectivores	−20	−54	+77
Omnivores	−54	−74	−20
Granivores/frugivores	−38	−66	+89

* Percentage difference between birds seen during Count 6 (last pre-treatment count) and Count 8 (first pre-treatment count).

Normal variations were observed among plots in the abundance of certain species. These differences were not related to treatments, but undoubtedly reflected the preference of birds for habitat resources on specific plots. Such habitat preferences were not identified, but such variations in the abundance of a species among plots illustrate why replication of plots is necessary in experimentation. Resources affected by insecticide treatments were not uniform among plots, so the possibility of each treatment's effect on birds was not equal. Replication of plots increases the probability that variations in resources and thereby in the kinds and numbers of birds will be equally tested against each treatment.

BIRD COUNTS IN DEPRESSIONS

A total of 55 species of birds was seen during depression counts, including incidentals and palaearctic migrants. Of these, only 17 species were relatively abundant. There were large variations in counts, both within individual depressions and among different depressions. Numbers of observations were too few to test for significant changes due to treatments. Still, it was of interest that the data, when compiled, suggested the same detrimental effects of fenitrothion as indicated by transect counts and other observations. Whereas depression counts in the control and chlorpyrifos plots indicated an increase in total birds present after treatments, numbers in fenitrothion plots apparently decreased. These findings do not conflict with the increase in 'obligate depression species' shown in Table 3. Counts in depressions reported here included all birds that were seen in depressions and were not limited to only the obligate depression species.

These results again suggested that fenitrothion treatments affected birds to a greater extent than chlorpyrifos treatments. In contrast to transect counts, depression counts on the chlorpyrifos plots and the control plot suggested bird numbers increased. Birds on those plots may have used the verdant depressions more frequently as the savannah habitat dried following the rainy season.

EVALUATION OF BREEDING PERFORMANCE

Buffalo weavers

It was impossible through casual observation to monitor the establishment, progress, and success or desertion of all colonies on study plots. However, records were maintained for a small number of active colonies observed during the first five and last four weekly transect counts on each plot. These records documented the locations of colonies, their desertion, and in many cases their re-establishment. The number of colonies active before and after treatment compared to the total initiated are shown in Table 4.

Eleven of 13 colonies on treated plots were deserted at about the time of spraying. None of three colonies on the control plot was deserted. Casual observations in plot 1C indicate that two weaver colonies were deserted the day following treatment. Observations were insufficient to determine if desertion was due to treatments, but results indicated insecticides may have caused changes that occurred. Some evidence suggested that, during applications, areas containing colonies that persisted on plot 2C were not sprayed (I.F. Grant, personal communication; W.C. Mullié, personal observation).

Table 4. Occupancy rate of buffalo weaver nesting colonies before and after treatment of plots*

	Plot				
Period	1C	2C	1F	2F	Control
Pre-spray (end of August)	3/6	5/7	3/6	2/4	3/6
Post-spray (mid-September)	0/6	2/7	0/6	0/4	3/6

* Data represent number of active colonies/total number of colonies initiated on plot.

Singing bush-larks

Breeding performance of bush-larks was studied only before treatment (Mullié & Keith 1991). Therefore, there was no direct evidence of treatment effects on bush-lark breeding performance. However, singing activity of male bush-larks in both plots sprayed with fenitrothion decreased significantly after treatment compared to singing activity in the control plot (Mullié & Keith 1991), while mortality of adults in breeding condition and debility or mortality of immatures strongly suggested that treatment might have affected breeding success.

SEARCHES FOR DEAD AND DEBILITATED BIRDS

Searches

A few dead or debilitated birds were found in all treated plots (Table 5), while none was located in the control plot. The greatest number and variety of birds were found in plot 2F. Button quail (*Turnix sylvatica* (Desfont.)), Abyssinian rollers, hoopoes, and singing bush-larks were most frequently affected on plots. Searchers captured a number of fledglings from the ground, and these also were predominantly singing bush-larks. These were likely to be affected by treatments, based on the ChE analyses.

Search efficiency

Of the 22 larger birds placed in the search area of plot 1C, nine (42%) were found, while only two (14%) of 14 smaller birds were located. These results, and the fact that vegetation was more dense on most

Table 5. Dead (D) and debilitated (d) birds found on plots after treatment*

	Plot			
Species	1F	2F	1C	2C
Button quail	–	2(d)	1(d)	–
White-throated bee-eater	–	–	–	1(d)
Abyssinian roller	1(d)	1(d)	–	3(D)
Hoopoe	1(D)	2(d)	–	–
Singing bush-lark	1(D)	1(D)	–	1(D)
Tree pipit	–	1(d)	–	–
Woodchat shrike	–	2(d)	–	–
Cricket warbler	–	1(d)	–	–

* Fledglings of the long-tailed beautiful sunbird (2), buffalo weaver (1), singing bush-lark (28), pink-headed dove (1), and black-headed shrike (1) were picked up during searches. Results of ChE analyses suggest that at least a number of these birds were debilitated, rather than simply flightless (see text). Two fledgling larks and one fledgling pink-headed dove and no dead or debilitated birds were found on the control plot.

other plots, prompted us to intensify the searches by increasing search time from 1 h to 1·5 h km^{-1}. In plot 2F, 33 (56%) of 59 larger birds were recovered. After 24 h, another search was made, and seven more birds were found, giving a total recovery of 68% for larger birds. No individuals of the two smaller birds were recovered. Calculated efficiencies are given in Table 6.

Carcass disappearance rate

Of 14 birds put out on plot 1C, three (22%) disappeared within 24 h. After 48 h, most carcasses contained fly larvae. In plot 2F, none of 33 birds was missing after 24 and 48-h checks, and there was little evidence of sarcophagic fly and beetle activity. For calculations it was assumed that the proportion of carcasses remaining on plot 2C was the same as on 1C, and on plot 1F the same as on 2F. Therefore, the proportion of carcasses remaining was taken to be 1·0 on plots 1F and 2F, and 0·8 on plot 2C (Table 6).

Population mortality

Values for calculation of mortality in large and small species populations of savannah birds on plots 1F, 2F, and 2C are given in Table 6. In plot 1C, only one debilitated bird was found, and population mortality was not calculated. Calculated population mortality, corrected for search efficiency and carcass disappearance rate, was low on all plots, but perhaps somewhat greater on plot 2F. Mortality (2–3% in chlorpyrifos plots, 2–7% in fenitrothion plots; Table 6) was not sufficiently high to account for all decreases observed in bird numbers on transect counts, corrected for the natural decrease in numbers on the control plot (8–10% decrease on chlorpyrifos plots, 30–47% on fenitrohion plots; Table 2).

FOOD HABITS ANALYSES

Singing bush-larks

The gizzard contents of singing bush-larks collected after treatments are shown in Fig. 4. In untreated areas, food items consisted predominantly of grasshopper instars, with seeds present in only two of the 17 gizzards containing food (11%). In the sprayed plots, however, 17 of 38 gizzards (45%) had seeds in them. The proportion of Orthoptera in the gizzard remains from the control areas was statistically greater ($P < 0{\cdot}05$) than in the chlorpyrifos and fenitrothion plots (plots 2C and 2F).

There were no apparent differences in prey selection between adults and fledglings. There was, however, a marked difference in the presence of grit in gizzards between adults and juveniles. In juvenile birds, 16 of 25 gizzards (64%) contained 1–25 small stones (maximum weight 0·25 g per gizzard), while in adult birds only four out of 33 birds (12%) contained grit in the gizzard.

Flightless fledgling singing bush-larks were significantly heavier ($P < 0{\cdot}05$) in the control (17·2 g, $n = 3$) than in the treated plots (1C (13·4 g, $n = 8$), 2C (12·3 g, $n = 4$), 1F (12·3 g, $n = 2$), 2F (13·4 g, $n = 14$)), while among treated plots there were no significant differences in weights. Weight differences could not be attributed to differences in 'age', as tail plus wing length did not differ significantly among plots ($P > 0{\cdot}10$, NS): control (83·3 mm, $n = 3$), 1F (73·0 mm, $n = 2$), 2F (90·2 mm, $n = 16$), 1C

Table 6. Calculated percentage minimum mortality (p) of the bird populations occurring in savannah habitat due to treatment with insecticides

Plot	Size of birds	Birds found (N)[§]	Density of birds (ha^{-1}) (D)*	Carcasses remaining (R)*	Search efficiency (E)*	Hectares searched (A)*	Population mortality (p(%))*
1F	>30 g	2	3·6	1·0	0·68	50	2
	<30 g	1	2·7	1·0	0·12[†]	50	7
2F	>30 g	7	2·8	1·0	0·68	50	7
	<30 g	3	8·6	1·0	0·12[‡]	50	6
2C	>30 g	3	5·8	0·8	0·55[‡]	50	2
	<30 g	2	12·6	0·8	0·14	50	3

* The proportion of the population that died has been calculated by using the formula $p = n\,100\%/DREA$ (after Fite *et al.* 1988).

[†] Search efficiency coefficients used for birds <30 g in plots 1F and 2F are the combined figures for the experiments in plots 2F and 1C.

[‡] The search efficiency coefficient for birds >30 g in plot 2C has been calculated using the combined results from the only search in plot 1C and from the second search in plot 2F.

[§] The fledglings that were picked up in the searches (Table 5) are not included in the calculations. At least a number of these birds were not simply flightless, but also debilitated due to the effect of treatment (see text). Adult birds found debilitated are included in the calculation; based on brain ChE levels it is assumed that they would have died as well.

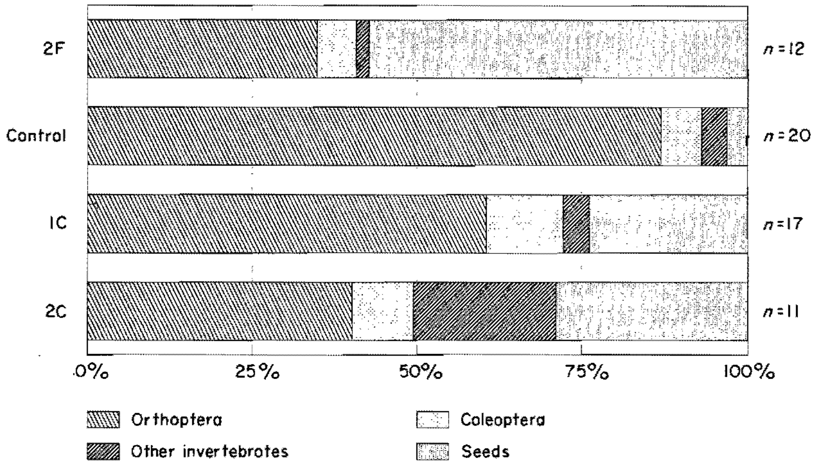

Fig. 4. Percentage composition of various foods in gizzards of singing bush-larks on experimental plots after treatments (based on numbers of food items in gizzards).

(78·7 mm, $n = 9$), and 2C (66·0 mm, $n = 4$). There were no significant differences in adult lark weights between control and treated plots.

Abyssinian rollers

Treatment effects were not obvious in Abyssinian roller gizzard contents. Grasshoppers made up 60–95% of all prey remains in birds from all areas. The main species was *Oedaleus senegalensis*, but *Acrida bicolor* (Thunberg) and *Cataloipus cymbiferus* (Krauss) were also identified in the prey remains. Based on the size of the jaws, predominantly adults or subadults were eaten. Four rollers that were found dead or debilitated 24 h after spraying (1 in plot 1F and 3 in plot 2C) had 35, 32, 29 and 51 grasshoppers, respectively, in their gizzards. In contrast, up to 14 grasshoppers were found in each of the nine rollers from untreated areas and up to 19 grasshoppers were found in each of the 39 gizzards collected in treated plots. An immediate shift to feeding on dying grasshoppers and rapid intoxication is likely, therefore, to have been responsible for the observed direct effects on Abyssinian rollers in the study plots. A comparison of the relative proportion of the different prey items in roller gizzards between week 1 and week 3 post-treatment shows a decreasing proportion of grasshoppers present in treated plots and a stable proportion in untreated areas. However, because of large individual variation, decreases were not statistically significant.

Abyssinian roller weights were not significantly different in control and treated plots. There were also no significant differences in weights of rollers between week 1 and week 3 post-treatment.

Buffalo weavers

Treatments had little effect on gizzard contents of buffalo weavers. Orthoptera were an important prey of buffalo weavers, making up 25–90% of the total remains present in individual gizzards and averaging 35–70%. Apparently, buffalo weavers were opportunistic feeders, adapting rapidly to the prey that was locally available. Birds from a colony at the project camp, used as controls, showed a dramatic shift in their diet within 1 week. Therefore, it was more difficult to determine if changes in diet were an effect of treatments. Like Abyssinian rollers, the buffalo weavers had a lower proportion of Orthoptera in their diet in week 3 than in week 1 post-treatment, but changes were significant ($P < 0{\cdot}05$) only in plot 2C.

Adult female buffalo weaver weights decreased significantly from week 1 to week 3 post-treatment in both plots 2C and 1F. Weavers captured while flying to or from their nests, when feeding young, showed a decrease in weight from 71·0 g ($n = 10$) to 56·3 g ($n = 10$) ($P < 0{\cdot}05$) in Plot 2C and from 67·8 g ($n = 9$) to 53·0 g ($n = 2$; $P < 0{\cdot}05$) in Plot 1F. No such changes were observed in untreated areas; insufficient data were available from other plots to examine possible effects.

CHOLINESTERASE ANALYSES

Due to breakage of tubes in which frozen brains were stored, only 66 of the 216 brains collected were available for study. Sufficient samples of unexposed birds were available for two species: Abyssinian rollers and singing bush-larks. After treatments, singing bush-larks, Abyssinian rollers, and buffalo weavers were the principal species collected. Buffalo weavers decreased on all plots, except plot 2C, and were difficult to collect, especially on plot 2F. Likewise, singing bush-larks decreased on all plots, and adequate collections were not always obtained.

Dead and debilitated birds found on plots immediately after treatments (Table 5) had low ChE levels

Table 7. Brain cholinesterase levels (µmol min^{-1} g^{-1}) in brains of individual dead (D) and debilitated (d) birds and in groups of fledglings found on plots after treatments*

	Plot											
Birds		1C			2C			1F			2F	
Button quail		–			–			–			5·2 (d) 6·2 (d)	
Abyssinian roller		–			20·5 (D) 16·5 (D)			5·1 (d)			–	
Hoopoe		–			–			–			8·6 (d) 7·9 (d)	
Singing bush-lark		–			23·5 (D)			–			–	
Woodchat shrike		–			–			–			11·2 (d) 7·7 (d)	
Fledglings												
Bush-larks												
24 h	(4)	20·1	5·8	(2)	16·2	0·9		–		(4)	11·6	2·4
48 h	(2)	15·9	5·9	(2)	20·5	0·4	(2)	16·8	0·5	(3)	12·6	3·2
72 h		–			–			–		(3)	7·9	0·8
Buffalo weaver												
24 h		–		(1)	15·5	0·0		–			–	
Pink-headed dove												
24 h		–		(1)	18·5	0·0		–			–	

* See Table 8 for ChE levels in control birds. For fledglings, *n* is given in parentheses before means, and standard errors follow means when pertinent.

in their brains (Table 7). Compared with unexposed birds (Table 8), ChE levels were sufficiently inhibited (39–85%) to have caused death and debility of the birds. ChE levels also were low in fledglings found by searchers. In the young larks from plot 2F, ChE ranged from 6·32 to 16·27 µmol min^{-1} g^{-1}; lowest levels were in birds found 72 h after treatment. ChE levels in brains of fledgling larks from all plots were well below those in adult larks ($\bar{x} = 40{\cdot}0$ µmol min^{-1} g^{-1}) and in one fledgling (29·9 µmol min^{-1} g^{-1}) from untreated areas (Table 8). This suggested that lark fledglings were impaired by exposure to insecticides, but reliable means for their normal ChE levels were not determined.

ChE inhibition of 50% or more is accepted as severe and is considered diagnostic as the cause of death (Hill & Fleming 1982). Debilitated adult birds and fledgling larks in plots 1F and 2F showed an

Table 8. Brain cholinesterase levels (µmol min^{-1} g^{-1}) in live unexposed (control) birds and in birds collected on study plots after treatments

	Plot														
Species and period post-treatment	1C			2C			1F			2F			Control		
	(*n*)	$\bar{x}$	SE	(*n*)	$\bar{x}$	SE	(*n*)	$\bar{x}$	SE	(*n*)	$\bar{x}$	SE	(*n*)	$\bar{x}$	SE
Abyssinian roller															
1 week	(1)	30·7	0·0		–		(4)	21·3	1·2	(5)	27·1	2·5	(5)	34·2	3·4
3 weeks		–		(1)	46·4	0·0	(6)	37·4	5·2	(10)	34·8	3·5		–	
Bush-lark (adult)															
1 week	(7)	33·1	3·8	(2)	32·0	7·5		–		(4)	20·8	1·7	(7)	38·4	4·6
3 weeks		–		(4)	41·1	4·5		–			–			–	
Bush-lark (juv.)															
1 week	(2)	18·5	7·5		–			–		(1)	15·2	0·0	(1)	29·9	0·0
Buffalo weaver															
1 week	(8)	30·6	2·7	(10)	32·4	2·1	(7)	22·0	2·2	(1)	14·4	0·0	(2)	26·2	3·7
3 weeks		–		(9)	29·5	2·2	(1)	54·2	0·0		–			–	
Golden sparrow															
3 weeks		–			–		(1)	38·8	0·0		–		(2)	31·1	1·1
Woodchat shrike															
3 weeks		–		(2)	28·6	2·3		–			–			–	
Red-beaked hornbill															
3 days		–			–			–		(1)	15·2	0·0		–	
Hoopoe		–			–			–			–		(2)	37·3	0·4
Pink-headed dove		–			–			–			–		(1)	20·8	0·0

inhibition greater than 50% compared with controls. ChE inhibition was not as severe in dead birds found in plots 1C and 2C.

Live birds collected from the plots 1 week after treatments often had lower ChE levels than controls, but after 3 weeks ChE levels in birds from treated plots were about the same as those in controls (Table 8). ChE inhibition usually was not severe in live birds collected from plots after treatments, but singing bush-larks collected 1 week after treatment of plot 2F showed a 50% inhibition. After 1 week, Abyssinian rollers on plots 1F and 2F had ChE levels in the same range as those in rollers found dead on plot 2C. One red-beaked hornbill (*Tockus erythrorhynchus* (Temm.)) shot 3 days post-treatment on plot 2F, had a low ChE activity (16·6 μmol min^{-1} g^{-1}) compared with a control level of 27·8 μmol min^{-1} g^{-1} found in this species in Kenya (Bruggers *et al.* 1989). According to Hill (1988), and based on generally low coefficients of variation, the use of such data is allowed as emergency substitute in diagnosis of lethal anticholinesterase poisoning when concurrent controls cannot be obtained.

Discussion

The varied and abundant avifauna on study plots provided an excellent situation for study of insecticide effects on the habits and population abundance of diverse species. Total bird numbers (sum of 71 species) decreased on all plots after treatments. Some of this decrease was due to bird mortality, but most apparently represented movement of birds from plots. Mortality, debility, and decreases in bird numbers were greatest on plots treated with fenitrothion. Decreases in Abyssinian rollers, blue-naped mousebirds, and singing bush-larks were statistically significant, but decreases were also indicated in numbers of hoopoes and buffalo weavers. Fenitrothion treatments caused decreases in these species and, in addition, reduced numbers of birds grouped on the basis of either their systematic relationships or life-history traits.

Insecticides kill insects and other arthropods, reducing the food supply of birds. Decreases in bird numbers observed on study plots probably were largely due to such decreases in food. Results suggested fenitrothion more seriously reduced food availability than chlorpyrifos. For instance, singing bush-larks ate few seeds on the control plot after treatments, and relied primarily on insects. On the chlorpyrifos plots, larks ate about 75% insects and 25% seeds, but on the high dose fenitrothion plot (2F), larks ate more seeds than insects. These findings suggest larks were forced to eat seeds as insect biomass decreased.

The two insecticides appeared to differ in their impact on birds. Fenitrothion applications resulted in greater decreases in bird numbers. If decreases were caused by reductions in food availability, it follows that fenitrothion must have reduced arthropod biomass to a greater extent than chlorpyrifos. This appears to have been the case. Singing bush-larks and Abyssinian rollers consumed primarily grasshoppers in the study area before treatments. After insecticide applications, four to five times as many adult grasshoppers remained on chlorpyrifos plots as on fenitrothion plots (Balança & De Visscher 1990; Fig. 5). Also, in contrast to the chlorpyrifos plots, grasshopper larvae were absent on fenitrothion plots after treatment, and grasshopper recolonization began later and progressed at a slower rate. These findings support the idea that a greater decrease in food resources was responsible for a greater movement of birds from fenitrothion plots and thereby a greater decrease in their numbers.

Insect biomass should increase as insects invade or otherwise re-establish populations on plots. Bird abundance would respond to increased food resources and return to normal. Under such conditions, the effects of treatments should be temporary. Birds are opportunistic in their feeding habits and tend to respond negatively to food decreases and to congregate where food resources are the richest. However, food restrictions can have more serious and long-lasting effects if they occur during the reproductive period and adversely influence nesting success. Observations suggested nesting success of singing bush-larks and buffalo weavers were affected by fenitrothion treatments. Both species were reproducing during spraying, and their numbers decreased rapidly afterwards. This implied that the insecticide terminated the process of reproduction in some buffalo weavers and may have caused some singing bush-larks to move before young were fully fledged. Young larks usually leave the nest well before they can fly (Green 1985; Cramp 1988). However, fledgling larks analysed were debilitated by ChE inhibition, and many probably died on all treated plots. Stromborg *et al.* (1988) dosed nestling European starlings (*Sturnus vulgaris* L.), with dicrotophos to examine its influence on post-fledging survival and development. They found effects were rapid (death and reduced ChE levels), but survivors recovered rapidly and adverse effects did not extend into the post-fledging period.

Birds are not equally exposed to insecticides applied to the environment. Their activities and habits at the time of treatments largely determine the intensity of their exposure. ChE measurements suggested that a few adults of species eating grasshoppers ingested sufficient insecticides to cause intoxication and death. Fledglings, and especially those of the singing bush-lark, received high exposure to the insecticides, which appeared to result in an even greater inhibition of ChE than in adults. However, normal ChE levels of young larks deserve further study. It has been demonstrated that nestling

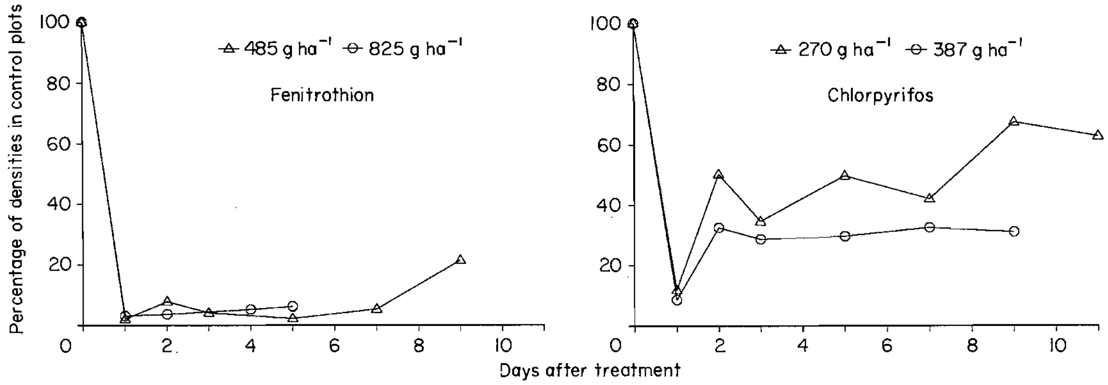

Fig. 5. Reduction in numbers of adult grasshoppers after treatment. Redrawn with permission from data in Balança & De Visscher (1990).

starling brain ChE activity was age-dependent and increased linearly over 17 days to 70% of adult levels (Grue, Powell & Gladson 1981). Serum ChE activity in tree sparrows (*Passer montanus* L.) was also age-dependent when measured during 2 weeks after hatching. Levels increased at a much higher rate after birds were *c.* 11 days old (Thompson 1988). As young larks were in grasslands, they were probably subjected to greater dermal contamination than birds active in trees and depressions. Dermal absorption and preening were recently identified as major exposure routes leading to ChE inhibition in birds exposed to field application of organophosphates. Contrary to a widely held view, ingestion contributed only 10–20% to the overall anticholinesterase impact on bobwhite (*Colinus virginianus* (L.)) under simulated field conditions (Driver *et al.* 1991). Young birds being fed by adults probably were given contaminated insects, as insect protein is a prerequisite for growth in young of most bird species. ChE levels in fledglings decreased substantially during the first 3 days following insecticide treatments.

In passerines, reduced food intake was observed following sublethal exposure to organophosphorus compounds under laboratory conditions (Grue, Powell & McChesney 1982). The significantly lower weights of flightless fledgling singing bush-larks collected 24 and 48 h post-treatment compared with those collected in the control area may have been an effect of exposure to the insecticides. This is supported by the observation that among the five plots no significant differences in the 'age' of the fledgling larks were found. Delayed growth or loss of weight in nestling songbirds, in the range of 5–25%, in the first 24 h after experimental oral exposure to organophosphates has been reported in various studies (Grue & Shipley 1984; Stromborg *et al.* 1988). If the parent birds are also affected by exposure to organophosphates, an even stronger effect on the development of the nestlings may be expected. Female starlings given an oral dose of dicrotophos made significantly fewer sorties to feed their young and they remained away from their nests longer than controls (Grue, Powell & McChesney 1982). ChE levels in some adult singing bush-larks in breeding condition indicated that they were probably affected.

Weights of female buffalo weavers (*c.* 70 g) tending nests with young decreased 21% in plot 2C between week 1 and week 3 post-treatment. It is unlikely that the observed loss of weight is entirely due to energy requirements for feeding young, and it may have partially resulted from exposure to the pesticide or from severe reduction in food supplies. In temperate regions, loss of weight in the starling — a species of comparable size and prey choice — due to energy requirements for feeding young, is much less than the 21% observed in this pilot study. Female starlings (*c.* 80 g) attending adjusted broods of 3, 5 and 7 young lost an average of 5·0, 5·5 and 7·1%, respectively, of their initial weight between 1–5 and 16–20 days after hatching (Westerterp, Gortmaker & Wijngaarden 1982).

ChE measurements in mature birds after insecticide treatments did not indicate serious inhibition at 1 week, and ChE levels in general were near normal after 3 weeks. These findings are consistent with the observation of minimal mortality and debility in adult birds resulting from insecticide applications. Applications of fenitrothion at 300 g ha^{-1} in forests of northern Scotland resulted in ChE inhibition in four species of songbirds. Inhibition averaged 47% on the day after treatments in one species, and it was still 34% after 1 week and 13% after 3 weeks in another species (Hamilton, Hunter & Ruthven 1981).

Re-analysis of these data by Hart (1990) revealed evidence of significant differences in the effects of fenitrothion between species and between spraying operations under similar conditions and with the same nominal dosage. This could possibly have resulted from differences in deposition. If birds cannot be recognized individually or if observers are insufficiently familiar with their behaviour, it is virtually impossible, 3 weeks post-treatment, to establish whether or not an individual was already present at the time of spraying. If many new individuals have entered the plot, measured ChE activities may severely underestimate a treatment effect. These effects are less likely to occur when surveyed plots are within a larger sprayed area.

Chlorpyrifos degrades rapidly in birds and residues largely disappear after about 9 h (Odenkirchen & Eisler 1988). In wheat fields treated with 560 and 1000 g ha^{-1} of chlorpyrifos, horned larks (*Eremophila alpestris* (L.)) showed a 22% reduction in ChE after 3 days and only 8% after 16 days. No dead larks were found in treated fields (McEwen, DeWeese & Schladweiler 1986). Our results also indicated that ChE inhibition was brief, and mortality in adult birds was low in areas treated with chlorpyrifos.

Residues of 1·0 ppm and higher have been reported from grasshoppers following applications of organophosphate insecticides (Stromborg, McEwen & Lamont 1984). Dead and dying grasshoppers collected the day of spraying with azinphos-methyl at 280 g ha^{-1} (ULV) even contained 14 ppm of the insecticide (McEwen, Knittle & Richmond 1972). In consuming their own weight of grasshoppers carrying 1·0 ppm of fenitrothion residues, birds would ingest 1·0 mg kg^{-1} of fenitrothion. Zebra finches (*Poephila guttata* (Viellot)) dosed with about 1·0 mg kg^{-1} fenitrothion showed 50% ChE inhibition (Holmes & Boag 1990). ChE inhibition increased at higher doses, and some mortality occurred. It follows that singing bush-larks that consumed their weight or more in contaminated grasshoppers could possibly suffer ChE inhibition of 50% or more and die. Fledgling larks collected on treated plots and showing ChE inhibition of 50% or more were apparently debilitated, rather than just flightless, and probably would have died if left in the field.

Conclusions

The objective of this study was to determine the kinds of effects on birds most likely to result from aerial applications of fenitrothion and chlorpyrifos for locust and grasshopper control. Chlorpyrifos and fenitrothion treatments resulted in temporary decreases in the abundance of birds, bird foods, and ChE levels in several bird species. Fenitrothion effects appeared somewhat greater than those of chlorpyrifos. It is possible that both insecticides decreased reproductive success on plots either by reducing numbers of birds fledged or by killing fledglings soon after they left the nest. Reproductive effects were apparent and could potentially cause the greatest long-term effects on bird populations. Further study of avian reproductive effects in plots treated with fenitrothion would be of high priority in future programmes of study in Senegal and throughout Africa where insecticides are applied to control locusts and grasshoppers.

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