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DWRC
Research Report
No. 11-55-005

An Ecotoxicological Assessment of Insecticides Used for Locust Control in Southern Morocco

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An Ecotoxicological Assessment of Insecticides Used for Locust Control in Southern Morocco

By James O. Keith, Richard L. Bruggers, Patricia C. Matteson, Abderrahim El Hani, Said Ghaout, Lynwood A. Fiedler, El Hassan Arroub, John N. Gillis, and Robert L. Phillips[1]

[1] Drs. Keith and Bruggers and Messrs. Fiedler and Phillips work for the Denver Wildlife Research Center (DWRC), a unit of USDA's Animal and Plant Health Inspection Service's (APHIS) Animal Damage Control (ADC) program DWRC is located in Denver, CO. Dr. Matteson is with the Department of Entomology at Iowa State University, Ames, IA. Messrs. El Hani, Ghaout, and Arroub are with the Direction de la Protection des Végétaux, des Contrôles Techniques et de la Repression des Fraudes (DPVCTRF) in Rabat, Morocco. Dr. Gillis is with the Water Management Division of the Environmental Protection Agency (EPA) at Denver, CO.

Abstract: This paper discusses experimental results obtained in an ecotoxicological training and research program in southern Morocco During the 1986–90 irruption of desert locusts in Africa, more than 4 5 million ha in Morocco were treated with insecticides Malathion and dichlorvos were two of the principal insecticides used In January and February 1992, U S and Moroccan scientists conducted studies on nine 3-km^2 experimental plots near Guelmim, Morocco, to evaluate the effects of these chemicals on birds, mammals, and insects. A helicopter sprayed three plots with malathion at rates of 750 g/ha and three with dichlorvos at rates of 200 g/ha, three plots were untreated. However, some applications resulted in less-than-anticipated deposits of insecticides Malathion residues on vegetation were low, and between 85 and 90 percent of residues in soil were gone after 1 week Only trace amounts of dichlorvos were recovered from either soil or plants Among birds and mammals, inhibition of acetylcholinesterase was found only in brains of thekla larks on malathion-treated plots No apparent mortality or significant effects on numbers or activity of birds and mammals were recorded Malathion killed bees and reduced the abundance of ants, orthopterans, and apparently one species of beetle. Dichlorvos did not affect insects as severely, but it appeared to reduce the abundance of Tenebrionid beetles and the numbers of bees entering hives The food habits of birds and mammals were not greatly affected The percentage of animal matter eaten by red-rumped wheatears decreased on dichlorvos-treated plots, and ants largely disappeared from diets of birds on malathion-treated plots.

Key words: Ecotoxicology; malathion; dichlorvos; bird and mammal abundance, food habits; acetylcholinesterase; environmental effects of locust control

Preface

During the 1986 to 1990 locust plague in northern Africa, considerable amounts of insecticides were applied in Morocco. Many Moroccans and others involved in the program expressed concern about possible effects of these treatments on nontarget wildlife, beneficial insects, livestock, and humans. In response to these concerns, the Moroccan Government, in cooperation with the U S Agency for International Development (AID), studied various aspects of human and environmental exposure

One of the projects involved training Moroccan scientists in ecotoxicological methods to prepare them to evaluate environmental effects of future pesticide uses in Morocco. This training was conducted by the Denver Wildlife Research Center of USDA, APHIS' ADC program and involved numerous groups within the Moroccan Ministries of Agriculture and Interior

Training sessions of 1 to 3 weeks each were conducted periodically in 1990 and 1991 on a variety of subjects, including the science of ecotoxicology, experimental design and statistical analyses for field study of organophosphate and carbamate insecticides, measurement of cholinesterase levels in wildlife, the collection and preservation of samples for residue determination, analytical methods for residue determination, the use of wildlife telemetry, methods for study of wildlife food habits, and assessment of insecticide effects on populations of small mammals, birds, and beneficial insects (Denver Wildlife Research Center 1992, unpubl)

The culmination of this ecotoxicological training was the planning and conducting of a field program to study the environmental effects of experimental application of insecticides to areas heavily treated during locust control programs. In 1992, teams of both Moroccan (26) and U.S (13) scientists conducted field research on a study area established in southern Morocco. Field investigations were conducted between January 20 and February 23, 1992, from a tent camp, which housed about 30 additional Moroccans, including field assistants, camp cooks, drivers, laborers, and guards.

The following report presents results of that study effort. The deposits of insecticides on study plots were variable, but most were less than prescribed As a result, the effects found undoubtedly would have been greater had the prescribed amounts been deposited. In any aerial application of insecticides, deposits can be less than those calculated from the amounts sprayed from planes: wind and thermal activity often are responsible for drift of insecticides from target areas. The program was successful, however, in meeting its goal of providing valuable training in ecotoxicological research methods.

Introduction

In 1986, a major irruption of desert locusts *(Schistocerca gregaria)* occurred in Africa Locust populations had increased following rains that ended a prolonged drought in the Sahel region of Africa just south of the Sahara Desert Historically, locust plagues have caused serious localized damage to grains grown by subsistence farmers, to market crops in agricultural areas, and to forage used by livestock on grazing lands throughout the Sahel and adjacent areas of northern and central Africa.

In locust irruptions between 1950 and 1965, organochlorine insecticides (e g , dieldrin and BHC) were used to control locust populations However, in the 1970's, many countries of the world discouraged or banned the use of organochlorine insecticides. Few studies were conducted to identify effective, safe replacement insecticides for locust control until 1986, when short-term research was initiated (Overseas Development Natural Resources Institute 1988). Organophosphate and carbamate insecticides in ultra-low-volume (ULV) formulations proved to be practical replacements.

In the 1986–90 outbreak throughout Africa, the insecticide used most often was fenitrothion (Symmons 1992), but malathion, chlorpyrifos, deltamethrin, lambda-cyhalothrin, carbaryl, bendiocarb, and propoxur also were used. Some applications of dieldrin and BHC continued, but most countries respected the consensus against their use. Morocco, Senegal, Algeria, and Sudan treated the largest areas, ranging from 1.5 million ha to 4 6 million ha; Niger and Mauritania also treated sizable areas—about 1 million ha; and nine other countries treated areas of 0.5 million ha or less. These programs covered a total of 13 7 million ha (Everts 1990) The cost.benefit ratios of these various efforts to protect crops and reduce locust populations were not evaluated. In late 1988, during the northward movement of these pests through Mauritania, strong easterly winds blew the largest segment of the migrating locust population into the Atlantic Ocean. Subsequently, massive numbers of African locusts occurred in the West Indies; some locusts had been transported by winds across more than 5,000 km of ocean.

In Morocco, past outbreaks of locusts have severely damaged high-value crops such as oranges Likewise, in southern Morocco, locust consumption of range forage has restricted food available to livestock (files· AID/Morocco). If substantial populations of locusts cross the low, western edge of the Anti-Atlas Mountains into the Sous-Massa agricultural valleys, serious economic damage can be expected.

Lands ravaged by locusts in Morocco are primarily in private or collective ownership (source: AID/Morocco). Nevertheless, the Moroccan Government organizes locust control efforts because of the need to cover extensive areas and cooperate internationally in coordinated campaigns. The

Ministry of Interior (Gendarmerie Royale and Centre National de la Lutte Antiacridienne) is responsible for locust control with entomological and logistical assistance from the Ministry of Agriculture Military aircraft and pilots apply insecticides to flying swarms, while teams from the Ministries of Agriculture and Interior conduct ground treatment of hopper bands

Over 2.3 million L of malathion, fenitrothion, and dichlorvos (DDVP) were used to control locusts in Morocco during the 1987-89 campaigns (source AID/Morocco) These organophosphorous insecticides differ in some of their basic toxicological characteristics, but all are broad-spectrum insecticides that cause mortality among many kinds of insects and other invertebrate organisms (Smith 1987)

Malathion has a low toxicity to birds and mammals Although decreasing residues can persist for several weeks in some terrestrial environments, mortality of vertebrates has not been reported following terrestrial applications of 500 to 1,140 g/ha (Black and Zorb 1967, unpubl , Parsons and Davis 1971, Giles 1970, McEwen 1982) In contrast, malathion is highly toxic to fish and aquatic invertebrates (Mulla et al 1979), and the use of malathion to treat wetland habitats must be avoided

Dichlorvos is seldom applied for insect control under field conditions, it has been used primarily in homes, restaurants, factories, and livestock facilities Dichlorvos is extremely toxic to birds and moderately toxic to mammals (Smith 1987), but we found no published studies of wildlife evaluations following its field use Even though it degrades within hours in the environment, dichlorvos could cause wildlife mortality immediately following applications.

In this study, we evaluated the direct and indirect effects of field applications of malathion and dichlorvos on birds, mammals, and beneficial insects We did not evaluate the effects of fenitrothion because its effects on the environment (Everts 1990) and birds (Mullié and Keith 1993) had been studied in Senegal. We recognized that malathion and dichlorvos would be applied to experimental plots where, most likely, locusts would not be present The study objectives were to (1) determine numbers and activities of birds, mammals, and beneficial insects on large experimental plots before and after aerial treatments with insecticides; (2) determine degree of exposure, extent of mortality, and movements of selected vertebrate species by measuring brain acetylcholinesterase (AChE) and by using radio telemetry; (3) determine indirect effects on vertebrates by documenting changes in food availability and food habits; and (4) measure spray deposits, initial residue levels, and the persistence of the residues in soil and vegetation.

Study Area

We established the study area northwest of Guelmim, Morocco (fig 1) This area supported resident populations of birds, small mammals, and insects and had received repeated applications of insecticides during past control campaigns During the 1987–89 locust outbreak in Morocco, the most intense control efforts took place in the region near Guelmim, where locust swarms attempted to move north from the desert across the Anti-Atlas Mountains and into the Sous-Massa Valleys

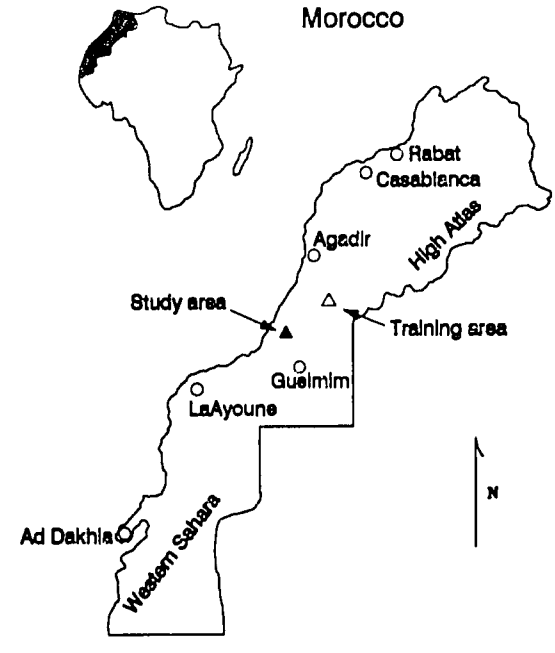

Figure 1—Location of study area in Morocco

The study area consisted of rolling hills, internal basins, and narrow drainages without perennial streams. Topography on the northern one-third of the study area, and especially in the west, was more uneven with greater variations in elevation, steeper slopes, and deeper drainages Vegetation has been described as a daghmous steppe, which is an overgrazed, degraded state of an *Argania spinosa* climax that is now dominated by *Euphorbia echinus* (Savage 1947). The area contained scattered low bushes (seldom above 1 m in height) and a sparse ground cover of forbs and grasses. The forbs and grasses appear in winter, and their growth varies annually depending on the rainfall. Ground cover was sparse during the study as rainfall had been low. Most of the space between shrubs was bare soil and rocks.

Methods

During January and February 1992, daily maximum temperatures, as recorded at a Guelmim meteorological station 30 km from the study area, varied between 13 and 31 °C, and nighttime minimums ranged between 3 and 18 °C. Trace amounts of rain fell on January 31 and February 14, 15, and 19. Strong easterly winds began the night of January 31 and continued uninterrupted until the evening of February 4. A scattered emergence of small annual plants occurred in early February.

Experimental Design

We established nine 3-km² (1.5×2.0-km) experimental plots in the 128-km² (8×16-km) study area (fig. 2). Plots receiving insecticide treatments were located at least 700 m from all other plots in an attempt to prevent drift contamination. A 0.5-x1.0-km sampling area in the center of each plot was

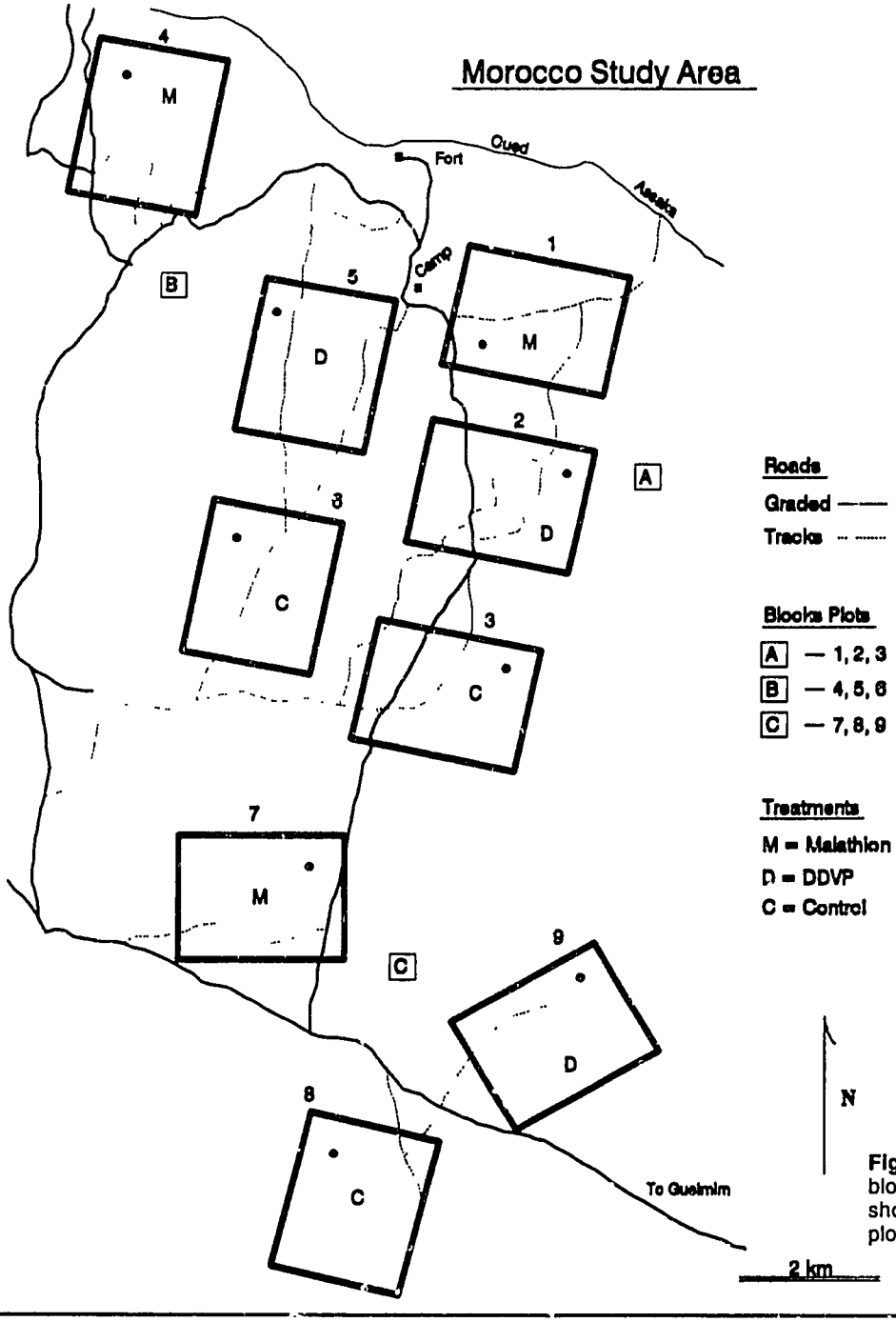

Figure 2—Study area, showing roads, plots, blocks, and treatments. The dot in each plot shows location of starting points within the plot (see fig. 3).

laid out for obtaining biological data (fig. 3). Large plots and wide buffer zones within plots were necessary to help ensure that study animals would be exposed to the insecticides. The plots were grouped into three blocks on the basis of their topography and vegetation. The three plots in each block were randomly assigned to one of the three treatments (malathion, control, and dichlorvos). Figure 4 shows the schedule followed for measuring animal abundance before and after insecticide treatments

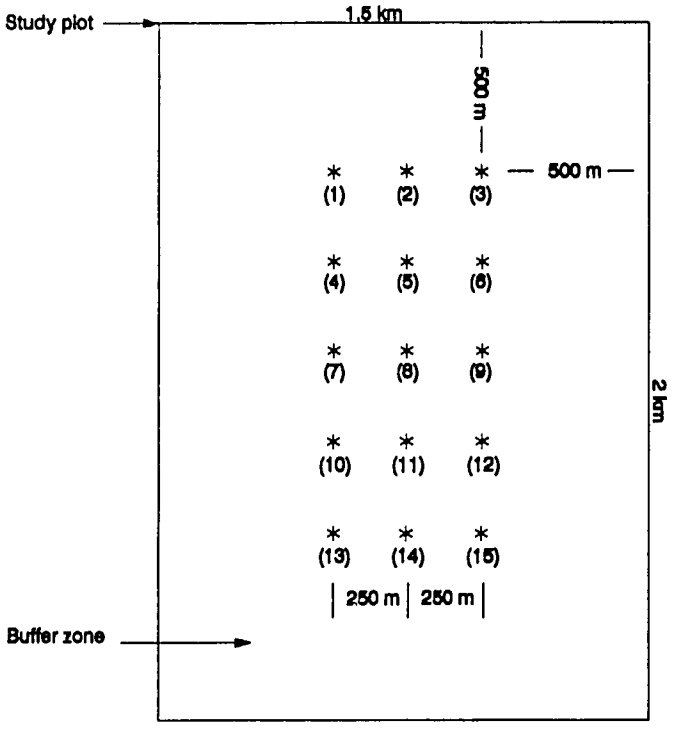

Figure 3—Diagram of a study plot. The asterisks indicate points from which bird counts were taken (piles of stones marked these points on the actual plots). The asterisks also delineate the 0.5-×1-km sampling area within each plot

Period of Experiment

January 1992

M	T	W	T	F	S	S
20	21	22	23	24 B-R	25 B-R-I	26 B-R-I
27 B-R-I	28 B-R-I	29 B-R-I	30 I	31 B-R-I		

February 1992

					1 B-R-I	2 B-R-I
3 I	4 I	5	6	7	8	9 I
10 I M-1	11 I	12 I M-4,7	13 B-R-I D-2	14 B-R-I	15 B-R-I	16 B-R-I D-5
17 B-R-I	18 B-R-I D-9	19 B-R-I	20 B-R-I	21 B-R-I	22 I	23 I

Figure 4—Schedule of research events during January and February 1992. Large numbers in blocks represent calendar days. Species sampled: B=birds, R=rodents, I=insects. Insecticides used: M=malathion, D=dichlorvos. Hyphenated numbers following insecticide abbreviations represent plot numbers.

Vegetation Measurements on Plots

We measured the incidence of plant species and percentage of ground cover on each plot with the use of a 1-m^2 plot frame. We placed the frame at 3 locations near each of 15 points in the central sampling area of each plot and counted the species and calculated the percentage of ground cover within the frame. The percentage of ground covered (including plant canopy) by each species was visually estimated. Plant nomenclature follows Savage (1947).

Insecticide Applications

Applications of insecticides scheduled for the week of February 3 were repeatedly delayed by wind, fog, and mechanical problems with the helicopter. Treatments began on February 10 by use of a Lama helicopter equipped with an AIRBI™ spray system (table 1). The helicopter flew at an airspeed of 100 km/hour and varied elevation with the topography. Insecticides were applied to plots in 30-m-wide swaths perpendicular to the wind direction at rates used for locust control in Morocco. Malathion was sprayed at a rate of 750 g of active ingredient per ha. A 96 percent formulation was applied at a volume of 0.78 L/ha and a rate of 3.9 L/min (5 ha/min). Dichlorvos was sprayed at a rate of 200 g of active ingredient per ha. A formulation containing

Table 1—Conditions during insecticide applications

Conditions	Treatments and plot numbers					
	Malathion			Dichlorvos		
	1	4	7	2	5	9
Date	Feb 10	Feb 12	Feb 12	Feb 13	Feb 16	Feb 19
Rotors	4	3	3	4	3	3
Orifice number	5	—[a]	—	3	3	7
Temperature (°C)	19 0	25 0	—	23.2	23.0	20.0
Relative humidity (%)	47	—	—	39	30	67
Windspeed (m/sec)	0.4–1.0	2 5–5.0	3.5–4.5	2.3–3.0	3.5–8.0	2.8–5.0
Time (start)	0915	1330	1600	1408	0910	1145

[a] Dash indicates no data were obtained.

20 percent dichlorvos and 80 percent solvent was applied at a volume of 1 L/ha and a rate of 5 L/min (5 ha/min). Spray cards were distributed haphazardly on treated plots to measure densities of spray droplets.

Initial Mortality

A team of eight individuals searched the sampling areas of all six treated plots for dead animals the day after insecticides were applied Identical searches were conducted on control plots The team walked about 40 m apart across the 500-×1,000-m sampling area within each plot Each search took about 1 hour

Residue Sampling

To measure initial residues reaching the ground, we exposed filter papers to the spraying. Samples of spray formulations and insects found dead on plots were submitted to Moroccan chemists for residue analysis However, we received no results from them Samples of soil and vegetation were obtained from plots before treatments to test for interfering materials and after treatments from the six treated plots to determine levels of initial residues and their persistence over time. Plans called for sampling before treatments, on days 1 and 2 after treatments, and again after 1 and 2 weeks As spraying was delayed, no 2-week posttreatment samples were collected from any plots, and the 1-week posttreatment samples on dichlorvos-treated plots 5 and 9 could not be obtained

Rocks were removed from a sampling area at points 5, 8, and 11 on each plot from which all future soil samples were taken. About 100 g of soil from each area was collected in glass jars during each period Near each point, 100 g of *Lycium intricatum*, a preferred forage plant for livestock in the area, was collected in a paper bag. Samples were labeled, stored frozen in Guelmim, and later transported on ice to freezers in the Laboratoire Officiel d'Analyses et de Recherches Chimiques in Casablanca for analysis. Samples were extracted with acetone and analyzed by gas-liquid chromatography on Varian 3400 gas chromatographs equipped with thermionic-specific detectors.

AChE Measurements

We collected selected species of birds and rodents from the study area to determine if changes in brain AChE levels occurred due to treatments. Thekla larks *(Galerida theklae)*, red-rumped wheatears *(Oenanthe moesta)*, and little owls *(Athene noctua)* were selected for study. These species are sedentary, insectivorous, relatively abundant, widely distributed, and fairly easy to collect Likewise, we used fat sand rats *(Psammomys obesus)* and two species of jirds *(Meriones shawi* and *M libycus)* to determine brain AChE levels in mammals.

Before insecticide applications, animals were collected near the edges or just outside of several experimental plots. Following spray applications, most animals were taken within the buffer zone of the plots or, in the case of owls, collected from within the central sampling area. Several collecting techniques were used, including mist nets, rat and *balchatri* traps, and guns with birdshot An attempt was made to collect birds from each of at least two plots treated with malathion or dichlorvos within 1 to 5 days of treatments. The brains of the animals were removed, placed in labeled vials, and stored in liquid nitrogen The brains were then transferred to a freezer at the Centre National de la Lutte Antiacridienne in Ait Melloúl, where they were analyzed within 6 weeks of collection. Samples were randomly selected for analysis over time, rather than by species or by the schedule of their collection. Analyses of brains for AChE followed methods of Hill and Fleming (1982).

Bird Observations

To record bird activity, three individuals observed three plots each and obtained all counts on those plots. The observers counted birds 6 times at and between the 15 points on each of the experimental plots, usually between 0800 and 1300 hours (see fig. 3). At each point, birds seen within and beyond 50 m were tallied separately during a 5-min period. Birds observed between points were recorded separately. These counts provided an inventory of birds in the study area and indices to the relative abundance of particular birds on the nine plots before and after treatments with

insecticides. Only bird numbers seen within 50 m of stations were analyzed statistically. Bird names follow Clements (1991).

Rodent Observations

We evaluated the relative abundance of rodents using both live trapping and the closed-burrow technique. We set Sherman box traps for small rodents (<50 g) and Tomahawk traps for large rodents (>50 g) at sites in each plot where animals appeared to be the most abundant Along traplines, points were marked about 5 to 20 m apart where 3 or 4 traps were set within a 5-m circle Usually 2 Tomahawk traps were set for each Sherman trap, and about 50 to 65 traps were set in each plot Trap baits included dates, apple slices, oats, or wheat for the birds or portions of local plants favored by fat sand rats Trapping took place before and after plots were treated with insecticides During each period, traps were set and then checked in the morning and afternoon for 3 consecutive days All trapped rodents were weighed, sexed, eartagged, and released. We recorded points of capture of new and previously marked animals and compiled and analyzed the average captures per trap-night (24-hour period) before and after treatments

Our field crew live-trapped rodents and equipped them with radio transmitters to determine any direct effects of insecticide sprays

In each plot, 4 to 15 burrow systems along a selected route at least 50 m from the trapline were marked, and all burrow openings were closed with small rocks and dirt. Observers checked marked burrow systems 24 hours later and recorded the number of closed holes that were reopened by rodents. The closed-burrow technique was used before and after treatment, and the percentage of reopened holes was compared and analyzed. Names of rodents are from Aulagnier and Thevenot (1986)

Radio Telemetry

Prior to insecticide application, 30 thekla larks, 16 little owls, and 16 Barbary ground squirrels *(Atlantoxerus getulus)* were captured and equipped with radio transmitters so that their movements and mortality could be monitored before and after insecticide applications. A total of 20 or 21 animals of the 3 species were marked on each treatment block Mist nets and Tomahawk live traps captured larks and ground squirrels, respectively. Little owls were captured using *balchatri*, Verbail, and Tomahawk traps, or by hand when a bird could be collected from a rockpile or burrow Transmitters were attached to birds by gluing them to the dorsal base of the tail feathers (Fitzner and Fitzner 1977, Linz et al. 1989). Transmitters on leather collars were attached to ground squirrels. Radio-marked animals were located during most days using a receiver and a handheld, three-element Yagi antenna.

Typical vegetation in the study areas included low bushes and sparse ground cover of forbs and grasses. Little owls, as seen perched on this vegetation, were captured and radio-equipped to determine any direct effects of the pesticide sprays.

Food Habits of Vertebrates

Thekla larks, red-rumped wheatears, little owls, two species of jirds, and fat sand rats collected pretreatment and posttreatment for AChE measurements were also used in studies of food habits Bird gizzards and mammal stomachs were removed, placed in labeled vials, and stored in methyl alcohol for subsequent examination We measured the volume of wet contents, identified dominant foods, and visually estimated the percent of animal and plant matter. Our goal was to document any changes in foods eaten by vertebrates due to treatment effects

Insect Observations

Because grasshoppers and locusts, the usual targets of the insecticides applied to plots, were not common during the study, the ecological focus of insect studies was on insects that either were important in bird and mammal diets or were beneficial insects, such as pollinators The objectives of the insect sampling were to measure numbers and activities of bees and other beneficial insects before and after insecticide applications. We recorded mortality and activity of bees at four hives placed near the center of each of the three plots receiving different treatments in block B. Pitfall traps (24 on each of the 9 plots) and transect counts (one 2,500-m transect per plot) were used to obtain abundance indices of selected insects, and sugarcubes (20 points per plot) were used to attract and monitor the presence of ants. Mortality of insects was noted in plots before and after treatments. For more detailed methodology, see Keith (1992, unpubl.); specialists identifying diverse insect groups are given there in table 37.

Statistical Analyses

An analysis of variance (ANOVA) for a two-factor factorial in a randomized block design was used to evaluate differences among the three treatments and among the times that data were collected. The effects of interest (treatment, time, or treatment × time) were tested using their block interaction as the denominator for the F-tests. For example, the effect of primary interest, the treatment × time interaction, was tested using block × treatment × time interaction as the error term Mean separation tests, such as Duncan's multiple-range test, were applied to locate the differences among the means of data sets where significant effects were indicated by the ANOVA.

Bee data were obtained in only one block and were analyzed using a two-factor, repeated-measures ANOVA, where time was the repeated measure and hives within a treatment were a random effect. A one-way ANOVA was used to analyze AChE data because animals were collected by categories of pretreatment and posttreatment for each of the three treatments.

Because honey production is important to farmers in the regions normally sprayed during locust control operations, we established hives to assess the impact of malathion and dichlorvos on bee numbers

Results

Vegetation Measurements on Plots

Only three plants were present on all plots: *E. echinus*, *Senecio anteuphorbium*, and *L. intricatum* (table 2). *Ephorbia* spp and *L. intricatum* were most common on northern plots, while *Salsola vermiculata* and *Sueada ifniensis* were more common on southern plots. *Convolvulus trabutianus* occurred primarily on plot 5 The percentage of ground covered by vegetation was higher on northern plots (23 to 50 percent) than on southern plots (6 to 22 percent). Vegetation appeared more lush on northern plots, and shrubs grew higher. In part, this appearance was due to the presence of *E. obtusifolia*, which was the largest and tallest of the shrubs

General Spray Results

For an acceptable treatment, 20 or more droplets/cm^2 should reach the ground (A. Afrass, pers. commun.). Only malathion applications to plots 1 and 7 were acceptable (table 3). However, the range in droplet numbers on cards was great, varying from 0.7 to 52/cm^2 on plot 7 (57 cards) and 0.9 to 42/cm^2 on plot 1 (121 cards). None of the dichlorvos treatments was acceptable, as only between 0 and 6 droplets/cm^2 were deposited.

Study team members found no dead or debilitated birds, mammals, reptiles, or amphibians in study plots. The researchers did find two dead birds after treatments within the overall study area. One had been hit by an automobile; the cause of death of the second was unknown, but it had a normal AChE level.

Table 2—Incidence of plant occurrence and the percentage of plant cover on the study area[a]

Measurement	Plot numbers 1	2	3	4	5	6	7	8	9	Average
Percentage of occurrence[b] by species										
Euphorbia echinus	93	80	67	80	87	87	27	13	7	59
E. obtusifolia	73	53	7	87	73	20	0	0	0	34
Senecio anteuphorbium	60	40	67	53	33	87	40	46	20	50
Lycium intricatum	67	67	20	67	33	33	20	33	27	41
Salsola vermiculata	20	7	46	0	0	20	53	60	27	25
Salicornia fruticosa	0	13	53	0	0	33	20	33	20	19
Convolvulus trabutianus	0	0	0	7	53	0	0	0	0	6
Asphodelus tenuifolius[c]	—	—	—	0	13	—	27	40	27	21
Sueada ifniensis	0	0	0	0	7	0	0	40	27	8
Asperagus pastorianus	0	0	0	27	20	0	0	0	0	5
Others	7	27	20	13	20	13	0	0	0	10
Percentage of plant cover										
$\bar{x}$	29	23	21	50	28	22	6	18	8	
SE	4.3	4.2	4.1	4.9	4.6	2.8	1.8	3.4	2.2	

[a]Nomenclature follows Savage (1947).
[b]Percentage of 15 sites on each plot where species occurred.
[c]This species had not emerged in October 1991, when records were taken on four plots.

Table 3—Quantitative and qualitative assessment of spray deposits on experimental plots

Treatments	Plots	Drops per cm² on spray cards	Visual assessment of treatment
Malathion	1	16	Acceptable. High thermal movement and evaporation.
	4	7	Poor. Helicopter high over hilly terrain.
	7	26	Ideal. Plot flat; weather conditions good.
Dichlorvos	2	5	—[a]
	5	0	Poor. High wind to 8 m/sec; hilly terrain.
	9	6	—

[a]Dash indicates no assessment was made.

Long-dead beetles were abundant on all plots (probably due to the study area having been treated several times during previous control campaigns between 1987 and 1989). However, abundant newly dead beetles, most being Tenebrionids, were found only on malathion-treated plots. Their absence on dichlorvos-treated plots suggested that insufficient insecticide reached the ground to noticeably affect them or other organisms. A few other dead arthropods were found (table 4). Numbers of long-dead beetles found during searches varied among plots and averaged 92, 299, and 441 on control, malathion-treated, and dichlorvos-treated plots, respectively. The reason for these differences was not clear until data on beetle abundance on plots were compiled. Apparently, pretreatment beetle numbers also differed among plots. Sample counts of live beetles taken by entomologists before treatments averaged 31, 60, and 94 on the control, malathion-treated, and dichlorvos-treated plots, respectively.

Table 4—Arthropods found dead on plots the day after insecticide applications

Treatment status	Plot number	Beetles: Long dead	Beetles: Newly dead	Beetles: Debilitated	Other dead arthropods[a]
Control	3	30	1	—[b]	0
	6	111	1	—	0
	8	136	1	—	1
Malathion	1	235	207	—	15
	4	313	88	—	11
	7	351	65	50	22
Dichlorvos	2	536	4	50	1
	5	263	1	39	1
	9	524	9	140	0

[a] Includes ants, grasshoppers, wasps, and spiders.
[b] Dash indicates live beetles were present but not debilitated.

Residue Sampling

Pretreatment samples of soil and plants from plots did not contain any detectable residues of insecticides or other materials that could interfere with analyses for insecticides. On plots treated with malathion, initial residues in soil were quite variable, with averages ranging from 2 8 to 30.2 p/m of malathion (table 5) Residues in soil decreased rapidly and were less than one-fifth to one-tenth as high after 6 or 7 days No malathion was detected on most vegetable samples, and, based on the residues in soil, the residues on vegetation should have been higher The low residues suggested that malathion may have been lost during posttreatment storage or analysis of samples Only trace amounts (<0.01 p/m) of dichlorvos were found in vegetation and soil from treated plots, again indicating that dichlorvos applications were inadequate and that any residues that did reach the ground either metabolized rapidly or were lost during storage or analysis.

Both trace amounts of dichlorvos and low levels of malathion (0 02–0.5 p/m) were found in soil and vegetation from plot 2 following a dichlorvos treatment on February 13; the presence of malathion was likely due to drift. As further indication of drift, debilitated beetles were found on untreated plots 2 and 3 after plot 1 was sprayed with malathion on February 10. Malathion may have drifted more than 3 km in amounts sufficient to affect beetles and contaminate soil and vegetation.

AChE Measurements

No biologically significant changes in AChE activity occurred in either birds or mammals as a result of treatments (table 6). A 20 percent depression is an indication of substantial

Table 5—Malathion residues (p/m) in soil and vegetation *(L. intricatum)* from study plots treated with malathion[a]

Plot numbers	Days posttreatment 1	2	6	7
Soil				
1	4.8 (1.1)	4.3 (1.4)	—	0.5 (0.1)
4	2.8 (0.3)	1.7 (0.2)	0.3 (0.2)	—
7	30.2 (12.6)	16.4 (4.3)	—	4.6 (0.4)
Vegetation				
1	0.1 (0.1)	<0.01	—	<0.01
4	ND	ND	ND	—
7	ND	ND	—	ND

[a]Data are $\bar{\chi}$ and SE for three separate analyses. Dash indicates no sample was collected. Malathion residues were not detected in soil or vegetation on these plots before treatment.

Table 6—Mean and SE of acetylcholinesterase (AChE) activity (µmoles/min/g) in brain tissues of selected birds and rodents before and after insecticide treatments

Animals sampled	Pretreatment			Posttreatment on plots receiving: No insecticide			Malathion			Dichlorvos		
Birds												
Thekla larks	17.6	0.9	(16)[a]	15.8	1.0	(10)	14.4[b]	0.3	(10)	15.2	1.1	(11)
Red-rumped wheatears	16.7	0.9	(10)	14.0	1.1	(11)	14.6	1.4	(10)	16.4	0.9	(11)
Little owls		—		12.2	2.1	(5)	13.9	1.1	(6)	14.0	0.7	(5)
Rodents												
Fat sand rats	8.3	0.9	(6)	9.5	0.7	(8)	9.4	0.7	(11)	9.4	(0.7)	(8)
Jirds[c]	6.0	0.6	(10)	8.1	0.8	(11)	7.1	0.3	(10)	7.8	(1.1)	(7)

[a]Sample sizes are in parentheses.
[b]AChE levels in brains of thekla larks from malathion-treated plots were significantly different ($P < 0.05$) than pretreatment levels.
[c]Includes both Shaw and Libyan.

exposure to organophosphate insecticides, while a 50 percent depression can be related to debility and mortality (Hill and Fleming 1982) The largest depression measured was 18 percent in thekla larks from malathion-treated plots. This reading was the only statistically significant ($P < 0.05$) change, and it suggested that the larks from malathion-treated plots had been exposed to the insecticide.

Bird Observations

Of the 36 species of birds identified on the study plots, 20 were resident species, and 15 were migrants (table 7).

Table 7—Relative abundance of bird species among the nine plots[a]

Species[b]			Plot numbers									
Common name	**Scientific name**	**Status[c]**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
Long-legged buzzard	*Buteo rufinus*	R		1		1			1			3
Western marsh-harrier	*Circus aeruginosus*	M				2						2
Red-capped lark	*Calandrella cinerea*	M			3				3	3	10	19
Thekla lark	*Galerida theklae*	R	115	88	85	77	57	92	81	81	84	760
Eurasian hoopoe	*Upupa epops*	M	2	3		3		1				9
Common swift	*Apus apus*	M		1	3							4
Black-billed magpie	*Pica pica*	R						3				3
Rock bunting	*Emberiza cia*	R	2	4	3	5	4	1				19
House bunting	*Emberiza striolata*	R	3		1							4
Barbary falcon	*Falco pelegrinoides*	R						1				1
Eurasian kestrel	*Falco tinnunculus*	R	5			7	6	1			1	20
	Falco sp	—					2					2
European goldfinch	*Carduelis carduelis*	R									2	2
Barn swallow	*Hirundo rustica*	M	26	11	10	35	14	27	5	4	9	141
Northern shrike	*Lanius excubitor*	R		6	3	5	3	1				18
Black-crowned tchagra	*Tchagra senegala*	R					1					1
White wagtail	*Motacilla alba*	M	4	6	3		2		1		1	17
Tawny pipit	*Anthus campestris*	M	1						1	1	1	4
European pied flycatcher	*Ficedula hypoleuca*	M				1						1
Great tit	*Parus major*	R									1	1
Barbary partridge	*Alectoris barbara*	R	1	2		4	4	1	2			14
Common quail	*Coturnix coturnix*	M	1									1
Eurasian thick-knee	*Burhinus oedicnemus*	R			1	2					1	4
Little owl	*Athene noctua*	M	1	1	3		2	2	6	4	1	20
Cetti's warbler	*Cettia cetti*	M				1						1
Eurasian chiffchaff	*Phylloscopus collybita*	M		3			1					4
Spectacled warbler	*Sylvia conspicillata*	R		1					12	9	7	29
Sardinian warbler	*Sylvia melanocephala*	R	84	19	1	21	13	8	2	5	3	156
Streaked scrub-warbler	*Scotocerca inquieta*	R	1	2	4	1		5				13
European robin	*Erithacus rubecula*	M									1	1
Desert wheatear	*Oenanthe deserti*	R								12		12
Black wheatear	*Oenanthe leucura*	M	3	7	14			3	9	14	18	68
Red-rumped wheatear	*Oenanthe moesta*	R	8	11	16	1	1		46	22	42	147
Moussier's redstart	*Phoenicurus moussieri*	R	26	20	19	26	15	31	27	28	21	213
Whinchat	*Saxicola rubetra*	M	1	1	1	7	2	9				21
Common stonechat	*Saxicola torquata*	R	9	9	9	16	19	12	10	1	2	87
Total number of birds			293	196	179	215	146	198	206	184	205	1,822
Total number of species			18	19	17	18	16	16	14	12	17	36

[a]Data are the total number of birds seen at and between sampling points on each plot during one pretreatment and two posttreatment counts.
[b]Scientific names follow Clements (1991).
[c]Status is either migrant (M) or resident (R).

Only five species of birds were seen on all plots. Thekla larks and Moussier's redstarts *(Phoenicurus moussieri)* were the most common and widely distributed, and little owls were often seen throughout the study area A falcon was seen but not identified, and its status was unknown. At the time of the counts, early migrants had begun their northward movements, and barn swallows *(Hirundo rustica)* were seen flying over the plots Two species, the whinchat *(Saxicola rubetra)* and stonechat *(S torquata)*, occurred in greatest numbers on plots 4, 5, and 6 (block B), while wheatears were almost absent from those plots, being most common on plots with the least ground cover (plots 7, 8, and 9). Plot 1 had the greatest abundance of birds, and the Sardinian warbler *(Sylvia melanocephala)* was much more common on plot 1 (84) than on other plots (2–21). The number of species on plots was rather consistent and varied only from 12 on plot 8 to 19 on plot 2

Statistical analyses of total birds seen within 50 m of sampling points on plots (table 8) did not suggest any changes due to insecticide treatments ($P = 0\ 68$) On plots 2, 5, 6, 7, 8, and 9, counts were lowest during period 3. Strong easterly winds between January 31 and February 4 probably were responsible for these lower counts.

The thekla lark was the most abundant species on each plot. Numbers varied between plots and periods (table 9), but no

Table 8—Total number of birds seen within 50 m of sampling points on each plot during each period

	Treatment and plot numbers								
	Malathion			None (control)			Dichlorvos		
Periods	1	4	7	3	6	8	2	5	9
1	56	22	20	40	25	27	91	12	34
2	49	33	34	52	26	37	89	11	38
3	59[a]	24	15	31	9	17	38	7	26
4	58	19	37	51	38	36	54	20	39
5	49	23	30	48	31	29	42	20	37
6	53	30	50	28	19	27	42	18	32

[a]Underline shows last pretreatment count.

Table 9—Numbers of thekla larks and Moussier's redstarts seen within 50-m points of sampling on each plot during each period

		Treatment and plot numbers								
		Malathion			None (control)			Dichlorvos		
	Periods	1	4	7	3	6	8	2	5	9
Thekla larks	1	38	12	9	26	12	15	72	4	25
	2	30	11	14	31	19	19	64	6	22
	3	37[a]	18	9	17	4	13	28	4	21
	4	39	4	23	35	27	28	33	17	25
	5	29	18	26	32	20	19	32	14	23
	6	29	12	45	19	17	21	33	13	26
Moussier's redstarts										
	1	4	2	3	9	40	7	5	2	2
	2	1	5	3	6	3	4	6	0	3
	3	5	2	2	1	0	1	1	0	0
	4	0	7	3	3	2	3	1	1	0
	5	3	0	0	1	2	2	2	0	0
	6	2	0	2	1	0	2	0	2	0

[a]Underline shows last pretreatment count.

consistent trends were evident due either to time or treatments, and again statistical analyses did not suggest any differences due to treatments ($P = 0.49$). Moussier's redstarts tended to decrease on all plots over time, but only the decreases on the dichlorvos plots after treatments were statistically significant ($P = 0.05$)

Rodent Observations

Rodents were present on only a small portion of each study plot. Barbary ground squirrels were locally abundant in areas near manmade or natural rock walls. Jirds were more common in low drainages, while fat sand rats were common on slopes above these drainages. Fat sand rats were diurnally active, while the jirds were crepuscular or nocturnal. Both are fossorial and usually remained in or near their burrow systems.

By selective placement of traps in areas with rodents present, a sufficient number of larger rodents were captured to evaluate treatment effects (table 10). Before treatments, the total number of rodents captured was higher in plots where malathion (27) and dichlorvos (25) were used than in control plots (18). Following treatments, more rodents were caught in the control plot, but differences in these capture rates among treatments and periods were not significant ($P = 0.36$). Similarly, while mean captures per trap-night of jirds and fat sand rats decreased on insecticide-treated plots and increased on control plots, differences were not significant ($P = 0.17$).

Examination of trapping results on malathion-treated and control plots suggested that total catch of rodents varied with malathion residues in soil (fig 5). The greatest

Table 10—Mean number, by treatments, of new rodents captured in Tomahawk live traps

Treatment	Period	Total trap-nights	Total new captures	Mean captures per trap-night: Total rodents	Jirds	Fat sand rats	Barbary ground squirrels
Malathion	Pre	283	27	0.10	0.05	0.03	0.02
	Post	284	20	0.07	0.03	0.02	0.02
Dichlorvos	Pre	357	25	0.07	0.06	0.01	0.01
	Post	348	17	0.05	0.03	0.00	0.02
None (control)	Pre	358	18	0.05	0.03	0.01	0.01
	Post	366	24	0.07	0.04	0.02	0.00

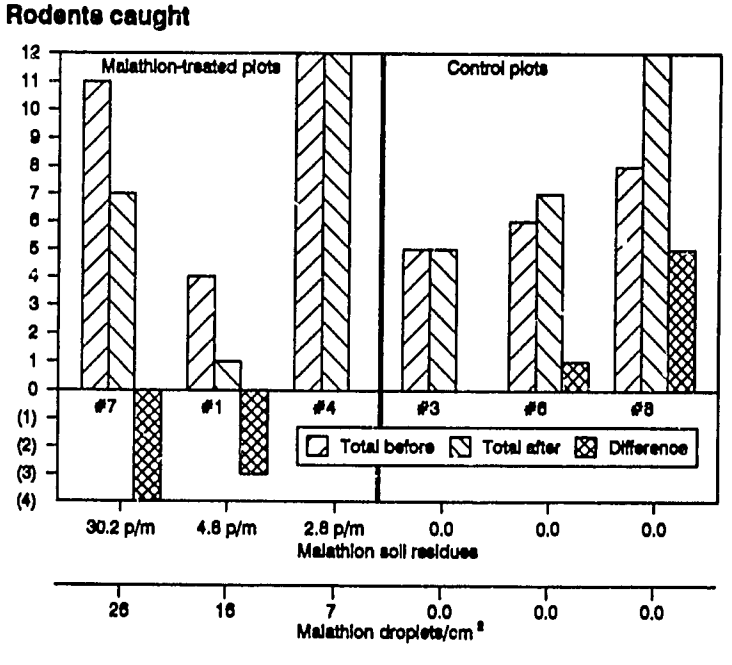

Figure 5—Rodents (mostly jirds and fat sand rats) caught on malathion-treated and control plots before and after spraying in relation to measurements of malathion deposits and residues. Numbers below each column are plot numbers (see fig. 2).

decrease in catch occurred on plot 7, where highest residues (30.2 p/m) were found and where malathion deposits were greatest (26 droplets/cm²). Plots with residues of 2.8 p/m or less malathion in soil had posttreatment catches that equaled or exceeded the pretreatment catch. Rodent activity data obtained by the closed-burrow sampling technique from the treated and control plots did not indicate treatment effects (table 11).

Radio Telemetry

The 62 radio-equipped animals on experimental plots were located 629 times during the 32-day study period. Due to a number of factors, including the delay in spraying caused by the week of strong winds, dislodgment and malfunction of radios, and possibly movement of birds, only 59 percent (24 of 41) of the radio-equipped animals on sprayed plots had functioning radios at the time of spray applications. Animals on the plots treated with malathion and dichlorvos were monitored up to 20 and 28 days, respectively, prior to spraying Postspray monitoring ranged from 9 to 11 days on the plots treated with malathion and from 3 to 8 days on those treated with dichlorvos.

No radio-equipped animals were found dead or debilitated on the treatment plots from insecticide poisoning. Neither did any animals make unusual movements that could be related to insecticide treatments. Most radio-marked thekla larks consistently remained within 150 m of their capture sites. The same was true for little owls, which usually had an estimated home range of less than 10 ha. Most Barbary ground squirrels remained close to their capture sites throughout the study period However, for unknown reasons, one male from a dichlorvos-treated plot and one female from a control plot moved to an area over 500 m from their original capture locations by the time fieldwork was concluded.

Food Habits of Vertebrates

Decreases in invertebrates after treatments for insect control can reduce food supplies of birds and mammals, change their food habits, cause their emigration, and reduce their reproductive success. To evaluate the indirect effects of the insecticides on vertebrates, we measured changes in the abundance of their food resources and food habits following treatments.

Before and after treatments, the stomach contents of rodents consisted of 99 to 100 percent plant material. Both jirds and fat sand rats fed almost exclusively on vegetation, including *Salsola vermiculata* and *Salicornia fruticosa*. Shaw and Libyan jirds and fat sand rats are known to eat plants, primarily of the family Chenopodiaceae (Aulagnier and Thevenot 1986). However, the complete absence of animal matter in the stomachs of jirds was surprising, as they reportedly eat some animal foods. None of the rodents examined after treatments had consumed greater than 1 percent animal material.

Table 11—Number and percentage of closed burrows that rodents (fat sand rats and jirds) reopened within 24 hours during both pretreatment and posttreatment periods

Treatment	Period	Date	No. of burrow systems	No. of holes closed	Holes reopened after 24 hours	
					No.	Percent
Malathion	Pre	1/24–25	33	282	80	28.4
	Post	2/13–14	31	145	51	35.2
Dichlorvos	Pre	1/28–29	53	407	106	26.0
	Post	2/19–20	53	191	105	55.0
None (control)	Pre	1/30–2/1	40	304	100	32.9
	Post	2/16–17	40	217	106	48.8

The kinds and relative amounts of animal and plant matter in gizzards of birds varied among the three species (table 12). Although thekla larks ate the least animal matter, they consumed a great variety of insects and spiders. Red-rumped wheatears ate more kinds of arthropods on treated (11 identified) than on untreated plots (4 identified). All birds ate beetles, but only the gizzards of little owls contained beetle larvae No effects of treatments were apparent on either thekla larks or little owls, although the food habits of little owls were not documented before treatments. However, for red-rumped wheatears, the posttreatment proportion of animal matter eaten (68 percent) was lowest on the dichlorvos-treated plots Apparently, sufficient insects were killed on those plots to influence wheatears' feeding habits. Likewise, ants occurred in only 11 percent of gizzards examined from malathion-treated plots, but ants occurred in 54 to 64 percent of gizzards from other plots. These posttreatment results suggest that insecticide treatments reduced some food sources (e g., ants) but did not greatly alter the diets of birds

Insect Observations

After malathion treatments, the number of dead bees observed at bee hives on treated plots increased ($P = 0.0001$) from 0 to an average of 22. No increase in mortality was evident at hives on the dichlorvos-treated plots. Numbers of entries and exits did not change on the malathion-treated plots, but these numbers temporarily decreased ($P = 0.003$) on the plots sprayed with dichlorvos. While no change was detected on the latter plots in the percentage of sugarcube points with ants present, significant ($P = 0.02$) reductions (97 to 19 percent) were recorded on the malathion-treated plots.

Effects on insects seemed to vary with the monitoring method used. Data from pitfall traps showed a weak indication ($P = 0.09$) that beetles decreased due to dichlorvos but did not suggest effects of malathion. Thus, pitfall data did not reflect the mortality of beetles found by searchers on the treated plots (table 4). Pitfall catches of ants decreased after malathion exposure, but numbers were too

Table 12—Food habits of birds in relation to insecticide treatments

Species and treatment	*n*	Food in gizzards[a] Volume (mL)	Animal (%)	Vegetation (%)	Major kinds of arthropods present
Thekla larks					
Pretreatment	9	0.52	30	70	Most varied of birds. Beetles, caterpillars, termites, thrips, bees, spiders, scorpions, wasps, and termites.
Posttreatment					
None (control)	10	0.90	38	62	
Malathion	10	0.53	42	58	
Dichlorvos	12	0.65	39	61	
Red-rumped wheatears					
Pretreatment	10	0.45	87	13	Ants, beetles, bees, wasps, and caterpillars. Birds in malathion-treated plots ate fewer ants.
Posttreatment					
None (control)	10	0.97	89	11	
Malathion	9	1.03	84	16	
Dichlorvos	11	0.85	68	32	
Little owls					
Posttreatment					
None (control)	5	3.4	96	4	Beetles, scorpions, termites, cockroaches; also vertebrates.
Malathion	6	3.5	90	10	
Dichlorvos	5	3.1	97	3	

[a]Grit as a percentage by volume of total gizzard contents ranged among treatments from 14–43 percent for thekla larks and 1.0–7.8 percent for red-rumped wheatears to 0 percent for little owls.

variable to show a statistically significant treatment effect. Transect counts on malathion-treated plots showed significant decreases ($P = 0.02$) in numbers of *Adesmia dilatata*, the most common Tenebrionid beetle found dead during searches on plots.

We observed no effects of dichlorvos on orthopterans. However, a comparison of posttreatment and pretreatment transect counts (table 13) may suggest that malathion reduced grasshopper populations.

Table 13—Average number of orthopterans seen during transect counts[a]

Period	Plots treated with Malathion	Nothing (control)	Dichlorvos
Pre-1	45 3 B	6.3 D	8.7 C, D
Pre-2	100.3 A	9.0 C, D	15.7 B, C, D
Post	39.7 B, C	11 7 C, D	21.7 B, C, D

[a]Means followed by different letters are significantly different at $P = 0.03$.

Discussion

Our research was an attempt to evaluate the effects of field applications of malathion and dichlorvos on birds, mammals, and beneficial insects. Unfortunately, complete interpretation of the results was compromised by ineffective and inadequate insecticide treatment to some plots Effective treatments of broad-spectrum insecticides, such as malathion and dichlorvos, should result in large numbers of dead and dying arthropods for several days after treatments.

Deposits measured on spray cards reflected the subjective visual appraisals of treatment effectiveness. Thus, it appeared the malathion treatments on plot 7 (26 droplets/cm^2) and plot 1 (16 droplets/cm^2) were acceptable, while insecticide sprays to other plots were not satisfactory. Likewise, deposits were a good index to malathion residues measured in soil on the day after spraying Initial average malathion residues in soil reflected average deposits measured on spray cards, but variation among measurements was high. Lowest initial residues (2 8 p/m on plot 4) probably persisted for about 1 week and highest (30.2 p/m on plot 7), for about 2 weeks. Malathion residues were not detected in most vegetation samples, so nothing was learned of malathion's persistence on livestock forage.

Only trace amounts of dichlorvos were found on either soil or vegetation. As droplet counts on plots 2 (5 droplets/cm^2) and 9 (6 droplets/cm^2) were similar to those on plot 4, which had been treated with malathion (7 droplets/cm^2), initial residues similar to those on plot 4 (2.8 p/m) might have been expected. However, initial samples were not obtained until the day after treatments were made to plots, and any residues present could have degraded or otherwise disappeared. The half-life of dichlorvos in soil and on vegetation was only hours long in other studies, which found that this pesticide rapidly disappeared due to hydrolysis and volatilization (Food and Drug Administration 1982).

Drift of malathion from plot 1 may have contaminated plots 2 and 3. If insecticide drift of such proportions occurred, posttreatment information from some study plots may reflect effects of more than just assigned treatments.

Searches on treated plots did not locate any dead vertebrates, and invertebrate mortality appeared minimal. AChE measurements, which served as a bioassay of plot contamination, did not suggest a serious exposure of birds and mammals to the insecticides. Of 10 thekla larks collected from malathion-treated plots, 8 came from plot 7, the only plot that received satisfactory insecticide application. These larks were the only birds with significantly depressed brain AChE.

Neither AChE measurements nor radio-telemetry monitoring suggested any mortality or movement of vertebrates. Population sampling gave indications of some treatment effects on bird and mammal numbers, although no important biological impacts were documented. Moussier's redstarts decreased significantly on dichlorvos-treated plots, but the magnitude of the changes was small. In addition, rodent catch on treated plots appeared to decrease, but these apparent treatment effects were not supported by data analyses.

Red-rumped wheatears ate fewer ants on malathion-treated plots. Only one of nine birds (11 percent) had eaten ants, while 54 and 64 percent of wheatears from dichlorvos-treated and control plots, respectively, had ants in their gizzards A decrease in ant activity occurred on malathion-treated plots, and we surmise that wheatears did not find ants as often there Wheatears also had eaten a lower proportion (68 percent) of animal foods on plots treated with dichlorvos than on control plots (89 percent), and this decrease was the only other effect of treatments on the foods of vertebrates

Insect studies showed statistically significant effects of malathion on bees and ants, which are known to be highly susceptible to the insecticide (Levin et al. 1968) Dichlorvos is known to kill bees (Thomson 1982), and the absence of bee mortality from dichlorvos in the current study again suggests that dichlorvos treatments were inadequate.

Beetles were affected obviously by malathion applications and somewhat by dichlorvos applications. Although population sampling with pitfall traps and transect counts did not show conclusive effects of treatments, numbers of beetles found dead or debilitated during searches immediately after treatments documented beetle mortality and grossly reflected relative insecticide deposits measured on plots. Variation in numbers of newly dead beetles was not related to search efficiency as many previously dead beetles were found on all plots, including those treated with dichlorvos. Numbers of other dead arthropods were extremely low on all plots, though scavenging activity by animals may have masked some mortality.

Results of this study were compromised to some extent by inadequate spray applications to some plots. Certainly more-intense effects would have occurred if more effective insecticide applications had been made. The inadequacy of the spray effort is particularly regrettable because the scientific quality of sampling and the industriousness and thoroughness of the efforts of the multinational scientific teams were excellent.

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Participants listed in Appendix A collected data during the study period Michael L. Avery designed methodology for plant inventory and collected data on four plots in October 1991. John E. McConnell, Jr., coordinated all in-country logistical aspects, which were substantial. As study director, James O. Keith coordinated all technical aspects of the overall project, collected and compiled field data, and edited the study report. Richard L. Bruggers coordinated all DWRC administrative aspects of the study and participated in the field research and report writing. Patricia C. Matteson organized insect studies and identified contents of bird gizzards and rodent stomachs. Mark E. Tobin and Michael L. Avery provided editorial reviews of the draft manuscript.

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Directory of Personal Communications

Ahmed Afrass
Direction de la Protection des Végétaux
des Contrôles Techniques et de la Repression des Fraudes
B.P. 1308
Rabat, Morocco

Authors' Affiliations

James O. Keith, USDA/APHIS/ADC/DWRC, P.O. Box 25266, Denver, CO 80225-0266 U.S.A.

Richard L. Bruggers, USDA/APHIS/ADC/DWRC, P.O. Box 25266, Denver, CO 80225-0266 U.S.A.

Patricia C. Matteson, Iowa State University, Department of Entomology, 12A, Insectary, Ames, IA 50011-3140 U.S.A.

Abderrahim El Hani, DPVCTRF, BP: 1308, Rabat, Morocco

Said Ghaout, DPVCTRF, BP: 1308, Rabat, Morocco

Lynwood A. Fiedler, USDA/APHIS/ADC/DWRC, P.O. Box 25266, Denver, CO 80225-0266 U.S.A.

El Hassan Arroub, DPVCTRF, BP: 1308, Rabat, Morocco

John N. Gillis, EPA, Water Management Division, Region 8, 8WM-DW, 999 18th Street, Suite 500, Denver, CO 80202-2405 U.S.A.

Robert L. Phillips, USDA/APHIS/ADC/DWRC, P.O. Box 25266, Denver, CO 80225-0266 U.S.A.

Appendix A—Moroccan and American research teams for experiment

Subjects	Persons responsible for study	
Insects	P. Matteson[a]	A. Baou A. El Fayq A. El Bakkouri S. Ghaout A. Mouhim S. Sahil
Birds	R. Bruggers J. Heisterberg	A. Aloui A. Dliou H. El Addami A. El Hani
Mammals	R. Curnow L. Fiedler	H. Arroub A. Ouzaouit B. Id
Messaoud		M. Charhbili
Radio telemetry	J. Bourassa P. Hegdal R. Johnson R. Phillips	O. Alhillali A. Ben Ider M. Ramzi
AChE/residues	J. Keith J. Gillis[b]	M. Akch ki A. Daia M. Benchra M. Tarhy
Computers/data entry	R. Engeman	All participants as scheduled
Deposits	J. Keith	S. Lagnaoui A. Afrass
Searchers	J. Keith	Local residents

[a] Entomologist, CICP.
[b] Chemist, EPA.