PN-ABT-897

MOROCCO LOCUST PROJECT

IN 92833

RESEARCH REPORT

Effects of experimental applications of malathion and dichlorvos on populations of birds, mammals, and insects in southern Morocco

Editor

James O. Keith

Denver Wildlife Research Center
U.S. Department of Agriculture
P.O. Box 25266, Denver, CO 80225
U.S.A.

Prepared from contributions by American and Moroccan study participants

COOPERATING AGENCIES

U.S. Government

Department of Agriculture
Environmental Protection Agency

Government of Morocco

Ministry of Agriculture and Agrarian Reform
Ministry of Interior

Consortium for International Crop Protection

July 22, 1992

This work was funded by the U.S. Agency for International Development under the "Morocco Locust Control Project," PASA 608-0196-P-00-0005. Implementation of the Project was coordinated by the Denver Wildlife Research Center/Animal and Plant Health Inspection Service/U.S. Department of Agriculture.

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ABSTRACT

During the 1986-1990 eruption of desert locusts (*Schistocerca gregaria*) in Africa, over 4.5 million ha were treated with insecticides in Morocco. Malathion and dichlorvos were two of the principal insecticides used. In January and February 1992, studies were conducted by U.S. and Moroccan scientists on experimental plots in southern Morocco to evaluate the effects of these chemicals on birds, mammals, and insects. Nine 3-km^2 plots were used; three were controls, while a helicopter sprayed three with malathion (750 g/ha) and three with dichlorvos (200 g/ha). However, except for one malathion plot, very little of the insecticide reached the ground on treated plots. Poor application of insecticides compromised assessment of treatment effects. Studies were successful, however, in providing training and experience in ecotoxicological research, which was a primary objective of the project. Malathion residues in soil decreased 85-90 percent after 1 week. Residues of malathion on vegetation were low and only trace amounts of dichlorvos were recovered form either soil or plants. Inhibition of cholinesterase was found only in brains of Thekla Larks on malathion plots; but levels decreased only 18 percent, which was not sufficient to suggest serious impairment. No apparent mortality of birds and mammals occurred and no important, significant effects were found on numbers or activity of birds and mammals. Rodent activity was reduced 36 percent on malathion plots. Rodent catch in traps decreased 26 and 32 percent under malathion and dichlorvos treatments, respectively, while it increased 33 percent on control plots. However, these changes were not statistically significant. Malathion had real effects on mortality in bees, the occurrence of ants, the abundance of orthopterans, and apparently on numbers of one species of beetle. Dichlorvos did not have severe effects on insects, but reduced the numbers of bees entering hives and the abundance of beetles on plots. Bird and mammal food habits were not affected, except that ants largely disappeared from diets of birds on malathion plots. More intense effects of both insecticides undoubtedly would have occurred if treatments had been effectively applied to experimental plots.

INTRODUCTION

In 1986, a major eruption of desert locusts (*Schistocerca gregaria*) occurred in Africa. Locusts populations increased following rains that ended a prolonged drought in the Sahel region of Africa just south of the Sahara Desert. Historically, locusts plagues have caused serious losses, especially to grains grown by sustenance 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. Such damage can cause economic losses, and especially reductions in food supplies that result in human suffering.

Since World War II, attempts have been made to suppress locust eruptions through the use of synthetic insecticides developed during and after the war. In earlier outbreaks of locust populations (1950-1965), organochlorine insecticides[1], such as dieldrin and BHC, were used to control the large, scattered locusts swarms. However, in the 1970's, use of the organochlorine insecticides was discouraged or banned in many countries of the world. Few studies had been done to determine effective, safe replacement insecticides for locust control, and in 1986 short-term research was rapidly begun to identify substitute chemicals (Table 1).

The organophosphate and carbamate insecticides in ULV formulations proved practical as replacements for the organochlorine insecticides. In the 1986-1990 outbreak throughout Africa, most control was undertaken with ULV fenitrothion (Symmons 1992). Malathion, chlorpyrifos, deltramethrin lamdacyhalothin, carbaryl, bendiocarb and propoxur were also used, but in lesser amounts. Some use of dieldrin and BHC was continued, but most countries respected the consensus against their use.

Morocco, Senegal, Algeria, and Sudan treated the largest areas (1.5- to 4.6-million ha) for locust control and sizable areas (~ 1.0 million ha) were treated in Niger and Mauritania (Table 2). Control was undertaken on areas of ½-million ha or less in 9 other countries. The cost:benefit ratios of various efforts to protect crops and reduce locust populations were not evaluated. The largest segment of the migrating population was blown into the Atlantic Ocean by strong easterly winds during its northward movement through Mauritania in late 1988. Subsequently, massive numbers of African locusts were reported in the West Indies; some locusts had been transported by winds or other means across more than 5,000 km of ocean.

In Morocco high-value crops such as oranges were severely damaged by locusts in past outbreaks. 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. Likewise, locust consumption of range forage can restrict food available to livestock in southern Morocco (Table 3).

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[1] Throughout the report, reference to trade names does not imply endorsement by the U.S. Government.

Table 1. Insecticides that have proved effective for control of locust and grasshoppers.[a]

Insecticides	Formulation	Application method	Guide application rates g a.i./ha		Comments
			Grasshoppers	Locusts	
Organophosphates					
Diazinon	60-100% ULV	Spray	-	500	Effective, but hazardous for birds.
Dichlorvos	4% ULV	Spray	-	150-200	Rapid knockdown, very volatile, hence not for use at high temperature and little persistence.
Fenitrothion	50-100% ULV	Spray	200-300	400-500	Also used as an emulsifiable concentrate.
Malathion	96% ULV	Spray	500-700	1000-1500	Widely used in North America against locusts and grasshoppers.
Carbamates					
Bendiocarb	1% dust	Bait	-	20-30	Bait strength 0.5 g a.i./kg.
Carbaryl	480 g/L ULV	Spray	400-1100	1000-2000	Formulation usually diluted 4:1 which persists for 2-3 weeks; widely used in North America against locusts and grasshoppers.
Propoxur	1% dust	Bait	225	-	Bait strength 4.5 g a.i./kg.
	25% ULV	Spray	-	100-125	Highly toxic to some birds.
	1-2% dust	Bait	100-150	-	Active ingredient may break down if alkaline carrier used. Bait strength 2-4 g a.i./kg.
Organochlorines					
Dieldrin[b]	20% ULV	Spray	10-20	10-35	Deposits on vegetation persistent and highly toxic, hence association with barrier spraying.
HCH[b]	10-20% ULV	Spray	-	200-500	Highly persistent and highly toxic, hence association with barrier spraying.
	2-5% dust	Bait	-	13-40	Bait strength 1.3 g a.i./kg.
	Dust	Dust	400	-	-

[a] Source: Locust Handbook. 1988. Overseas Development Natural Resources Institute (ODNRI).
[b] Use prohibited in some countries and restricted in others.

Table 2. Desert locust control in Africa (September 1986-August 1990).[a]

Country	Estimated area treated (ha)
Morocco	4,652,000
Algeria	1,772,000
Libya	100,000
Tunisia	286,000
Mauritania	987,000
Senegal	2,039,000
Cape Verde	37,000
Gambia	177,000
Guinea-Bissau	2,000
Mali	504,000
Niger	1,097,000
Chad	163,000
Sudan	1,530,000
Ethiopia	117,000
Egypt	306,000
Total	13,769,000

[a] Source: Everts 1990.

Table 3. Land use in Morocco.[a]

Use	Area (1,000 ac)	Percent
Crops		
Grains	4,703	
Other Crops	1,499	
Fallow	2,137	
Total	8,339	12
Forests	5,200	8
Rangelands	23,461	34
Nonagriculture	32,000	46
Total	69,000	100

[a] Source: U.S. Agency for International Development (USAID), Morocco.

Lands ravaged by locusts in Morocco are primarily in private or collective ownership (Table 4). However, locust control was organized and undertaken by the government because logistics and planning involved control operations over extensive areas within Morocco, and international cooperation was needed for conduct of coordinated control campaigns. The Ministry of Interior was responsible for locust control in Morocco, with entomological and logistical assistance from the Ministry of Agriculture. Military aircraft and pilots were used to apply insecticides to flying swarms, while ground treatment of hopper bands was done by teams from the Ministry of Agriculture and Ministry of Interior (Centre National de Lutte Antiacridienne). In these campaigns, the Moroccan government gained experience in the use of ULV formulations of replacement insecticides for locust control. They now know when and how to use these new insecticides to protect their croplands and rangelands from locusts. The government also desired to assess the environmental hazards of the insecticides so that they could make informed decisions about which chemicals to use when locusts again appear.

Malathion, fenitrothion, and dichlorvos (DDVP) were the principal insecticides used to control locusts in Morocco during the 1987-1989 campaigns (Table 5). These organophosphorus insecticides differ in some of their basic toxicological characteristics, but all are broad spectrum insecticides that cause general mortality among many kinds of insects and other invertebrate organisms.

Malathion (Fig. 1) is slow in killing acridids, which die over a period of several days after their exposure. This is an undesirable characteristic in locust control. Treatments usually are made on moving swarms of locusts, and when not immediately killed, they may inadvertently be sprayed again. Malathion has a low toxicity to birds and mammals, and 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, Parsons and Davis 1971, Giles 1970, McEwen 1982). In contrast, it is highly toxic to fish and aquatic invertebrates (Mulla et al. 1979) and treatment of wetland habitats must be avoided.

Fenitrothion has caused bird mortality under certain conditions of field use. In the forests of Quebec, applications of over 284 g/ha for spruce budworm (*Choristoneura fumiferana clemens*) control usually resulted in some bird mortality (Buckner and McLeod 1977, Busby et al. 1983). Species killed were primarily foliage gleaners in tree tops. Application of 213 and 426 g/ha to rangeland for grasshopper control also caused bird mortality and decreased bird numbers (McEwen 1982). However, bird mortality was negligible from fenitrothion applications of 485 and 825 g/ha for locusts control in the open savannah of northern Senegal in 1989 (Keith and Mullié 1990). Habitat and climatic conditions differed sharply from those in the Canadian forests, and few birds were killed by rates of fenitrothion applications that were almost 3 times as high as those used in Canada. Fenitrothion did decrease bird food supplies (insects), reduce bird abundance, and decrease reproductive success. Because this knowledge was available from Senegal studies, additional evaluations of fenitrothion in Morocco was not considered to be of a high priority.

Table 4. Land ownership in Morocco.[a]

Owner	Percent
Private	74
Collective	14
Guice and Habous	6
State	6

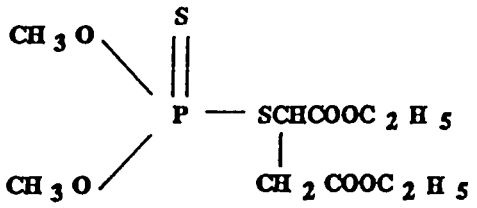
[a] Source: USAID, Morocco.

Table 5. Volume of different insecticides used in Morocco (1987-89) for locust control.[a]

Insecticides	Liters
Malathion	1,200,000
Fenitrothion	740,000
Dichlorvos	430,000
Carbaryl	40,000
Decis	30,000
Karate	20,000
Diazinon	10,000
Fenthion	6,000

[a] Source: USAID, Morocco.

Malathion



Dichlorvos

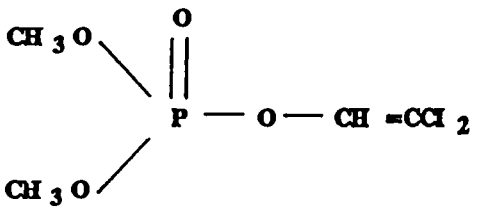


Fig. 1. Chemical structure of malathion and dichlorvos.

Dichlorvos (Fig. 1) is seldom applied for insect control under field conditions; it has been used primarily in homes, restaurants, factories, and dairy and other livestock facilities. There are no studies of wildlife effects from field use (Smith 1987). However, dichlorvos is extremely toxic to birds and moderately toxic to mammals (Smith 1987), and although it rapidly degrades (within hours) in the environment, it could cause wildlife mortality immediately following applications.

Evaluation of dichlorvos and malathion effects in habitats treated for locust control seemed most relevant for study in Morocco. Both malathion and dichlorvos have the potential to cause indirect effects on wildlife. Their application could reduce food supplies of vertebrates and cause movement of breeding adults from treated areas, which could result in nest desertion, death of nestlings, and reproductive failure. For these reasons, it seemed desirable to include evaluations of indirect effects in Moroccan studies. To do so required documentation of food habits for selected vertebrates and of changes in the abundance of their food resources following insecticide applications. Studies of nontarget insects also were desirable to evaluate treatment effects on invertebrate predators and parasites of locusts and on bees, which are of great economic importance in southern Morocco. Both vertebrates (Table 6) and invertebrates (Table 7) attack locusts and can help reduce locust numbers and their economic damage.

During the 1987-89 locust outbreak in Morocco, control campaigns were conducted from a number of regional locations (Table 8). The greatest intensity of control was in the region near Guelmim, where locusts swarms attempted to continue north from the desert across the Anti-Atlas mountains and into the Sous-Massa valleys. An area receiving intense treatment was the country northwest of Guelmim between the Ras et Tarf mountain range and the Oued Assaka (Fig. 2). This area seemed appropriate for study as it had received repeated applications of insecticides during control campaigns and supported fair numbers of birds, small mammals, and insects.

The goal of the current study was to evaluate the effects of field applications of malathion and dichlorvos on birds, mammals, and beneficial insects. It was accepted that treatments would be made to experimental plots where, most likely, locusts would not be present. Only by working on experimental plots can adequate data be obtained prior to treatments. In operational control, insecticides are usually applied onto swarms the day after the swarms are located in the field, which leaves inadequate time to collect pretreatment information.

Study objectives were:

1. Aerially apply malathion and dichlorvos to large experimental plots at rates and formulations used in locust control.

2. Treat plots in January and February when locust control was undertaken in the area.

3. Measure the numbers and/or activity of birds, mammals, and beneficial insects on study plots before and after treatments.

4. Determine treatment effects on the food habits and food availability of vertebrates.

5. Use radiotelemetry to monitor mortality and movements from plots by vertebrates in response to treatments.

6. Measure spray deposits on plots, initial residue levels, and their persistence in soil and vegetation.

7. Search plots for vertebrate mortality, and determine exposure of selected vertebrate species through measurement of brain cholinesterase.

For this cooperative research, teams that included both Moroccan and U.S. scientists were formed to conduct each aspect of the study (Table 9). Field investigations were scheduled during the 5 weeks between January 20 and February 23, 1992 (Fig. 3). This schedule allowed 2 weeks before and after treatment for measurement of abundance, foods, movements, and cholinesterase levels in animals. The middle week was for treatment of plots, searches for dead animals, and initial sampling for residue analyses. Collection of data on the abundance of birds, mammals, and insects was proposed for 9 days before treatments and 9 days following treatments, as indicated in Figure 3. However, weather and problems with the helicopter and spray apparatus caused delays in treatments and in the timing of posttreatment data collections. Actual activities were undertaken as shown in Figure 4. Strong, easterly winds that began the night of January 31 and continued until February 4 delayed the arrival of the helicopter. Morning fog often prevented spraying early in the day, while falling humidity, increasing temperatures, and convection currents often halted spraying well before noon. Electrical problems with the helicopter, failure of the spray pump, and breakage of spray pods (orifices and nozzles) often caused delays when weather was satisfactory.

Table 6. Birds observed to feed on the desert locust.[a]

Family	Common name	Scientific name
Coraciidae	Rufous-crowned Roller	*Coracias naevia*
	European Roller	*C. garrulus*
	Lilac-breasted Roller	*C. caudata*
Bucerotidae	Red-billed Hornbill	*Tockus erythrorhynchus*
	Yellow-billed Hornbill	*T. flavirostris*
	Grey Hornbill	*T. nasutus*
Upupidae	Hoopoe	*Upupa eopos senegalensis*
Alaudidae	Larks	(various species)
Motacillidae	African Pied Wagtail	*Motacilla aguimp*
	Yellow Wagtail	*M. flava*
Turdidae	Somali Wheatear	*Oenanthe phillipsi*
	Common Wheatear	*O. oenanthe*
Sylviidae	Unidentified Warblers	*Eremomela* spp.
Laniidae	Fiscal Shrike	*Lanius collaris*
Corvidae	Dwarf Raven	*Corvus edithae*
Sturnidae	Superb Starling	*Spreo superbus*
Accipitridae	Black Kite	*Milvus migrans*
	Spotted Eagle	*Aquila clanga*
	Steppe Eagle	*A. nipalensis*
	Tawny Eagle	*A. rapax*
	Long-legged Buzzard	*Buteo rufinus*
Falconidae	Lanner Falcon	*Falco biarmicus*
	Kestrel	*F. tinnunculus*
Ciconiidae	White Stork	*Ciconia c. ciconia*
	Black Stork	*C. nigra*
	Marabou Stork	*Leptoptilos crumeniferus*

[a] Source: TAMS, 1989.

Table 7. Desert locust natural insect enemies.[a]

Order and family	Species	Host stage	Mortality	Remarks
DIPTERA				
Bombyliidae	*Systoechus spp.*	eggs	< 30%	
Calliphoridae	*Stomorhina lunata*	eggs	0-90%	Only in East Africa
Calliphoridae	*Blaesozipha spp.*	nymphs, adults	0-40%	
Nemestrinidae	*Symmictus costatus*	nymphs, adults	0-34%	
Asilidae		eggs		
HYMENOPTERA				
Proctotrupoidea	*Scelio spp.*	eggs		
Sphecidae	*Sphex aegypticus*	nymphs, adults		Of little importance
COLEOPTERA				
Trogidae	*Trox procerus*	eggs	0-75%	
Meloidae	*Mylabris spp.*	eggs		Of little importance
Caribidae		eggs		Of little importance

[a] Source: van der Valk, 1990.

Table 8. Areas treated with insecticides for locust control in regions of Morocco.[a]

Region	Hectares
Guelmim	826,000
Ouarzazate	275,000
Tata	253,000
Laayoune	219,000
Aït Melloúl	156,000
Errachidia	130,000
Bouarfa	60,000
Oujda	42,000
Other	22,000

[a] Source: USAID, Morocco.

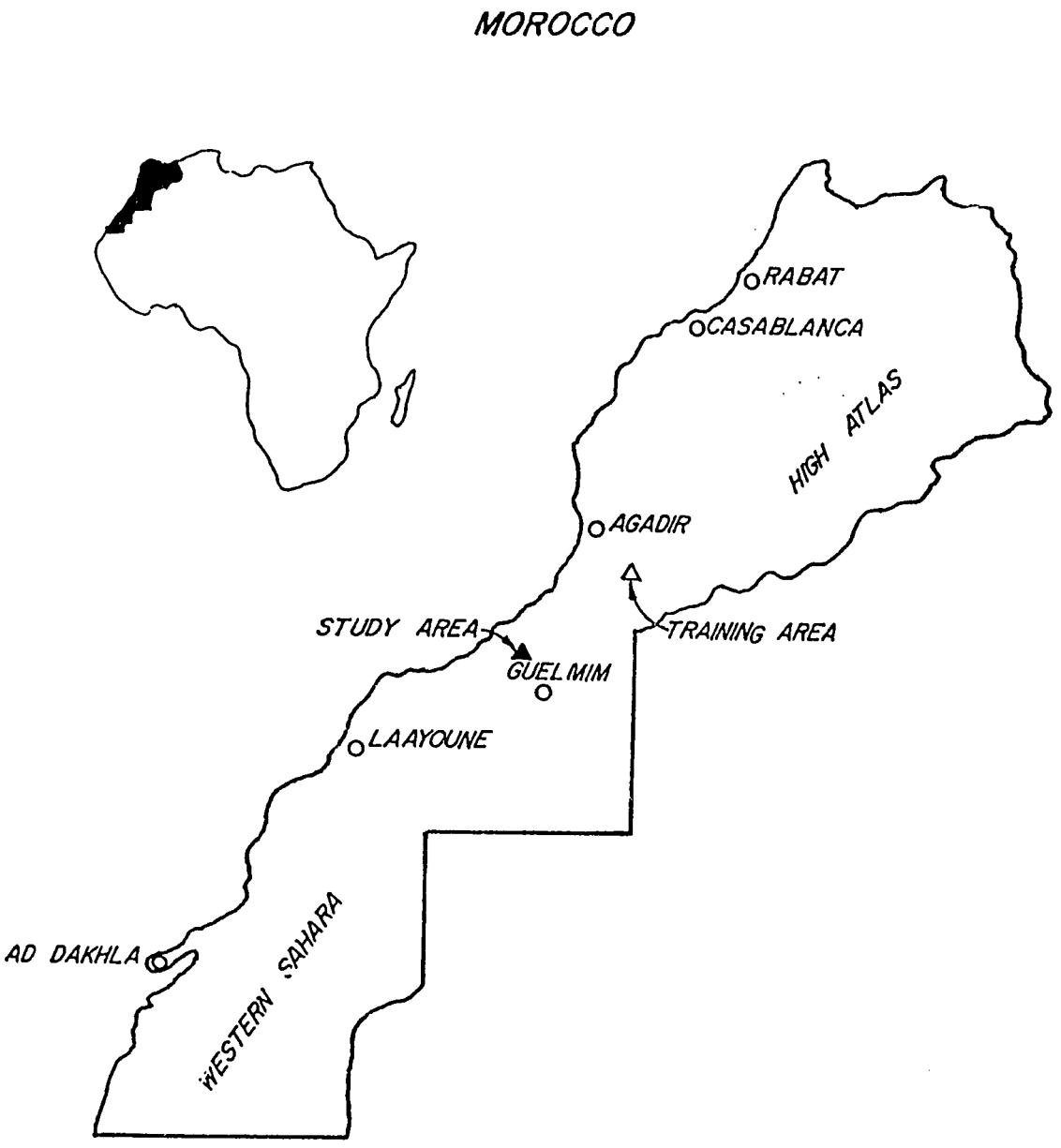


Fig. 2. Location of study area in Morocco.

Table 9. Moroccan and American research teams.

Teams	Americans	Moroccans
Insects	P. Matteson	A. Baou A. El Fayq S. Ghaout A. Mouhim El Jaouani A. El Bakkouri
Bees	--------	L. Abail D. Aid Belarbi L. Zerhloul S. Merzouk
Birds	R. Bruggers J. Heisterberg	A. Aloui A. El Hani H. El Addami
Mammals	R. Curnow L. Fiedler J. McConnell	H. Arroub A. Ouzaouit B. Id Messaoud
Radiotelemetry	P. Hegdal J. Bourassa R. Johnson R. Phillips	O. Alhillali M. Ramzi
Cholinesterase	J. Keith	A. Akchati M. Benchra S. Sahil
Residues	J. Gillis	M. Tarhy A. Daia A. Falaq
Searches	J. Keith	Local residents
Deposits	--------	A. Afrass S. Lagnaoui
Data Entry	R. Engeman L. Fiedler R. Curnow R. Johnson	All participants

PERIOD OF EXPERIMENT

1992	M	T	W	T	F	S	S
JANUARY	20	21	22	23	24 X	25 X	26 X
	27 X	28 X	29 X	30	31 X	1 X	2 X
FEBRUARY	3 MALA	4	5 DDVP	6	7 X	8 X	9 X
	10 X	11 X	12 X	13	14 X	15 X	16 X
	17	18	19	20	21	22	23

X - Days data to be gathered on mammals and birds

MALA - Application of malathion to plots (3)

DDVP - Application of DDVP to plots (3)

- collection of residue samples (MALA)

- collection of residue samples (DDVP)

Fig. 3. Schedule of events planned for the experiment.

PERIOD OF EXPERIMENT

1992	M	T	W	T	F	S	S
JANUARY	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	1 B-R-I	2 B-R-I
FEBRUARY	3 I	4 I	5	6	7	8	9 I
	10 I MALA-1	11 I	12 I MALA-4,7	13 B-R-I DDVP-2	14 B-R-I	15 B-R-I	16 B-R-I DDVP-5
	17 B-R-I	18 B-R-I DDVP-9	19 B-R-I	20 B-R-I	21 B-R-I	22 I	23 I

Sampling

B - Birds R - Rodents I - Insects

Fig. 4. Dates on which events actually took place during the experiment. Dates of insecticide applications to plots are shown as MALA-1 (refers to insecticide and plot number), etc.

STUDY AREA AND EXPERIMENTAL DESIGN

Study Area

The study area consisted of rolling hills, internal basins, and narrow drainages; there were no perennial streams. The largest part of the area sloped to the north towards the Oued Assaka. The southern part of the study area (plots 8 and 9) was on the south side of the Ras et Tarf divide and sloped to the south and east (Fig. 5). Near Oued Assaka the hills were higher and the drainages deeper. Thus, 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 in the study area is 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 study area currently supports only 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. Very little cover existed on the ground during the study as rainfall had been low. Most of the area between shrubs was bare soil and rocks.

The occurrence of and ground covered (including plant canopy) by plants on study plots were measured. A 1-m^2 plot frame was systematically placed at three locations near each of 15 points in the central sampling area of each plot (Fig. 6). The occurrence of plants and the percentage of the plot area covered by their foliage was estimated. Only three plants were present on all plots: *Euphorbia echinus*, *Senecio anteuphorbium*, and *Lycium intricatum* (Table 10). Some plants were most common on northern plots (*Euphorbia obtusifolia* and *Lycium intricatum*), while the presence of others was greatest on southern plots (*Salsola vermiculata* and *Sueada ifniensis*). *Convolvulus trabutianus* was found primarily on plot 5. Similarly, the percentage of ground covered by vegetation was higher (23-50 percent) on northern plots than on southern plots (6-22 percent). Vegetation appeared more lush on northern plots and shrubs grew higher. In part, this appearance was due to the presence of *Euphorbia obtusifolia*, which was the largest and tallest of the shrubs.

Average maximum monthly temperatures (1949-1956 records) at Guelmim, which is the nearest meteorological station to the study area, were highest between July and October (maximums above 30°C) and lowest in December, January, and February (21-22°C). Monthly minimum temperatures varied from about 10° to 18°C and were lowest in January and February (Table 11). Average precipitation (Table 12) was highest in December, January, and February, but is highly variable as shown by the 1987 and 1988 records. During January and February, the months in which this study was conducted, minimum and maximum temperature can be the lowest of the year and precipitation can be the highest.

During January and February 1992, daily maximum temperatures varied between 18° and 31°C, and nighttime minimums between 3° and 18°C. Trace amounts of rain fell on January 31 and February 14, 15, and 19. A strong easterly wind began the night of January 31 and continued until the evening of February 4. The rains added moisture to the soil, but the winds probably removed most of that moisture. Still, a scattered emergence of small annual plants occurred in early February.

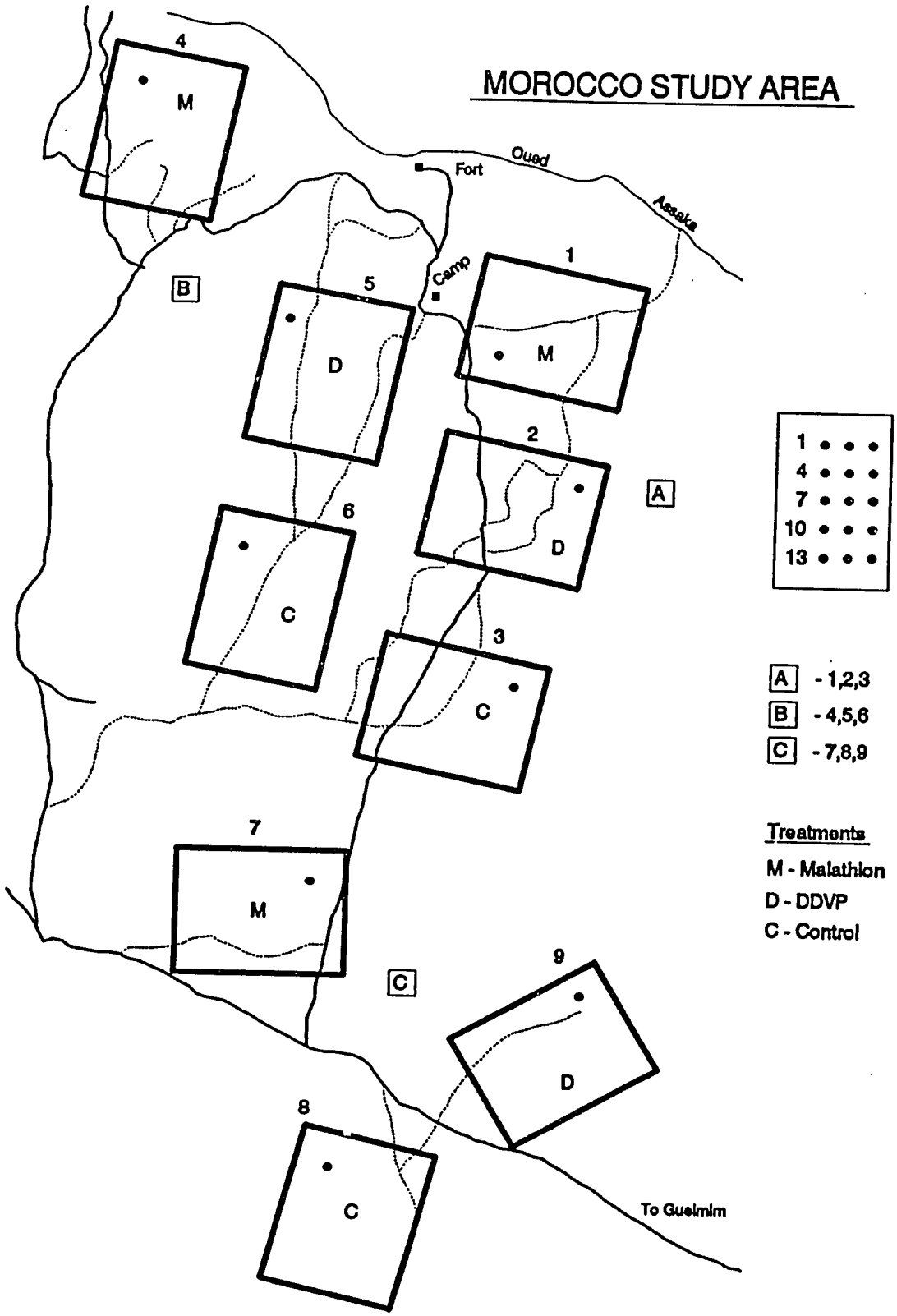


Fig. 5. Study area showing roads, plots, blocks, and treatments.

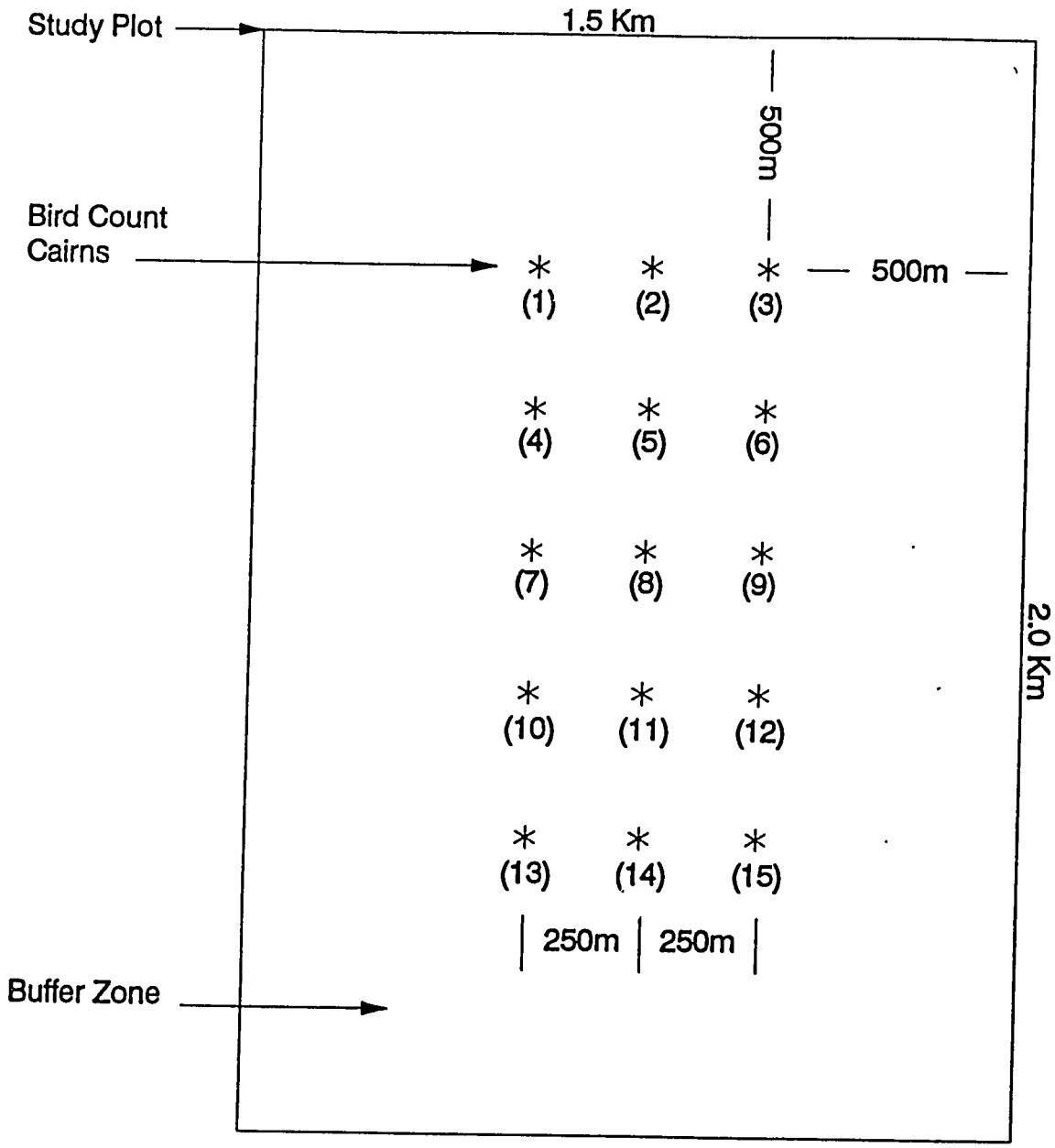


Fig. 6. A study plot showing bird counts points, which delineated the sampling area within the plot.

Table 10. Incidence of plant occurrence and the percent of plant cover on the study area.[a]

Measurement	Plots									Average
	1	2	3	4	5	6	7	8	9	
Percent occurrence[b]										
Species										
Euphorbia echinus	93	80	67	80	87	87	27	13	7	59
Euphorbia 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	13	0	0	0	0	6
Asphodelus tenuifolius		-	-	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
Percent 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 4 plots.

Table 11. Maximum (M) and minimum (m) monthly temperatures (°C) from Guelmim.

Years		Months											
		J	F	M	A	M	J	J	A	S	O	N	D
1949 to 1956[a]	m	10.6	9.7	11.2	12.5	13.8	15.8	17.9	17.7	15.9	14.9	13.1	12.2
	M	21.3	22.2	26.0	26.0	27.6	29.3	33.7	36.4	32.4	32.0	27.0	22.1
1987[b]	m	9.4	-	-	-	12.3	14.7	-	-	-	14.1	13.8	12.5
	M	19.4	21.6	16.3	28.6	26.8	25.9	28.2	29.2	37.9	27.0	24.7	20.4

[a] Dijon, R., 1964.
[b] Meteorological station at Guelmim.

Table 12. Precipitation (mm) for Guelmim.

Years	Months												Total
	J	F	M	A	M	J	J	A	S	O	N	D	
1938 to 1963[a]	25.09 (0-93)	18.62 (0-113)	8.78 (0-42)	7.19 (0-31)	2.72 (0-16)	1.26 (0-16)	0.10 (0-2)	2.57 (0-17)	12.17 (0-87)	12.04 (0-91)	14.32 (0-37)	29.88 (0-85)	134.74
1987[b]	16.4	16.2	10.1	Trace	5.3	1.0	Trace	0	39.1	19.4	37.6	53.3	198.4
1988[b]	57.1	41.5	15.10	0	6.1	0.6	0.7	0	0	18.3	98.9	0	238.34

[a] Dijon, R., 1964.
[b] Meteorological station at Guelmim.

Birds were not numerous on the study area; only 36 species were observed (Table 13). Thekla Larks and Wheatears were common and widely distributed. The Little Owl was often seen and occurred throughout the study area. Mammals also were sparse on the study area (Table 14). Larger mammals and hares were only occasionally seen, but ground squirrels were frequently observed. Rodents were present in open, bare country, but they were seldom seen or caught in the extensive stands of brush. A viper (*Cerastes* sp.) was present, but it was not commonly seen during the study. A listing of arthropods seen or caught shows some of the different kinds that were present (Table 15). Beetles were common and were observed almost everywhere. Ants were commonly seen also.

Experimental Design

Nine experimental plots, each 1.5 by 2.0 km (3 km^2), were established in the study area (Fig. 5). Plots receiving insecticide treatments were located at least 700 m from all other plots to help prevent contamination by drift. A central 0.5- by 1.0-km area in the center of each plot was laid out for obtaining biological data (Fig. 6). Large plots and wide buffer zones within plots were necessary to ensure animals studied were exposed to insecticides applied to plots.

The study area was large and features were not homogenous among all nine plots. However, the topography and vegetation was locally more similar, which was the basis for grouping plots into three blocks (A, B, and C) of three plots each (Fig. 5). The three plots in each block were randomly assigned one of the three treatments (malathion, control, and dichlorvos). Workers on each team were assigned to specific blocks; thus, any differences in their capabilities were restricted to their block of three plots. This approach confined differences in plot characteristics and worker abilities to blocks and facilitated use of a randomized block design in data analyses.

Schedules for data collection varied among teams, but all teams collected data several times before and after treatments. Data analyses involved testing for differences among the three treatments, among the times that data were collected, and most importantly, for the interaction of treatment and time (changes over time related to specific treatments). The analysis of variance (ANOVA) model shown was used for testing most bird, mammal, and insect data, and a diagrammatic description of treatment averages (e.g., all malathion values, regardless of time), time averages (e.g., all period 1 values, regardless of treatments), and treatment x time averages (e.g., each individual value for X).

ANOVA Source of variation
Treatment
Time
Treatment x Time
Block
Block x Treatment
Block x Time
Block x Treatment x Time

		Treatments		
		Malathion	Control	DDVP
Time	1	x	x	x
	2	x	x	x
	3	x	x	x
	4[a]	x	x	x
	5	x	x	x
	6	x	x	x

[a] Insecticides applied to plots

Table 13. Birds observed on study area.[a]

Scientific name	English name	French name
ACCIPITRIDAE		
Buteo rufinus	Long-legged Buzzard	Buse Feroce
Circus aeruginosus	Marsh Harrier	Busard des Roseaux
ALAUDIDAE		
Calandrella cinerea	Red-capped Lark	Alouette Calandre
Galerida theklae	Thekla Lark	Cochevis de Thekla
ALCEDINIDAE		
Upupa epops	Hoopoe	Huppe Fasciée
APODIDAE		
Apus apus	Swift	Martinet Noir
CORVIDAE		
Pica pica	Magpie	Pie Bavarde
EMBERIZIDAE		
Emberiza cia	Rock Bunting	Bruant Fou
Emberiza striolata	House Bunting	Bruant Striolé
FALCONIDAE		
Falco pelegrinoides	Barbary Falcon	Faucon de Barbarie
Falco tinnunculus	Kestrel	Faucon Crécerelle
FRINGILLIDAE		
Carduelis carduelis	Goldfinch	Chardonneret
HIRUNDINIDAE		
Hirundo rustica	Swallow	Hirondelle de Cheminée
LANIIDAE		
Lanius excubitor	Great Grey Shrike	Pie-grièche Grise
Tchagra senegala	Black-headed Bush Shrike	Tchagra à Tête Noire
MOTACILLIDAE		
Motacilla alba	White Wagtail	Bergeronnette Grise
Anthus campestris	Tawny Pipit	Pipit Rousseline
MUSCICAPIDAE		
Ficedula hypoleuca	Pied Flycatcher	Gobemouche Noir
PARIDAE		
Parus major	Great Tit	Mesange Charbonnière
PHASIANIDAE		
Alectoris barbara	Barbary Partridge	Perdrix Gamba
Coturnix coturnix	Quail	Caille des Blés
BURHINIDAE		
Burhinus oedicnemus	Stone Curlew	Oedicnème Criard
STRIGIDAE		
Athene noctua	Little Owl	Chouette Chevêche
SYLVIIDAE		
Cettia cetti	Cetti's Warbler	Bouscarle de Cetti
Phylloscopus collybita	Chiff Chaff	Pouillot Véloce
Sylvia conspicillata	Spectacled Warbler	Fauvette à Lunettes
Sylvia melanocephala	Sardinian Warbler	Fauvette Melanocephale
Scotocerca inquieta	Scrub Warbler	Dromoïque deu Sahara
TURDIDAE		
Erithacus rubecula	Robin	Rouge Gorge
Oenanthe deserti	Desert Wheatear	Traquet du Désert
Oenanthe leucura	Black Wheatear	Traquet Noir
Oenanthe moesta	Red-rumped Wheatear	Traquet à Tête Grise
Phoenicurus moussieri	Moussier's Redstart	Rubiette de Moussier
Saxicola rubetra	Whinchat	Traquet Tarier
Saxicola torquata	Stonechat	Traquet Pâtre
Turdus torquatus	Ring Ouzel	Merle à Plastron

[a] Nomenclature follows Cramp (1989).

Table 14. Wild mammals seen or caught on the study area.[a]

Order	Common name	Scientific name	Captured (c) or sighted (s)
Insectivora	Shrew	*Crocidura* sp.	c
	Elephant shrew	*Elephantulus rozeti*	c
	Algerian hedgehog	*Erinaceus algirus*	c
Lagomorpha	Brown hare	*Lepus capensis*	s
Rodentia	Barbary ground squirrel	*Atlantoxerus getulus*	c
	Garden dormouse	*Eliomys quercinus*	c
	North African gerbil	*Gerbillus campestris*	c
	Shaw's jird	*Meriones shawi*	c
	Libyan jird	*Meriones libycus*	c
	Fat sand rat	*Psammomys obesus*	c
	Barbary striped mouse	*Lemniscomys barbarus*	s
	Lesser Egyptian jerboa	*Jaculus jaculus*	
Carnivora	Jackal	*Canis aureus*	s
	Red fox	*Vulpes vulpes*	s
	African wild cat	*Felis libyca*	s
Artiodactyla	Wild boar	*Sus scrofa*	s
	Gazelle	*Gazella* sp.	s

[a] Nomenclature follows Aulagnier and Thevenot (1986).

Table 15. Common classes, orders, and families of arthropods on the study area.

CLASS INSECTA	
Orders	Families
Orthoptera	Acrididae Pamphagidae
Lepidoptera	Pieridae Lycaenidae
Diptera	Asilidae Sarcophagidae Bombyliidae
Coleoptera	Tenebrionidae Carabidae Scarabaeidae
Hymenoptera	Apidae Formicidae
CLASS ARACHNIDA	

The effects of interest (treatment, time, or treatment x time) were tested using their block interaction as the denominator for the F-tests. For example, the effect of primary interest, treatment x time interaction, was tested using block x treatment x 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 only on three plots in one block. These data were analyzed using a two-factor repeated measures, ANOVA, where time was the repeated measure, and hives within a treatment were a random effect. Cholinesterase data also were not collected in a randomized block design. A one-way ANOVA was used because animals were collected by categories of pretreatment and posttreatment for each of the three treatments.

TREATMENTS AND INITIAL MORTALITY

Treatments

Insecticides were aerially applied by a Lama helicopter equipped with an AIRBI spray system. The helicopter flew at an air speed of 100 km/hr and applied swaths 30 m in width perpendicular to the wind direction.

Insecticides were applied to plots at rates used for locust control in Morocco. Malathion was sprayed at a rate of 750 g/ha of active ingredient. 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/ha of active ingredient. A formulation containing 20 percent dichlorvos and 80 percent solvent (HAN) was applied at a volume of 1 L/ha and a rate of 5 L/min (5 ha/min). Plots were 3 km^2 or 300 ha in size. Conditions on plots during treatments are shown in Table 16.

Some assessments of treatment efficiency and deposits of insecticides on plots were obtained (Table 17). Only malathion applications to plots 1 and 7 were acceptable. However, deposits on plot 1 may have been reduced by thermal movement and evaporation. None of the dichlorvos treatments was acceptable. For an acceptable treatment, 20 or more droplets per cm^2 should reach the ground; on the dichlorvos plots between 0 and 6 droplets per cm^2 were deposited.

Initial Mortality

The sampling area (central 0.5 by 1.0 km) of all six treated plots were searched for dead animals the day after insecticides were applied (dates of applications are given in Table 16). Identical searches were conducted on control plots (plots 3 and 6 on February 11; plot 8 on February 12).

Eight individuals walked about 40 m apart across the 500- by 1,000-m sampling area. Searching of the 50 ha required about 1 hour of time.

Table 16. Conditions during insecticide applications.

	Treatments and plots					
	Malathion			Dichlorvos		
Conditions	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 no.	5	--[a]	--	3	3	7
Temperature (°C)	19.0	25.0	--	23.2	23.0	20.0
Relative humidity (%)	47	--	--	39	30	67
Wind speed (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 available.

Table 17. Quantitative and qualitative assessment of spray deposits on experimental plots.

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

[a] Dash indicates no assessment is available.

No dead or debilitated birds, mammals, reptiles, or amphibians were found during searches on any plots. Two dead birds were found after treatments on the study area. One had been hit by an automobile; the other was found on plot 1 and cause of death was unknown--its cholinesterase level was normal. Study teams (residues, radiotelemetry, birds, mammals, insects, and bees) also spent considerable time on plots after treatments without finding evidence of vertebrate mortality.

Dead beetles were abundant on all treated plots. Most of these consisted of only exoskeleton remains, and were called "old dead." Many beetles were killed or debilitated by the insecticide treatments. Lifeless beetles were called "newly dead." Beetles that were active, but moved slowly, were called "debilitated." "Unaffected" beetles were those that moved rapidly when approached and were difficult to capture. A few other dead arthropods were found (Table 18).

Old dead beetles were found on all plots, which confirmed the ability of searchers to find beetles. However, abundant newly dead beetles were found only on malathion plots. Newly dead beetles were not expected on control plots, but their absence on dichlorvos plots suggests little of the insecticide reached the ground to affect beetles or other organisms.

Table 18. Arthropods found dead on plots the day after insecticide applications.[a]

Treatment	Plots	Beetles			Other dead arthropods[c]
		Old dead	Newly dead	Debilitated	
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
DDVP					
	2	536	4	50	1
	5	263	1	39	1
	9	524	9	140	0

[a] No dead vertebrates were found.
[b] Dash indicates live beetles were present, but not debilitated.
[c] Includes ants, grasshoppers, wasps, and spiders.

RESIDUE STUDIES

Filter papers were exposed at spraying so that initial residues reaching the ground could be measured. Samples of formulations used to treat plots as well as insects found dead on plots were submitted for residue analysis. Samples of soil and vegetation were obtained from the six plots treated with insecticides 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 plots 5 and 9 could not be obtained.

Pretreatment samples were taken from all plots for analysis to ensure no extraneous residues were present. Larger rocks were removed from a sampling area at points 5, 8, and 11 (Fig. 5) on each plot from which all future soil samples were taken. About 100 g of soil were collected in a glass jar from each point during each period. Vegetation was clipped from the tops of scattered *Lycium intricatum* plants near each point until about 100 g were collected in a paper bag. *Lycium* was one of the preferred forage plants for livestock in the area. Samples were labeled and taken on ice to freezers in Guelmim. Samples were later transported on ice to freezers in the Laboratoire Officiel d'analyses et de Recherches Chimiques in Casablanca and held for analysis. Samples were extracted with acetone and analyzed by gas-liquid chromatography on Varian 3400 gas chromatographs equipped with thermionic specific detectors. All soil and vegetation samples had been analyzed by April 28, 1992, but no data on insects, filter paper, and formulation residues had been received by July 1, 1992.

Pretreatment samples of soil and plants from plots did not contain any residues of insecticides or other materials that interfered with analyses for insecticides. On plots treated with malathion, initial residues in soil were quite variable, with plot averages ranging from 2.8 to 30.2 ppm of malathion (Table 19). The highest, 30.2 ppm, is close to the level expected from an application of 750 g/ha. Residues in soil decreased rapidly and were less than one-fifth to one-tenth as high after 6 or 7 days. Malathion residues found in vegetation were unrealistically low (Table 20). Either storage conditions permitted rapid degradation of malathion or residues were destroyed during analyses.

Only trace amounts of dichlorvos were found in soil samples from plots treated with dichlorvos (Table 21 and 22). As no measurable amounts of dichlorvos were found on treated pots, either treatments were inadequate, residues metabolized very rapidly, or residues were destroyed during analyses. Chemists conducted tests to determine their ability to recover malathion and dichlorvos from soil samples. In the laboratory they fortified three samples of study-area soil with 4.1 ppm malathion and three samples with 4.1 ppm dichlorvos. The average recovery from soil was 87.3 percent for malathion and 85.1 percent for dichlorvos. While in camp, chemists fortified the same number of soil samples with the same amounts of malathion and dichlorvos. After transporting samples to the laboratory, chemists recovered an average of 82.0 percent of malathion from samples, but they were unable to detect any dichlorvos in the fortified soil

Table 19. Malathion residues (ppm) in soil from study plots treated with malathion.[a]

Plots	Pre-treatment	Days posttreatment			
		1	2	6	7
1	ND	4.8 (1.1)	4.3 (1.4)	---	0.5 (0.1)
4	ND	2.8 (0.3)	1.7 (0.2)	0.3 (0.2)	---
7	ND	30.2 (12.6)	16.4 (4.3)	---	4.6 (0.4)

[a] Data are $\bar{x}\pm$(SE) for three observations. ND indicates no residues were detected. T indicates trace amounts were present. Dash means no sample was collected.

Table 20. Malathion residues (ppm) in vegetation (*Lycium intricatum*) from study plots treated with malathion.[a]

Plots	Pre-treatment	Day posttreatment			
		1	2	6	7
1	ND	0.1 (0.1)	T	---	T
4	ND	ND	ND	ND	---
7	ND	ND	ND	---	ND

[a] Data are $\bar{x}\pm$(SE) for three observations. ND indicates no residues were detected. T indicates trace amounts were present. Dash means no sample was collected.

Table 21. Dichlorvos and malathion residues (ppm) in soil from study plots treated with dichlorvos.[a]

Plots	Residues	Pretreatment	Days posttreatment			
			0	1	2	7
2	Dichlorvos	ND	-	T	T	ND
	Malathion	ND	-	0.5 (0.3)	0.2 (0.0)	0.02 (0.01)
5	Dichlorvos	ND	-	T	T	-
	Malathion	ND	-	ND	ND	-
9	Dichlorvos	ND	T	T	T	-
	Malathion	ND	ND	ND	ND	-

[a] Data are $\bar{x}\pm(SE)$ for three observations. ND indicates no residues were detected. T indicates trace amounts were present. Dash means no sample was collected.

Table 22. Dichlorvos and malathion residues (ppm) in vegetation (*Lycium intricatum*) from study plots treated with dichlorvos.[a]

Plots	Residues	Pretreatment	Days posttreatment			
			0	1	2	7
2	Dichlorvos	ND	-	ND	ND	ND
	Malathion	ND	-	T	T	ND
5	Dichlorvos	ND	-	T	ND	-
	Malathion	ND	-	ND	ND	-
9	Dichlorvos	ND	T	ND	ND	-
	Malathion	ND	T	ND	ND	-

[a] Data are $\bar{x}\pm$(SE) for three observations. ND indicates no residues were detected. T indicates trace amounts were present. Dash means no sample was collected.

samples. Results showed that chemists could measure malathion and dichlorvos in soil if samples contained residues. Dichlorvos put in soil samples in camp apparently degraded before analysis. Dichlorvos samples collected on plots, if actually contaminated by spray application, may have lost that contamination during storage and transport. No recovery tests were conducted for vegetation.

Both trace amounts of dichlorvos and low levels of malathion were found in soil and vegetation from plot 2 after the dichlorvos application on February 13 (Tables 21 and 22). The presence of malathion residues could have been due to drift. After plot 1 was sprayed with malathion on February 10, debilitated beetles were found south of there on both plots 2 and 3 (Fig. 4). Malathion may have drifted more than 3 km in amounts sufficient to affect beetles and contaminated soil and vegetation. First residue samples from plot 2 were collected 4 days later and contained 0.5 ppm of malathion in soil and trace amounts in vegetation.

Initial residues of malathion and dichlorvos in soil and vegetation were not high enough to pose hazards to vertebrate animals. They rapidly degraded; traces of dichlorvos found in initial samples had disappeared in several days, and the less hazardous residues of malathion probably had disappeared within several weeks.

CHOLINESTERASE STUDIES

Selected species of birds and rodents were collected from the study area to determine if changes in brain cholinesterase levels occurred due to treatments. Before insecticide applications, animals were obtained at the edges or outside of experimental plots. Following treatment of plots, most animals were taken within the buffer area of plots; a few of the owls collected were taken from within the central sampling area of plots after treatments.

Thekla Larks, Red-rumped Wheatears, and Little Owls were selected for study of cholinesterase effects. These species were insectivorous, relatively abundant, and widely distributed. Likewise, the fat sand rat and the two species of jirds were used to follow brain cholinesterase levels in mammals. Animals were dissected of vertebrates and brains were removed, placed in labeled vials, and stored in liquid nitrogen. Gizzards of birds and stomachs of mammals were removed and stored in labeled vials filled with alcohol (see Food Habit Studies of Vertebrates).

Animal brains were transferred from liquid nitrogen into a freezer at the Centre National de Lutte Antiacridienne in Aït Melloúl where analyses were conducted. Brains were in storage for up to 2 months, depending on when they were collected and when they were analyzed. Samples were randomly selected for analysis over time, rather than by species or by the schedule of their collection. Analyses of brains for cholinesterase followed methods of Hill and Fleming (1982).

Cholinesterase activity measured in brains of birds and mammals is given in Tables 23 and 24 respectively. There were no biologically significant changes in cholinesterase activity due to treatments in either birds or mammals. A 20 percent depression is an indication of substantial exposure to organophosphate insecticides, while a 50 percent inhibition can be related to debility and mortality (Hill and Fleming 1982).

The largest depression measured was 18 percent in Thekla Larks from malathion plots. This decrease was the only change that was statistically significant, but biologically it only suggested that the larks from malathion plots had been moderately exposed to the insecticide.

Table 23. Cholinesterase levels (μmoles/min/g) in brain tissue of selected birds before and after insecticide treatments.[a]

Treatments	*Galerida theklae*	*Oenanthe moesta*	*Athene noctua*
Pretreatment	17.6 (0.9)	16.7 (0.9)	-
Posttreatment			
Control plots	15.8 (1.0)	14.0 (1.1)	12.2 (2.1)
Malathion plots	14.4[b](0.3)	14.6 (1.4)	13.9 (1.1)
DDVP plots	15.2 (1.1)	16.4 (0.9)	14.0 (0.7)

[a] Data are $\bar{x}\pm$(SE). Dash indicates no samples were collected.
[b] Cholinesterase levels in *Galerida theklae* brains from malathion-treated plots were significantly different ($P < 0.05$) than pretreatment levels.

Table 24. Cholinesterase levels (μmole/min/g) in brain tissue of selected rodents before and after insecticide treatments.[a]

Treatments	*Psammomys obesus*	*Meriones spp*[b]
Pretreatment	8.3 (0.9)	6.0 (0.6)
Posttreatment		
Control plots	9.5 (0.7)	8.1 (0.8)
Malathion plots	9.4 (0.7)	7.1 (0.3)
DDVP plots	9.4 (0.7)	7.8 (1.1)

[a] Data are $\bar{x}\pm$(SE).
[b] Includes both *M. shawi* and *M. libycus*.

BIRD STUDIES

Characteristics of Common Species

Galerida theklae (17 cm; wing-span 28-32 cm) was the most common species on the study area. It was susceptible to insecticide treatments because it eats some insects, forages in open country, rests on the ground, and feeds its young insects. *G. theklae* requires ample dry bare soil with rocks and boulders, as well as shrub cover and trees. Most food is taken from the ground, often by searching the understory. It consists of insects as *Orthoptera*, *Dermaptera*, *Hemiptera*, *Coleoptera*, *Hymenoptera*, *Diptera*, and also *Mollsuca*. Plant foods consists of the seeds of *Chenopodium*, *Spergula*, *Erodium*, *Linaria*, *Centaurea*, grasses (*Gramineae*) and cereal grains. Food of young includes larger insects and larvae. In Morocco eggs are laid in mid-February to late May. The nest site is on the ground. The 3-5 eggs are sub-elliptical, smooth, and glossy. The fledging period requires 15 days; young live in nests for 9 days and spend the next 6 days in surrounding cover.

Oenanthe moesta (16 cm; wing-span 25-29 cm) was perhaps even more susceptible to insecticide poisoning than *G. theklae*. It uses more open country and eats primarily insects. This species frequents flat, open ground, often in the vicinity of saline and barren areas, but not absolute desert. It is mainly sedentary, although there is some evidence of partial migration and local movements. The food includes beetles (*Coleoptera*), grasshoppers (*Ascrididae*), larval *Lepidoptera*, and ants (*Formicidae*). The prey usually are caught on the ground but also by perching higher (e.g. on top of bush) and pouncing at items on the ground. The breeding season is prolonged, with eggs laid from the first week of February until June. The nest is built up to 2 m deep in a hole in the ground, usually one made by rodents. The entrance may be concealed under a bush or root. The nest is constructed of leaves and lined with wool, hair, and feathers. Nest building and incubation are performed by the female. The number of eggs is 4-5. They are sub-elliptical, smooth, and slightly glossy. The young are cared for and fed by both parents.

Phoenicurus moussieri (12 cm; wing-span 18.5-20.5 cm) was common on the study area. It lives in the lower middle latitudes in warm, dry Mediterranean climate. In Morocco it is found up to 3,000 m in the High Atlas and is common in the east. It occurs on dry grassy, stony, or rocky slopes and in old or degraded forests in broken terrain. The species takes insects on the ground, essentially small ants, beetles, grasshoppers, and larvae. It also makes brief flights in pursuit of flying prey. The breeding season in Morocco is from mid-March to mid-June. The nest is built on the ground, under a tussock or low bush, but also in holes in trees or walls. It consists of vegetation, lined with feathers and hair. The eggs, which are subelliptical, smooth, and glossy, usually number 4. The young are cared for and fed by both sexes.

Bird Counts

Counts of birds, by species, were taken six times on each of the experimental plots (Table 25). Counts were made at and between 15 points on each plot (Fig. 5), usually between 0800 and 1300. At each point, birds seen within and beyond 50 m were tallied separately during a 5-minute period. Birds observed between points also were recorded. Each of 3 observers were assigned to a block of 3 plots and obtained all counts on those plots. Counts provided indices to the relative abundance of birds on the 9 plots before and after treatments with insecticides.

Table 25. Schedule of bird counts on experimental plots.

Periods	Dates	Treatments	Observers and Plots		
			Aloui	Addami	El Hani
	Jan 24	Malathion	1	4	7
1	Jan 25	Control	3	6	8
	Jan 26	DDVP	2	5	9
	Jan 27	Malathion	1	4	7
2	Jan 28	Control	3	6	8
	Jan 29	DDVP	2	5	9
	Jan 31	Malathion	1[a]	4	7
3	Feb 1	Control	3	6	8
	Feb 2	DDVP	2	5	9
	Feb 13	Malathion	1	4	7
4	Feb 14	Control	3	6	8
	Feb 15	DDVP	2	5	9
	Feb 16	Malathion	1	4	7
5	Feb 17	Control	3	6	8
	Feb 18	DDVP	2	5	(7)[b]
	Feb 19	Malathion	1	4	(9)
6	Feb 20	Control	3	6	8
	Feb 21	DDVP	2	5	9

[a] Underline shows last pretreatment counts.
[b] Order of counts on plots 7 and 9 was changed. Plot 9 was sprayed with DDVP on February 18, and birds could not be counted that day.

Of the 35 different species identified on study plots (Table 26), 21 were resident species and 14 were migrants; at the time of counts, early migrants had begun their northward movements. Only five species of birds were present on every plot, and *G. theklae* and *P. moussieri* were relatively abundant. *H. rustica* was migrating and was only seen flying over plots. Two species, *S. rubertra* and *S. torquata*, occurred in greatest numbers on plots 4, 5, and 6 (Block B), while the fewest *O. moesta* were present on those plots. The abundance of *S. melanocephala* was much higher on plot 1 (84) than on other plots (1-21). Reasons for variations in species abundance among plots probably were related to differences in vegetation and habitats.

Birds were tallied by numbers seen within 50 m of sampling points and also by totals seen at sampling points (both < 50 m and > 50 m) and between sampling points. The sums of all birds seen were higher, of course, than numbers seen only within 50 m of sampling stations. However, observers felt counts of birds within 50 m were more precise. Birds beyond 50 m could not as readily be seen and identified, while those between stations often may have previously been counted. Therefore, only bird numbers seen within 50 m of stations are discussed.

Numbers of total birds recorded on plots by periods are given in Table 27. On plots 7, 6, 8, 2, 5, and 9, counts were lowest during period 3. Very strong easterly winds blew between January 31 and February 4 and may have been responsible for lower counts. Neither counts nor statistical analyses suggested effects of malathion or dichlorvos treatments on the total number of birds present on plots.

G. theklae was the most abundant species seen on all plots. Numbers varied between plots and periods (Table 28). Counts on plot 4 (period 4) and plot 6 (period 3) were lower than usual, but the cause is not known. Likewise, the early counts on plots 7 and 5 are lower, and those on plot 2 are higher than later counts. No consistent trends are evident due either to time or treatment and statistical analyses did not suggest any differences existed.

P. moussieri counts tended to decrease on all plots over time (Table 29). Total numbers decreased 62, 54, and 37 percent after treatments on dichlorvos, control, and malathion plots respectively. Although an ANOVA indicated that numbers on dichlorvos plots after treatments had significantly ($p = 0.05$) decreased, *P. moussieri* abundance probably decreased over time throughout the study area, regardless of insecticide applications.

Three other species were common and occurred on most plots--*O. moesta*, *S. melanocephala*, and *S. torquata*. However, their numbers varied too greatly among plots and over time to permit meaningful analyses.

Breeding Observations

It was planned to observe the breeding behavior of selected species before and after spray. Insecticide sprays can directly kill birds. They also can kill insects used as a food source for nestlings, which can result in nest abandonment. However, birds did not come into breeding conditions until the postspray observation period, and no information on indirect effects was obtained.

Table 26. Relative abundance of bird species among the nine plots.[a]

Species	Status[b]	Plots									
		1	2	3	4	5	6	7	8	9	Total
Buteo rufinus	R		1		1			1			3
Circus aeruginosus	M				2						2
Calandrella cinerea	M			3				3	3	10	19
Galerida theklae	R	115	88	85	77	57	92	81	81	84	760
Upupa epops	M	2	3		3		1				9
Apus apus	M		1	3							4
Pica pica	R						3				3
Emberiza cia	R	2	4	3	5	4	1				19
Emberiza striolata	R	3		1							4
Falco pelegrinoides	R						1				1
Falco tinnunculus	R	5			7	6	1			1	20
Falco sp.	-					2					2
Carduelis carduelis	R									2	2
Hirundo rustica	M	26	11	10	35	14	27	5	4	9	141
Lanius excubitor	R		6	3	5	3	1				18
Tchagra senegala	R					1					1
Motacilla alba	M	4	6	3		2		1		1	17
Anthus campestris	M	1						1	1	1	4
Ficedula hypoleuca	M				1						1
Parus major	R									1	1
Alectoris barbara	R	1	2		4	4	1	2			14
Coturnix coturnix	M	1									1
Burhinus oedicnemus	R			1	2					1	4
Athene noctua	M	1	1	3		2	2	6	4	1	20
Cettia cetti	M				1						1
Phylloscopus collybita	M		3			1					4
Sylvia conspicillata	R		1					12	9	7	29
Sylvia melanocephala	R	84	19	1	21	13	8	2	5	3	156
Scotocerca inquieta	R	1	2	4	1		5				13
Erithacus rubecula	M									1	1
Oenanthe deserti	R								12		12
Oenanthe leucura	M	3	7	14			3	9	14	18	68
Oenanthe moesta	R	8	11	16	1	1		46	22	42	147
Phoenicurus moussieri	R	26	20	19	26	15	31	27	28	21	213
Saxicola rubertra	M	1	1	1	7	2	9				21
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	1822
Total number of species		18	19	17	18	16	16	14	12	17	36

[a] Total number of birds seen at and between sampling points during one pretreatment and two posttreatment counts.
[b] Status is either migrant (M) or resident (R).

Table 27. Total number of birds seen on each plot during each period.[a]

Periods[b]	Treatments and Plots								
	Malathion			Control			DDVP		
	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[c]	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] Includes only birds seen within 50 m of sampling points.
[b] See Table 25.
[c] Underline shows last pretreatment count.

Table 28. Total number of *G. theklae* seen on each plot during each period.[a]

Periods[b]	Treatments and plots								
	Malathion			Control			DDVP		
	1	4	7	3	6	8	2	5	9
1	38	12	9	26	12	15	72	4	25
2	30	11	14	31	19	19	64	6	22
3	37[c]	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

[a] Includes only birds seen within 50 m of sampling points.
[b] See Table 25.
[c] Underline shows last pretreatment count.

Table 29. Total number of *P. moussieri* seen on each plot during each period.[a]

Periods[b]	Treatments and plots								
	Malathion			Control			DDVP		
	1	4	7	3	6	8	2	5	9
1	4	2	3	9	4	7	5	2	2
2	1	5	3	6	3	4	6	0	3
3	5[c]	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] Includes only birds seen within 50 m of sampling points.
[b] See Table 25.
[c] Underline shows last pretreatment count.

With the exception of *O. moesta* and *S. melanocephala*, no birds exhibited any signs of breeding behavior during the prespray observation period. *O. moesta* were paired, territorial, and were seen entering holes in the ground. *S. melanocephala* were observed building nests. During the postspray period, larks and wheatears began breeding displays which increased towards the end of the study. Four lark nests were found, but only one had eggs. The two eggs in this nest hatched sometime between February 14 and 16. On February 18, the young were missing, presumably taken by predators. On February 15, one fledgling lark stayed next to three adult larks captured in mist nets on plot 7. Several wheatears also were seen entering holes with nest building materials. No conclusions can be drawn about the impact of the spray on breeding success from such incidental observations.

Collections for Brain Cholinesterase and Food Habits Analysis

G. theklae, *O. moesta*, and *A. noctua* were collected before and after sprays for cholinesterase and food habit analysis (Table 30). These species were selected since they were present on most plots, appeared to be sedentary, ate insects, and were fairly easy to catch. Several collecting techniques were used, including mist nets, rat and balchatri traps, and guns with birdshot. All birds collected were given to the cholinesterase team for processing of brains and gizzards. Most birds were collected at least 100 m outside of the bird sample area, but within the 0.5-km buffer zone of the plot. Some wheatears were caught in rat traps within the bird sample area by the mammal team.

Larks were baited to mist nets with a mixture of poultry scratch feed, wheat, and barley. All larks captured in nets were removed alive within an hour of capture. Because of time constraints, shooting was used to collect all owls and also larks from the dichlorvos plots. An attempt was made during postspray to collect birds from each of at least two plots treated with malathion or dichlorvos within 1-5 days of treatments.

In addition, a few birds and owl pellets were collected from the study area during the week of January 20. These early collections were examined by entomologists to determine which nontarget insects might be of greatest importance to the birds.

Conclusions

Counts of birds within 50 m of sampling points on plots did not suggest changes either in numbers of total birds seen or in the abundance of any single species due to insecticide treatments. An ANOVA of count data indicated dichlorvos treatment effects on abundance of *P. moussieri*, but numbers actually were decreasing on all plots. The effects of insecticide treatments on avian reproduction could not be evaluated, as treatments were made before the main reproductive period of species present in the study area.

Table 30. Birds collected for brain cholinesterase and food habits analysis.

Period and area	Species		
	G. theklae	*O. moesta*	*A. noctua*[a]
Prespray			
Study area	16	10	--
Postspray			
Malathion plots	10	10	6
DDVP plots	11	11	5
Control plots	10	11	5

[a] Owls were collected by the radiotelemetry team.

RODENT STUDIES

Rodent Species

The study area contained a variety of small mammals, but only two genera were abundant enough to be studied. The Shaw's (*Meriones shawi*) and Libyan (*M. libycus*) jirds were common in certain areas as was the fat sand rat (*Psammomys obesus*). Barbary ground squirrels (*Atlantoxerus getulus*) were locally abundant in areas near man-made or natural rock walls. 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. Jirds were more common in low drainages, while fat sand rats were common above these drainages but below hilltops. Fat sand rats had bred prior to the study period, since many burrow systems had young and several trapped females were pregnant. Breeding was not as evident in jirds during the study. Both jirds and fat sand rats consumed vegetation, including *Salsola vermiculata* and *Salicornia fruiticosa*; however, fat sand rats generally fed almost exclusively on this vegetation, while jirds were more omnivorous. For this reason, traps used for catching fat sand rats were baited with small pieces of apple and local vegetation, while traps for jirds were baited with dates and pieces of apple.

Meriones shawi (Shaw's jird). This species is active in the night, but is commonly observed in the morning or late afternoon near its burrow. In open areas, burrows are found mainly near the base of trees or bushes. They feed on green parts, fruits, and seeds of plants and, like other Meriones, they are great hoarders. The importance of animal food in the diet of this species is not known, but the stomach may contain remains of insects such as beetles and ants.

Meriones libycus (Libyan jird). The distribution of this species is Saharan. In the Sahara, caches are scattered throughout the burrow system. In southern Tunisia, *Meriones libycus* usually does not move very far from its burrow. Like the Shaw's jird, this species feeds on and stores edible vegetation such as succulent plants found near burrows or on selected grains, cereals, or fruits. *M. libycus* is adapted to desert conditions and can survive on diets of only dry grains. The breeding biology of *M. libycus* is generally the same as *M. shawi*. In the laboratory, reproduction can be uninterrupted, with a gestation period of less than 24 days and about 5 litters a year, each with 2-7 young per litter.

Psammomys obesus (Fat sand rat). The fat sand rat is mainly diurnal and lives in sandy areas. Its burrows have several entrances and include food storage chambers and a nest chamber lined with finely cut vegetation. The preferred food of the fat sand rat is the leaves and stems of succulent plants of the family Chenopodiaceae, which contain a high proportion of water and salt. Laboratory studies indicate yearlong breeding with a gestation period of about 25 days and a litter size of about 2-5 young.

Atlantoxerus getulus (Barbary ground squirrel). Endemic in North Africa, the barbary ground squirrel is particularly abundant in Morocco. This species is diurnal and colonial and prefers rocky habitats. It usually remains on the ground, even though it is a good climber and lives in burrows or rocks. It feeds on cereals and fruits of olive and pistachio trees, but prefers the fruit of the argan tree.

Trapping

The relative activity of rodents was evaluated using both live trapping and the closed-burrow technique. Live trapping involved two kinds of live traps--Sherman box traps for small rodents (< 50 g) and Tomahawk traps for larger (> 50 g) rodents. Trapping sites were selected in each plot where animals appeared to be the most abundant. Along trap lines, points were marked about 5-20 m apart where 3-4 traps were set within a 5-m circle. Usually two Tomahawk traps were set out for each Sherman trap and totals of 50-65 traps were set in each plot. Trapping points were flagged with surveyor's tape tied to the tallest nearby vegetation. Traps were baited with dates, apple slices, or portions of local plants eaten by rodents. In habitats with ground squirrels, rolled oats and wheat were used as bait. Traps were set and then checked once in the morning and again in the afternoon for 3 consecutive days. All trapped rodents were ear-tagged, weighed, sexed, and released. Recaptures were identified and the point of capture or recapture was recorded. These procedures were repeated after plots were treated with insecticides. For comparison, the average captures per trap-night were compiled and analyzed using an ANOVA for a randomized block design.

Capture rates of small mammals were examined and compared before and after treatments. Very few animals were captured in Sherman box traps since few small rodents were present on study plots. Jirds readily entered Tomahawk traps, but fat sand rats and ground squirrels were more reluctant to do so. However, a sufficient number of rodents were captured in Tomahawk live

traps to enable an evaluation of treatment effects (Table 31). Before treatments the total number of rodents captured was higher in malathion (27) and dichlorvos (25) plots 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, the mean captures per trap night of Meriones were reduced on insecticide treated plots, while they increased on control plots, but again differences were not significant ($p = 0.17$).

Examination of trapping results on individual malathion and control plots suggests that total catch of rodents varied with malathion residues in soil (Fig. 7). The greatest decrease in catch occurred on plot 7 where highest residues (30.2 ppm) were found and where malathion deposits were greatest (26 droplets/cm^2). Plots with residues of 2.8 ppm or less malathion in soil had posttreatment catches that equaled or exceeded the pretreatment catch.

Rodent Activity

In each plot 4-15 burrow systems along a selected route at least 50 m from the trap line were marked, and all burrow openings were closed with small rocks and dirt. Marked burrow systems were checked 24 hours later and the number of closed holes that were reopened by rodents was recorded. The same burrow systems were used before and after treatment and the percent of reopened holes was compared an analyzed using a randomized block ANOVA.

After treatments the holes closed by workers were mostly active ones; the inactive holes had not been reopened by rodents during pretreatment assessments. Therefore, about one-half fewer holes in malathion and dichlorvos plots and about one-third fewer holes in control plots were closed after treatment than before treatment. This resulted in a higher percent of reopened holes in all plots after treatments.

The decrease in the number of holes that were reopened by rodents after malathion treatments indicated a possible treatment effect (Table 32). However, ANOVA did not support the conclusion that rodent activity was significantly altered by the application of malathion ($p = 0.27$).

Conclusions

The application of insecticides apparently had no real effects on the activity or relative abundance of either jirds or fat sand rats. Although rodent capture rates on treated plots were reduced after insecticide applications, the 26-23 percent reduction was not significant despite a 33 percent increase in capture rates on control plots. The percent of closed burrow openings reopened after 24 hours was also not significantly affected by the application of either insecticide.

Table 31. Mean number, by treatments, of new rodents captured in Tomahawk live traps.

Treatment	Period	Total trap nights	Total new captures	Mean captures/trap night			
				Total	*Meriones*	*Psammomys*	*Atlantoxerus*
Malathion	Pre	283	27	0.10	0.05	0.03	0.02
	Post	284	20	0.07	0.03	0.02	0.02
DDVP	Pre	357	25	0.07	0.06	0.01	0.01
	Post	348	17	0.05	0.03	0.00	0.02
Control	Pre	358	18	0.05	0.03	0.01	0.01
	Post	366	24	0.07	0.04	0.02	0.00

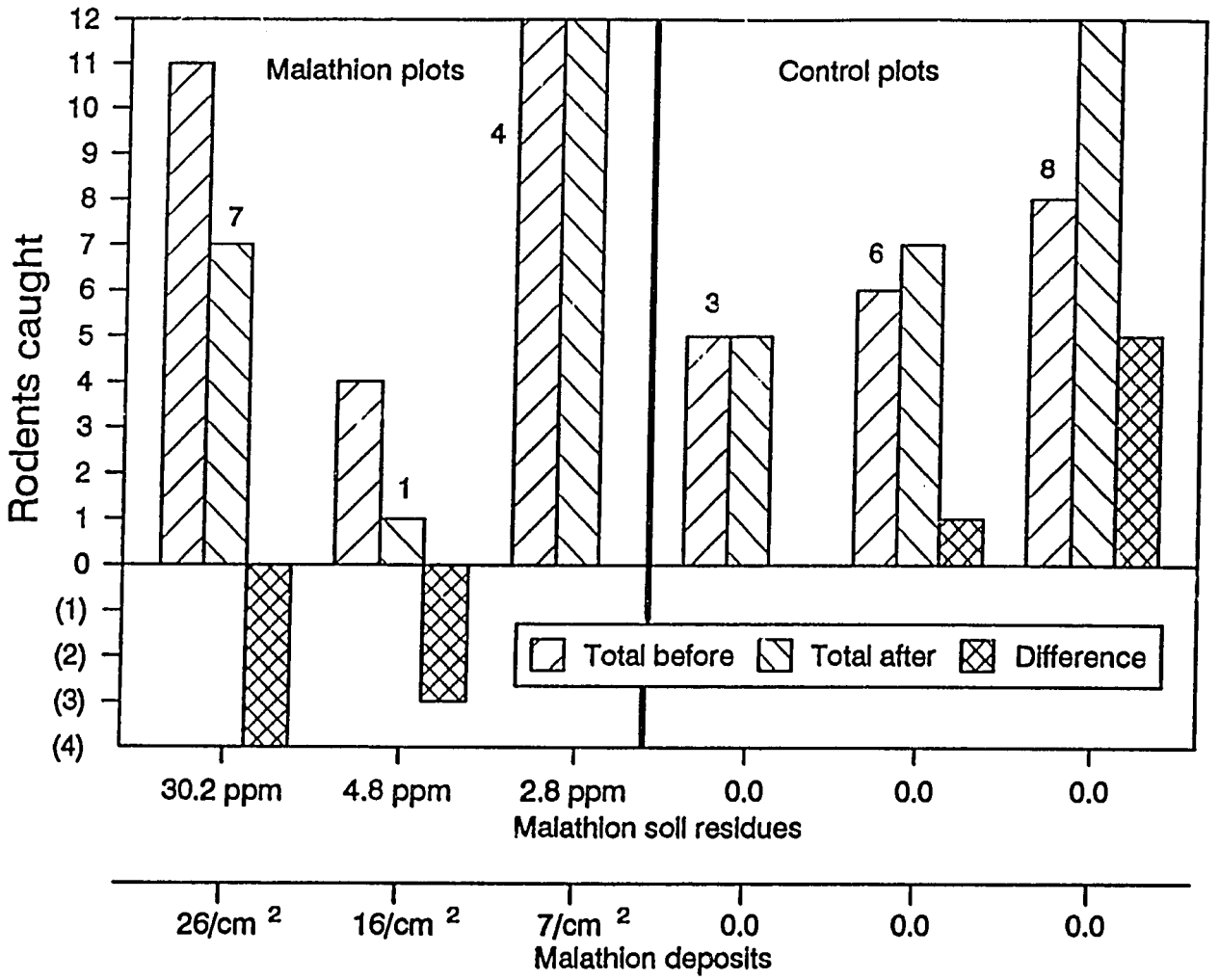


Fig. 7. Rodents caught on malathion and control plots before and after spraying in relation to measurements of malathion residues and deposits.

Table 32. Total number, by treatments, of closed burrow openings reopened within 24 hours by fat sand rats (*Psammomys obesus*) and jirds (*Meriones* spp.).

Treatment	Period	Date	Number of burrow systems	Number 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
DDVP	Pre	1/28-29	53	407	106	26.0
	Post	2/19-20	53	191	105	55.0
Control	Pre	1/30-2/1	40	304	100	32.9
	Post	2/16-17	40	217	106	48.8

RADIO TRACKING STUDIES

Methods

Fieldwork was conducted from January 21 to February 21, 1992. Prior to insecticide application, Thekla Larks, Little Owls, and Barbary ground squirrels were captured and equipped with radios so that their movements and mortality could be monitored before and after insecticides applications. Mist nets were used for capturing larks. Ground squirrels were captured in Tomahawk live traps. Owls were captured using balchatri, verbail, and Tomahawk traps, or by hand when a bird was recovered from a rockpile or burrow. Descriptive information on the transmitters used on each species is shown in Table 33. Transmitters were attached to birds by gluing them to the dorsal base of their tail feathers (Fitzner and Fitzner 1977, Linz et al. 1989). Radios were attached to ground squirrels by using a leather collar with prepunched holes to facilitate a custom fit. Radio-marked animals were located most days using a receiver and a hand-held, 3-element yagi antenna. Individual radio locations were recorded each day by referencing a compass bearing and an estimated distance to a known point such as a trap site or cairn marker (Fig. 6).

Results

A total of 62 animals were captured and radio-marked on experimental plots (Table 34). Marked animals were located 629 times during the 32-day study period. The total relocation for individual animals ranged from a minimum of 2 to a maximum of 28 (Table 35). Only fifty-nine percent (24 of 41) of the original radio-marked animals on the treatment plots had functioning radios at the time of spray application. Two of the 17 nonfunctioning radios were recovered after owls had their radios torn off by rocks or thorn bushes. In 5 cases we found tail feathers and radios from owls and larks on the ground and assumed that these either molted off or were loosened by snags and simply fell off. Eight radios that were attached to larks quit operating immediately prior to spray application and after they had functioned beyond their life expectancy of 19 days. Animals on the malathion and dichlorvos plots were monitored up to 20 and 28 days, respectively, prior to spraying. Postspray monitoring ranged from 9-11 days on the malathion plots and 3-8 days on the dichlorvos plots.

No radio-marked animals were found dead or debilitated on the treatment plots from insecticide poisoning. Neither were there any unusual movements by animals that could be related to insecticide treatments. Most radio-marked 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 <10 ha. An example of typical movements for a pair of owls is shown in Figure 8. Most ground squirrels remained close to their capture sites throughout the study period. However, 2 individuals (1 male and 1 female) had moved to an area over 500 m from their original capture location by the time fieldwork was concluded.

Table 33. Descriptive information on radio transmitters used on Little Owls, Thekla Larks, and Barbary Ground Squirrels in Morocco, January-February 1992.

Species	Transmitter type	Weight (g)	Life expectancy (days)
Little owl	tail-mount	4.5	60
Thekla lark	tail-mount	1.3	19
Barbary ground squirrel	collar	12	30

Table 34. Number and distribution of radio-marked animals on study plots.

	Control plots			Malathion plots			DDVP plots			
Species	3	6	8	1	4	7	2	5	9	Total
Little owl	1	3		5		1	4		2	16
Thekla lark			10	1		9			10	30
Barbary ground squirrel	7				5		3	1		16
Total		21			21			20		62

Table 35. Summary of radio-tracking data for three species monitored on the study plots.

Species	*n*	Tracking period	No. times located	
			Range	Mean
Little owl	16	1/21-2/21/92	2-28	18.3
Thekla lark	30	1/26-2/21/92	2-19	15.0
Barbary ground squirrels	16	1/25-2/21/92	2-19	15.0

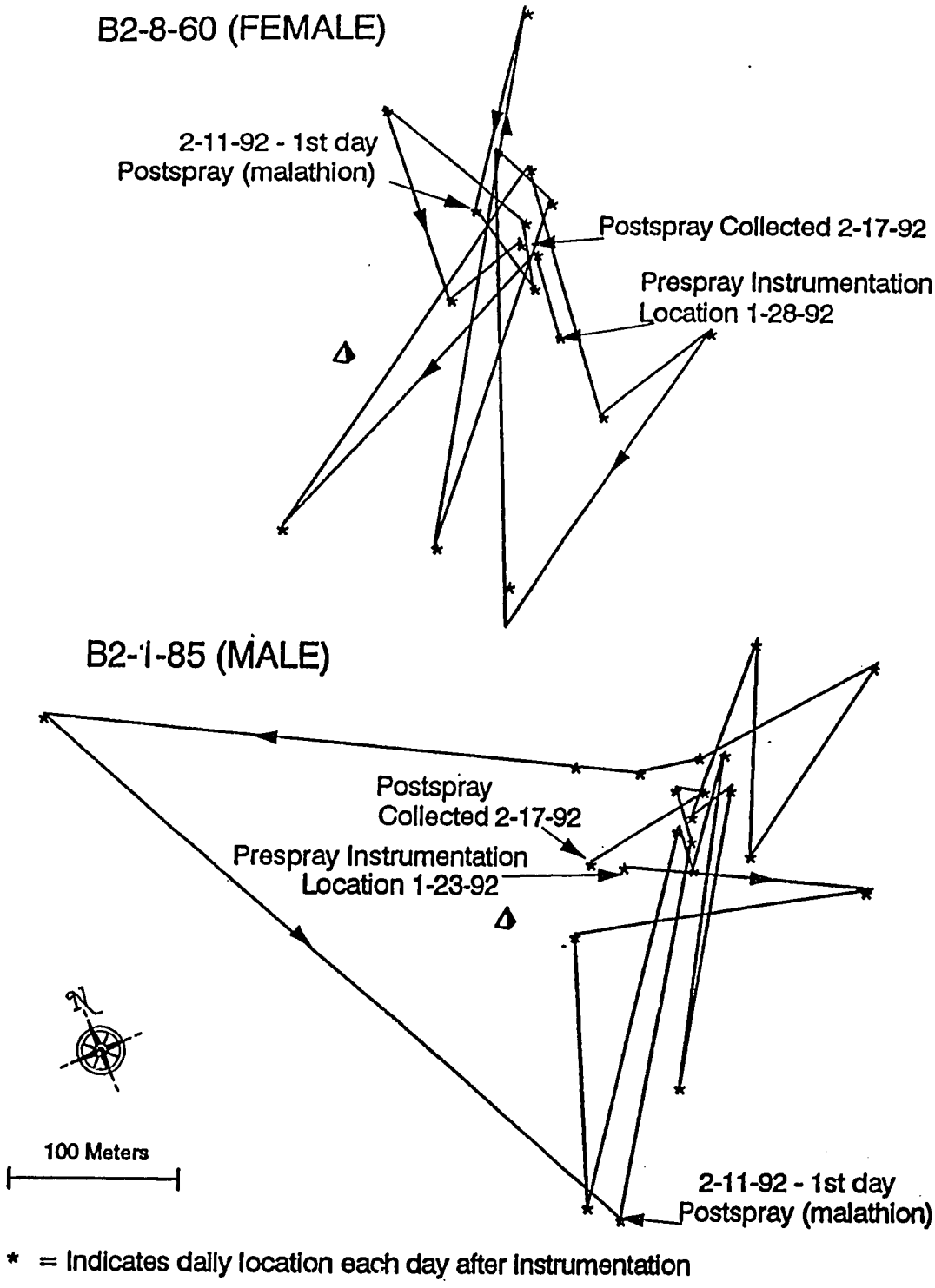


Fig. 8. Daily movements of Little Owls carrying radio transmitters on plot 1 before and after malathion application.

INSECT STUDIES

The ecological focus of insect studies was on insects important in bird and mammal diets and on beneficial insects, especially pollinators and the natural enemies of grasshoppers and locusts (Table 36). Grass-hoppers and locusts, the usual targets of the insecticides applied to plots, were not common during the study. Preliminary examination of a few mammal stomachs, bird gizzards and *Athene noctua* pellets was undertaken to gain information on the kinds of invertebrates of greatest importance as foods. Among mammals, *Psammomys obesus* ate only plants; *Atlantoxerus getulus* ate plants and a few ants and beetles. The birds sampled were primarily insectivorous. Gizzards of *Oenanthe moesta*, *Phoenicurus moussieri*, and *Galerida theklae* contained mostly ants and beetles, with some grit and a little plant matter. Owls were eating beetles, earwigs, grasshoppers, spiders, snails, and an occasional mammal.

Pilot population sampling tested various methods and indicated which insect groups of interest might be observable in adequate numbers on all plots. Sampling concentrated on insects that were numerous, large enough to be recognized without magnification, easily seen or trapped in the field, and of special ecological interest. Entomologists made reference collections of insects, mostly containing specimens caught during population sampling activities. Four reference collections were prepared, one each for the Plant Protection Service, Rabat; the Centre National de Lutte Antiacridienne, Aït Melloúl; the Inspectorate of Plant Protection, Agadir; and the Inspectorate of Plant Protection, Laayoune.

A separate master collection emphasizing the insect groups chosen for population sampling was assembled for identification purposes. Members of the families Tenebrionidae and Carabidae (Coleoptera) and Asilidae and Bombyliidae (Diptera) were assigned individual species numbers by which they were distinguished in pitfall and/or transect counts. Specimens were sent to specialists for identification to species level where possible. Identifications completed by June 15 are listed in Table 37. Most identified specimens are being returned to Dr. Ghaout of Direction de la Protection des Végétaux, des Controles Techniques, et de la Repression des Fraudes (DPVCTRF).

The approach taken in insect sampling was to measure numbers and activity of bees and other insects before and after insecticide applications to plots. Mortality and activity of bees was recorded on three plots by three bee experts (Table 38). Entomologists used pitfall traps and transects counts to obtain indices to the abundance of selected insects and used the presence of ants at sugar cubes to monitor activity (Fig. 9). Entomologists noted mortality of insects when they entered plots to collect data after insecticide treatments.

Table 36. Ecological significance of groups and methods used to assess insecticide effects.

Group	Significance	Method
Grasshoppers (Orthoptera)		
Acrididae	Target of insecticides	Transect counts
Spiders (Arachnida)	General predators	Pitfall trap
Beetles (Coleoptera)		
Tenebrionidae	Larvae of some species eat acridid eggs; owl food	Pitfall trap, transect counts
Scarabaeidae	Owl food	Transect counts
Carabidae	General predators as larvae and adults; bird food	Pitfall trap
Flies (Diptera)		
Asilidae	Larvae and adults general predators. Adults attack acridids.	Transect counts
Bombyliidae	Larvae of some species eat acridid eggs. [Two of nine species of Bombyliidae collected belong to genera known to attack Acrididae. See Appendix A.]	Transect counts [except genus *Usia* which was not recognized as a bombyliid during field sampling]
Ants (Hymenoptera)		
Formicidae	Important diet item for Thekla Lark and Red-rumped Wheat-ear; beneficial scavengers and soil aerators/mixers	Pitfall trap, activity index
Bees (Hymenoptera)		
Apoidea		
Wild	Pollinators	Transect counts, together with domestic bees
Domestic	Pollinators and producers of honey and wax	Transect counts (together with wild bees); counts of dead bees and bee exits and entrances at the hive, and counts of workers foraging along a transect; behavioral observations

Table 37. Insect identifications as of June 15, 1992.

Insect group[a]	Species name[b]	Date	Identified by
ORTHOPTERA		V/92	S. Ghaout (ID's tentative)
fam. Acrididae			
Calliptaminae	*Calliptamus barbarus*		
Oedipodinae	*Aiolopus thalassinus thalassinus*		
	Sphingonotus savignyi		
fam. Pamphagidae	*Pamphagus* sp.		
fam. ?	*Eugaster* sp.		
LEPIDOPTERA			
fam. Pieridae	*Euchloe belemia belemia* Esper	4/V/92	R. F. Denno, Dept. of Entomology, U. of Maryland, College Park, MD 20740 U.S.A.
	Elphinstonia charlonia charlonia Donzel		
	Anthocharis belia belia L.		
	**Euchloe ausonia crameri*		
	**Colias crocea* Geoffroy		
fam. Lycaenidae	*Tomares ballue* F.		
DIPTERA			
fam. Asilidae [D3]	*Machimus cribatus* (Loew)	26/III/92	J. C. Deeming, National Museum of Wales, Cathays Park, Cardiff CF1 3NP U.K.
	Habropogon senilis van der Wulp		
fam. Sarcophagidae [D11] (NOTE: *Heteronychia* = *Helicobia*)	*Helicophagella novercoides* (Böttcher)		
	#*Heteronychia (Asceloctis) balanina* (Pandelle)		
	**Heteronychia* sp.		
	**Parasarcophaga teretirostris* (Pandellé)		
[other specimens]	#*Sarcophila latifrons* (Fallén)		
	#*Stomorrhina lunata* (Fab.)		
	#*Blaesoxipha rufipes* (=*filipjeyi*) (Macquart)		
	**Camilla* spp.		
fam. Bombyliidae	*Usia ?claripennis* Macquart	23/III/92	D. J. Greathead, NERC Centre for Population Biology, Imperial College at Silwood Park, Ascot, Berks. SL5 7PY U.K.
	U. incisa Wiedemann		
	**U. aurata* Fabricius		
	Bombylius sp.		
[D4]	*B. argentifrons* Loew		
[D5]	*B. medius* Linnaeus		
[D7,8]	*Acanthogeron separatus* Becker		
[D6]	#*Anastoechus* c.f. *exalbidus* (Wiedemann)		
	**Prorachtes* sp.		
	#*Cytherea fenestrata* Loew		
	**Anthrax* sp.		
	**Exhyalanthrax* sp.		

Table 37. Continued.

Insect group[a]	Species name[b]	Date	Identified by
COLEOPTERA			
fam. Tenebrionidae			
[C18]	*Adesmia dilatata* Kl.	5/V/92	W. Schawaller
[C2]	*Blaps appendiculata* Mot.		Naturkunde-
[C31]	*B. barbara* Sol.		museum,
	B. emondi Sol.		Rosenstein 1
[C2]	*B. murati* Peyr.		7000 Stuttgart 1,
[C3]	*Sepidium* sp.		(West) Germany
[C47]	*Sepidium* sp.		
[C23]	*Pimelia crenata* F.		
[C23]	*P. echidna* Frm.		
	P. grandis Kl.		
[C33]	*P. tristis* H.		
[C26]	*Stenosis espanoli* Ant.		
[C41]	*Adelostoma granulithorax* Esc.		
[C21]	*Akis richteri* Q.		
[C39]	*Alphasida* sp.		
[C43]	*Zophosis atlantica* Esc.		
[C16]	*Z. bicarinata* Sol.		
[C11]	*Gonocephalum perplexum* Luc.		
[C17]	*Thalpobia meridionalis* Esc.		
[C27]	*Tentyrionota ifnica* Esc.		
fam. Carabidae -- Specialist(s) to be identified.			
fams. Scarabaeidae and Trogidae -- Specimens sent to J. Baraud, 111 rue Dubourdieu, 33800 Bordeaux, France			
HYMENOPTERA			
fam. Apidae			
(Apoidea) -- Specialist(s) to be identified.			
fam. Formicidae -- Specimens sent to X. Espadaler, Dept. de Biologia Animal, Universistat Autonoma de Barcelona, Edifici C, 08193 Bellaterra (Barcelona), Spain.			

[a] Letter/number combinations within families refer to labeled specimens in the reference collections.
[b] * Indicates specimens that will not be retained by DPVCTRF.
# Indicates known predators or parasites of Acrididae.

Table 38. Chronology of bee observations on plots 4, 5, and 6.

Date	Observers			Remarks
	1	2	3	
Jan 29	4	-	-	
30	6	4	-	
31	5	6	4	
Feb 1-6	-	-	-	High winds up to 80 km/hr disrupted observations.
7	4	-	5	
8	5	-	6	
10	6	5	-	Plot 4 partly sprayed (bee effects were observed)
12	-	-	-	Plot 4 sprayed with malathion
13	-	4	-	
14	4	6	-	
15	6	-	4	Plot 5 sprayed with DDVP; high winds disrupted observations on Plot 6
16	-	-	6	High winds disrupted observations on Plot 6
17	-	6	5	
18	-	5	6	
19	-	6	5	

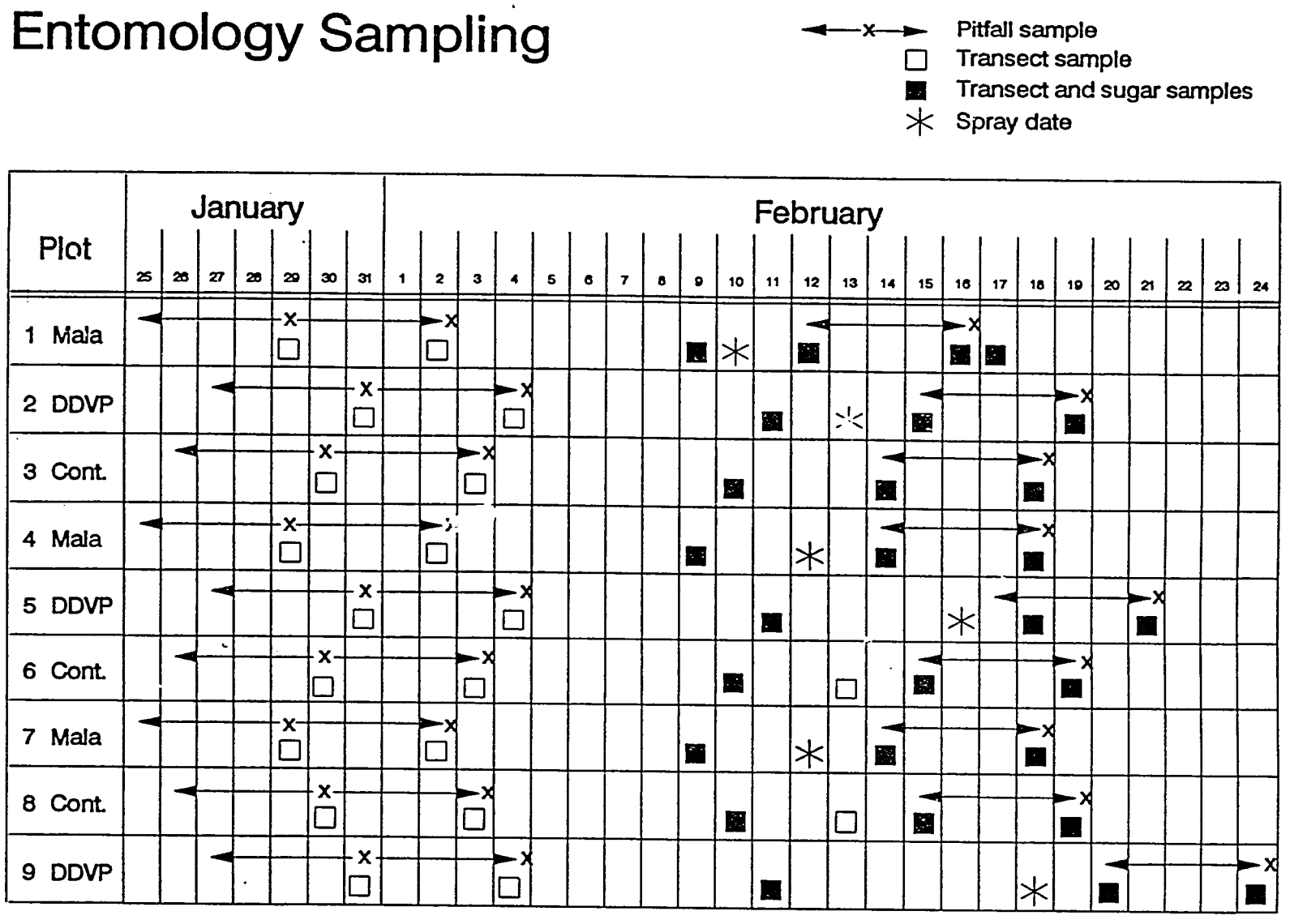


Fig. 9. Periods of sampling for insect abundance on study plots. On plot 1, one-half of transect and sugar sampling was done on February 16 and one-half on February 17.

Initial Mortality

An insect kill was evident to entomologists when they obtained data from malathion plots on the second and sixth mornings after treatments and included the following:

Orthoptera
- Calliptaminae (one individual)

Coleoptera
- Tenebrionidae (many individuals)
- Scarabidae (several individuals)

Hymenoptera
- Apoidea (several individuals)

Some dead and dying insects were seen on dichlorvos plots when plots were first entered to collect data on the second morning after treatments and included:

Coleoptera
- Tenebrionidae (several individuals)

Hymenoptera
- Apoidae (one individual)

Study of Honeybees

The insecticide treatments coincided with bee hibernation. Numbers of active adult bees were reduced due to physiological dormancy of the queen and a lack of food sources. Thus the treatments affected only a small number of foraging workers and the results did not reflect the full potential of the experimental insecticides to harm bee colonies. However, these results should indicate the impact of anti-locust treatments, which are usually applied during the time of year chosen for the experiment.

Plot 4 (malathion), plot 5 (dichlorvos), plot 6 (control), and Block B, were chosen for bee observations. The three plots were similar with regard to topography, exposure to sun, prevailing winds, and honey and pollen sources. A portion of plot 4 was treated twice 2 days apart with malathion. The first treatment covered only a few swaths along one edge of the plot but caused some bee mortality. The second treatment, which covered the entire plot including the beehives, was made at a time of day when the bees were observed to rest (1430-1600 hours).

Traditional hives were purchased locally for the bee observations. Twelve hives were divided into three groups of four. Each group of hives was placed together near the center of one of three experimental plots. One observer took data on each plot at 1000, 1200 and 1400 hours on each observation day (Table 38). Observations included the following:

- Number of foraging workers entering and leaving during a 5-minute period. The observer was stationed about 1 m from the hive entrance and used two mechanical tally counters, one in each hand.

- Number of foraging workers counted while walking in a 25-m radius circle around the hives.

- Number of dead bees at the hive entrances. A 1- by 2-m piece of cardboard was placed in front of each hive to collect dead bees and facilitate counting.

- Behavior such as aggressiveness, agitation, buzzing, ejection of dead bees, and pollen collection.

- Meteorological data (temperature, rH, wind speed).

Effects on honeybees. This data set was complex and there were missing cells in the design, so a General Linear Models procedure was used for the ANOVA. The reliability of the results is limited because of changes in observers, disrupted spray schedules, different observation schedules for different treatments, and the fact that there were no replications. Counts of foraging workers were not analyzed because of these problems and because those data follow a different model with no interaction effect and limited inference potential.

Mortality counts, hive entries and hive exits were analyzed for two pretreatment observations ("pre-1" and "pre-2") and two posttreatment observations ("post-1" and "post-2").

The ANOVA showed a highly significant treatment*time interaction for mortality ($p = 0.0001$), entries ($p = 0.0003$) and exits ($p = 0.0003$). The statistician noted, however, that the mortality data may violate ANOVA assumptions because there were so many observations of zero. Means were separated using Duncan's Multiple Range Test at an experiment-wise error rate of 0.05.

Number of dead bees at hive entrances

	Treatments		
Period	Malathion	Control	Dichlorvos
pre-1	0c	0c	0.08c
pre-2	0c	0c	0.17c
post-1	22.27a	10.25b	0.17c
post-2	5.27bc	0c	0.33c

This experiment did not detect any bee mortality caused by dichlorvos. Malathion killed plot 4 bees, which were then ejected from the hive. The effect was strongest in the first posttreatment observation.

Measurable bee kill also occurred on the control plot and could have been due to either or both of two causes. Malathion may have drifted from plot 4 to plot 6. In general winds from the northwest prevailed, which would be consistent with this hypothesis, but wind direction was not recorded at the time of treatment. An alternative explanation is that workers may have flown from plot 6 to forage on plot 4, which had more flowering vegetation. Bees are known to forage as far as 7 km from their hive to find adequate food.

There was no significant effect on worker bee entries and exits at hives in either the malathion or the control plot. This seems inconsistent with the bee mortality caused by malathion.

Number of worker entries and exits in 5 minutes

	Entries			Exits		
Period	Malathion	Control	Dichlorvos	Malathion	Control	Dichlorvos
pre-1	10.50cd	38.83bc	36.58bcd	12.25bc	26.58b	24.83bc
pre-2	13.42cd	35.00bcd	42.75b	11.08bc	25.33bc	25.83b
post-1	9.82cd	27.83bcd	8.75d	8.09bc	9.42bc	10.17bc
post-2	14.55bcd	11.27cd	87.67a	15.09bc	4.27c	65.75a

On the dichlorvos plot, worker entries decreased significantly after treatment (pre-2 vs. post-1) and exits followed a corresponding (but nonsignificant) numerical trend. However, the next observation showed a highly statistically significant surge in worker bee activity at the hive in both entries and exits. We do not have any explanation for these results. The aforementioned, weak reliability of data due to experimental design problems may be relevant here.

Studies of Other Insects

Transect counts, pitfall trapping, and baiting with sugar cubes were used to obtain measurements of relative insect abundance and activity. Direct counts of target insects seen while walking a transect were productive; insects were readily visible on the bare ground and low shrubbery. After light rain and germination of forbs, widely scattered single flowers were conspicuous points of attraction for flies, small beetles, and bees. Pitfall trap catches were substantial and contained two insect groups that were important in bird diets: beetles and ants. The number of pitfall

traps was kept small enough so that the catch could be sorted in camp. Baiting with sugar was undertaken in order to have a second measurement of insecticide impact on ants because the number of ants trapped in pitfalls were variable and did not appear adequate for statistical determination of treatment differences.

All sampling was done along a diagonal line about 1,118 m in length, lying across the central sampling area of each plot from point 1 to point 15 (Fig. 6). Figure 9 shows the entomology sampling schedule. Sampling was carried out by three teams of two entomologists, each team doing all sampling on a given block in order to eliminate observer bias. Team assignments were: Block A, Mouhim and Ghaout; Block B, El Fayq and Baou; Block C, El Bakkouri and Matteson.

Pitfall trapping. There were 24 pitfall traps on each plot. Six pitfall sampling stations were established along the diagonal line at 180-m intervals, starting about 10 m from point 1. Four pitfall traps were installed within a 10-m radius of each sampling station, two in the open and two under one or more of three plant species that occurred on all plots: *Lycium intricatum*, *Euphorbia echinus*, or *Senecio anteuphorbium*.

A pitfall trap consisted of two nested 12-oz plastic coffee cups. The outer cup held the shape of the pitfall in the ground while the inner one was removable for harvesting the catch. The cups were filled with a solution of water containing 1 percent vinegar (to attract beetles) and 0.3 percent liquid detergent (to weaken the surface film). Each trap was covered by a large flat rock supported by smaller rocks at a height of 1-2 cm. The rock cover excluded rain and helped conceal the traps from passersby. Pitfalls were left out for 4 days before catches were removed.

Three pitfall samples were taken, two samples on each plot before insecticide application and one sample afterward (Fig. 9). The second pretreatment sample was taken under abnormal windstorm conditions. Pitfall catches were drained placed in labeled plastic bags, then sorted and counted the same day. After the second pre-application sample, the pitfall traps were drained, closed with tightly-fitting plastic covers, and then activated again after treatments.

Results of pitfall trapping. The following groups of interest were trapped in pitfalls in numbers large enough for statistical analysis: all beetles; all Tenebrionidae; the tenebrionids *Pimelia echidna* + *P. crenata* (these two species, which looked similar, were counted together) and *P. tristis* + *P. rugosa* (also similar and counted together); all Carabidae; all ants; all spiders; and all Orthoptera.

The ANOVA showed a weakly significant treatment*time interaction for all beetles ($p = 0.09$), Tenebrionidae ($p = 0.08$), and *P. echidna* + *P. crenata* ($p = 0.09$). The following tables give means as separated by Duncan's Multiple Range Test at an experiment-wise error rate of 0.10. Since Tenebrionidae were the bulk of all beetles trapped in the pitfalls, the data shown below for beetles is indicative of Tenebrionidae results as well.

Numbers of beetles caught in pitfall traps

	All beetles			*P. echidna* + *P. crenata*		
Period	Malathion	Control	Dichlorvos	Malathion	Control	Dichlorvos
pre	34.3b	81.2b	81.5b	6.3c	16.3c	21.2bc
wind	68.5b	233.2a	177.3a	13.8c	45.5ab	31.8bc
post	62.5b	239.7a	74.5b	13.2c	71.3a	13.7c

Pitfall trapping did not show clear, consistent effects of treatments on mean numbers of all beetles or of *P. echidna* + *P. crenata*. However, the numbers of all beetles after dichlorvos treatments differed ($p = 0.09$) from the number found in the second pretreatment sample (but not from the number found in the first pretreatment sample). In addition, mean numbers of both beetle groups on control and dichlorvos plots were not different during the pretreatment periods, but numbers on dichlorvos plots were significantly lower ($p = 0.09$) than controls after treatments. These comparisons indicate beetle numbers were affected by dichlorvos treatments.

The ANOVA indicated that the tenebrionids *P. tristis* + *P. rugosa* were captured in larger numbers in pitfall traps placed in the open. The mean catch of 16.5 with no vegetation cover was significantly different ($p = 0.01$) from the mean catch of 12.7 under vegetation cover. These beetles were observed to feed on the lily *Asphodeleus* and small annual plants which sprouted after showers. The fact that these food sources occurred in relatively open spaces may account for more *P. tristis* + *P. rugosa* being trapped there.

A time effect was shown in the ANOVA for Carabidae ($p = 0.05$) and ants ($p = 0.08$). The means for Carabidae were separated at an experiment-wise error rate of 0.05, whereas the means for ants were separated an experiment-wise error rate of 0.10.

Numbers of carabidae and ants caught in pitfall traps

Period	Carabidae	Ants
pre	4.6ab	417.9a
wind	10.7a	311.1ab
post	2.1b	95.7b

Carabid captures declined significantly in the posttreatment observation. Since their decline is not attributable to insecticide treatment, the dry "chergui" wind may have been the cause. In general, Carabidae are associated with relatively moist environments. As conditions become more xeric, their niche is increasingly filled by Tenebrionidae. The windstorm may have killed Carabidae selectively. The numerical trend of the carabid catch was up during the windstorm (although not significantly), which may have reflected the attrac-tiveness to them of the liquid in the traps under unusually arid conditions.

The numbers of ants caught in pitfalls were too variable to show a statistically significant treatment effect. Nevertheless, both decreasing ant activity (see below) and decreasing capture data of ants in pitfall traps indicate that ant activity declined sharply on malathion plots after treatment.

Transect counts. Transect counts were begun at 1130 hours when it was warm and insect activity was at or near a maximum. On each plot, two observers walked a 500-m transect and counted insects seen 1 m on each side of their path. The paths of the two observers were parallel lines 30 m to the left and 30 m to the right, respectfully, of the pitfall sampling diagonal, starting parallel with pitfall sampling station 2. Each observer was permanently assigned either the path to the left or the path to the right of the diagonal in order to minimize variability in observations among dates.

Results of transect counts. The following insect groups of interest occurred in numbers large enough for statistical analysis: all beetles; all Tenebrionidae; the tenebrionids *Adesmia dilatata*, *Pimelia echidna* + *P. crenata*, and *P. tristis* + *P. rugosa*; all Asilidae; all Bombyliidae; all bees; and all Orthoptera.

Three pretreatment transect samples were considered: "pre-1," taken January 29-31; "wind," taken during the dust storm February 2-4; and "pre-2," taken February 9-11 just before most of the treatments were made (Fig. 9). However, for Asilidae, Bombyliidae, bees and Orthoptera, the "wind" sample was excluded because of lack of data. "Post," taken on the second day

after insecticide application to each plot, was used for comparison. Due to an oversight, the second posttreatment transect count was not included in the analysis.

The ANOVA showed a significant treatment*time interaction for beetles ($p = 0.02$), Tenebrionidae ($p = 0.03$), *Adesmia dilatata* ($p = 0.02$) and Orthoptera ($p = 0.03$). However, no consistent effects due to treatments (increases or decreases following treatments) were apparent. The following tables give the means for variables as separated by Duncan's Multiple Range Test at an experiment-wise error rate of 0.05. Since the bulk of beetles counted were Tenebrionidae, the results presented for beetles are representative for the family as well.

Numbers of Coleoptera seen during transect counts

Period	All beetles			*Adesmia dilatata*		
	Malathion	Control	Dichlorvos	Malathion	Control	Dichlorvos
pre-1	60.0cd	31.0d	94.3abc	44.7abc	10.0d	62.3ab
wind	127.3a	87.3abc	71.0bcd	73.3a	23.3cd	27.0cd
pre-2	88.7abc	63.3cd	111.3ab	57.7ab	24.3cd	56.3ab
post	103.7abc	123.3a	171.3a	42.3bc	33.7cd	61.7ab

There was some indication of a malathion effect on *Adesmia*, as *Adesmia* numbers on malathion plots were consistently greater than the controls before treatment, but the same as the control after treatment.

No dichlorvos effect was observed on Orthoptera. Malathion, however, appeared to reduce grasshopper populations (comparison of post- and pre-2 samples).

Number of Orthoptera seen during transect counts

Period	Malathion	Control	Dichlorvos
pre-1	45.3b	6.3d	8.7cd
wind	--	--	--
pre-2	100.3a	9.0cd	15.7bcd
post	39.7bc	11.7cd	21.7bcd

The ANOVA showed a significant time effect for *P. tristis* + *P. rugosa* ($p = 0.02$), Asilidae ($p = 0.04$) and Bombyliidae ($p = 0.05$). The following table gives the means for those variables separated at an experiment-wise error rate of 0.05.

Numbers seen during transect counts

Period	*P. tristis* + *P. rugosa*	Asilidae	Bombyliidae
pre-1	5.8b	6.6b	6.0a
wind	29.4ab	--	--
pre-2	19.7b	2.1a	3.0ab
post	49.7a	2.2a	1.8b

New adult emergences are the only explanation we can suggest for the increase in *Pimelia* over time. The decrease in numbers of Asilidae and Bombyliidae is probably largely due to the prolonged, drying windstorm. Wind interfered with normal feeding activity--almost no flies were observed on the transect on very windy days. It also may have killed some of these delicate insects through direct injury and dehydration (they have a high surface to volume ratio compared to that of, for instance, tenebrionid beetles).

Ant activity index. Twenty sugar baiting points were established on each plot. They were marked with flagging, at 20-m intervals along the transect between pitfall sampling stations 2 and 5. At each baiting point, two 10- by 15- by 30-mm cubes of sugar were placed on open ground with their long sides contiguous. The sugar was put out between 1600 and 1800 hours. The presence or absence of living ants on or near the sugar was noted the next day between 1100 and 1300 hours. Sugar was collected immediately after ant counting. Three ant activity counts were taken on each plot--once, 1-5 days before insecticide application, and twice afterward, on days 2 and 6 postspray.

Results of ant activity index. The General Linear Models procedure was used for the ANOVA because there were missing cells in the design. The variable analyzed was the percentage of sampling stations with at least one living ant present.

One pretreatment sample and two posttreatment samples ("post-1" and "post-2," days 2 and 6 after treatment respectively) were considered. The ANOVA showed a significant treatment*time interaction ($p = 0.02$). The means were separated using Duncan's Multiple Range Test at an experiment-wise error rate of 0.05.

Period	Malathion	Control	Dichlorvos
	Percent stations with ants		
pre	97a	78abc	63bc
post-1	19d	60bc	71abc
post-2	47cd	85ab	73abc

Results showed no change in ant activity on dichlorvos plots after treatment. In contrast, malathion significantly diminished ant activity, with a partial recovery evident after 4 days.

Malathion treatment probably caused a large, temporary reduction in the availability of food for animals that depend on ants in their diet. These data are insufficient, however, to draw conclusions about insecticide impact on ant populations themselves. A drop in worker activity shortly after treatment may be caused by a temporary cessation of foraging rather than by ant mortality. Even if an insecticide does cause worker mortality, nests must be followed for months to gauge longer-term population effects. Surviving workers remaining active for their lifetimes may mask the fact that the queen ant has been poisoned and that the nest will ultimately die out.

Conclusions

Although dichlorvos and malathion each showed significant effects on some arthropod groups, the effects were fewer and less severe than might have been expected from broad-spectrum insecticides. Most of the arthropod groups that occurred in numbers large enough for statistical analysis showed no treatment effects. Sampling indicated that malathion killed honeybees and reduced the activity or populations of several other insect groups. Smaller numbers of Orthoptera and of the tenebrionid beetle *Adesmia dilatata* were observed during posttreatment transects on malathion plots. Malathion treatment reduced ant numbers greatly at sugar baits and ant catch decreased over time in pitfall traps. All these results are consistent with the kinds of insects found dead or dying on malathion plots the morning after treatment, which included high numbers of *A. dilatata* as well as some grasshoppers, large-sized ants, and wild bees (Table 18).

Dichlorvos appeared to have had less overall impact. The only evidence of a posttreatment change was a reduction in comparison to control plots on one but not both of pretreatment counts in the exit of bees from the hives and number of beetles--all beetles as well as *Pimelia echidna* + *P. crenata*--caught in pitfall traps. Posttreatment searches on dichlorvos plots agreed with these findings, resulting in little except large numbers

of disabled beetles (pitfall data would seem to indicate that these beetles died rather than recovered). It is particularly noteworthy that honeybees and ants, two groups that generally show great sensitivity to insecticides, seemed to be unaffected by dichlorvos.

Certain results were inconsistent, but reasons for some inconsistencies can be suggested. Malathion killed bees, while no significant effect was detected on hive entries and exits. However, these conflicting results may have been caused by sampling problems discussed above. Malathion's reduction of Orthoptera in transect samples, but not in pitfall traps, is probably due to the grasshopper's tendency to hide when dying.

Dichlorvos appeared to reduce numbers of all beetles ($p = 0.09$) and of *Pimelia echidna* + *P. crenata* ($p = 0.09$) in pitfall traps, but not in transect counts. The difference in results for all beetles might be due to the species that are active and readily visible at midday being, as a group, less sensitive to dichlorvos than the broader spectrum of species collected in pitfall traps. Moreover, since dichlorvos is so volatile, the timing of applications may have had a bearing on which group of beetles was most exposed.

FOOD HABIT STUDIES OF VERTEBRATES

Food habits of six common and widely distributed vertebrates were followed before and after insecticide applications. Decreases in invertebrates after treatments for insect control can reduce food supplies of birds and mammals and even change their food habits, cause their emigration, or reduce their reproductive success. Ornithologists collected *G. theklae* and *O. moesta*, the radiotelemetry team collected *A. noctua*, and mammalogists trapped *M. shawi*, *M. libycus*, and *P. obesus*. Animals were taken from the study area pretreatment and from the experimental plots, including controls, after insecticides were applied. The cholinesterase team dissected animals, froze brains for analysis, and placed bird gizzards and mammal stomachs in alcohol for subsequent examination.

Results showed rodents had eaten almost 100 percent plant material (Table 39). The presence of plant foods was expected before treatments as *Meriones* spp. and *P. obesus* are known to eat plants, primarily of the family Chenopodiaceae (Aulagnier and Thevenot 1986). The complete absence of animal matter in the stomach of *Meriones* spp. was surprising, as they are reported to eat some animal foods. Most vertebrates will consume arthropods that are killed and became available after insecticide applications. However, none of the rodents examined after treatments had consumed much animal material. Animal material present in a few stomachs may have been present on plants eaten by rodents. Either these rodents did not readily consume insects in the study area, or the insecticide applications did not kill insects so that they were available to the rodents.

The relative amounts of animal and plant matter in gizzards of birds varied among the three species (Table 40). *G. theklae* ate more vegetation than insects and spiders. *O. moesta* ate considerably more animal than plant material, and the diet of *A. noctua* was mostly animal matter and included vertebrates. Although *G. theklae* ate the least animal matter, they consumed a great variety of insects and spiders (Table 40). *O. moesta* ate more kinds of arthropods on treated plots (11 identified) than on untreated plots (4). All birds ate beetles, but only owl gizzards contained beetle larvae. No effects of treatments were apparent on either *G. theklae* or *A. noctua*. However, for *O. moesta*, the proportion of animal matter eaten (68 percent) was lowest on the dichlorvos plots after treatments. Likewise, ants occurred in only 11 percent of gizzards examined from malathion plots posttreatment, while from other plots, they occurred in 54 to 64 percent of gizzards. These results suggest that insecticide treatments reduced some food sources such as ants, but did not greatly alter the diets of vertebrates.

Table 39. Food habits of rodents in relation to insecticide treatments.

Species and treatments	*n*	Stomach contents (%)	
		Animal	Vegetation
Meriones spp.[a]			
Pretreatment	8	0.0	100
Posttreatment			
Control	8	< 1.0	> 99
Malathion	9	0.0	100
Dichlorvos	6	< 1.0	> 99
Psammomys obesus			
Pretreatment	4	0.0	100
Posttreatment			
Control	8	0.0	100
Malathion	11	0.0	100
Dichlorvos	8	< 1.0	> 99

[a] Includes both *M. shawi* and *M. libycus*.

Table 40. 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
Galerida theklae					Most varied of birds
Pretreatment	9	0.52	30	70	Beetles, caterpillars, termites, thrips, bees, spiders, scorpions, wasps and termites
Posttreatment					
Control	10	0.90	38	62	
Malathion	10	0.53	42	58	
Dichlorvos	12	0.65	39	61	
Oenanthe moesta					Ants, beetles, bees, wasps, and caterpillars. Birds in malathion-treated plots ate fewer ants.
Pretreatment	10	0.45	87	13	
Posttreatment					
Control	10	0.97	89	11	
Malathion	9	1.03	84	16	
Dichlorvos	11	0.85	68	32	
Athene noctua					
Posttreatment					Beetles, scorpions, termites, cockroaches; also vertebrates.
Control	5	3.4	96	4	
Malathion	6	3.5	90	10	
Dichlorvos	5	3.1	97	3	

[a] Grit as a percentage of total gizzard contents, by treatments, ranged from 14-43 percent for G. theklae, 1.0-7.8 percent for *O. moesta*, and was 0 percent for *A. noctua*.

DISCUSSION

The goal of this study was to evaluate the effects of field applications of malathion and dichlorvos on birds, mammals, and beneficial insects. Research teams developed suitable methods to measure animal abundance, movements, mortality, food habits and exposure to the insecticides. Data were diligently collected during the 5-week period of the study, often under adverse conditions of weather and the logistical problems inherent in large studies. With this effort by scientists, it was frustrating that treatments of plots with insecticides were so ineffective. Little insecticide was deposited on most plots (Table 17) and kill of arthropods was minor after most applications (Table 18). Effective treatments of broad-spectrum insecticides such as malathion and dichlorvos should result in impressive numbers of dead and dying arthropods for several days after treatments. Results obtained in this study perhaps can be used to evaluate effects of malathion and dichlorvos on birds, mammals, and beneficial that might occur under some locust control operations. But, certainly more intense effects would have occurred if more precise applications of insecticides had been made.

However, the primary objective of the project, of which this research was a part, was to train Moroccan scientists in the conduct of ecotoxicological research. This field study accomplished that objective. Scientists who worked on this research gained a broad appreciation of how each aspect of the study contributed to an understanding of overall treatment effects. It is appropriate to discuss the findings, acknowledging that treatments were inadequate but that good biological data was collected.

On malathion plots, deposits measured on spray cards reflected the initial, subjective appraisals of treatment effectiveness (Table 17). Likewise, deposits were a good index to malathion residues measured in soil on the day after spraying (Table 19). Thus, it appeared the malathion treatment on plot 7 was ideal with an average of 26 drop-lets/cm^2 and acceptable on plot 1, with 16 droplets/cm^2 (Table 17). Variation in droplet numbers was high, however, ranging from 0.7 to 52/cm^2 on plot 7 (57 cards) and 0.9 to 42/cm^2 on plot 1 (121 cards). Treatments to other plots were not satisfactory.

Searches on treated plots did not locate any dead vertebrates, and invertebrate mortality appeared minimum. Beetles killed by insecticide treatments were found on malathion plots, but few freshly killed beetles were present on dichlorvos plots. Variation in numbers of newly dead beetles was not related to search efficiency, as many old dead beetles were found on all plots, including dichlorvos plots. Numbers of other dead arthropods were extremely low on all plots.

Initial average malathion residues in soil reflected average deposits measured on spray cards, but variation among measurements was high. Locust initial residues (2.8 ppm on plot 4) probably persisted for about 1 week, and highest (30.2 ppm on plot 7) for about 2 weeks (Table 19). Malathion residues were not recovered from most vegetation samples, so nothing was learned of its persistence on livestock forage.

Only trace amounts of dichlorvos were found on either soil or vegetation. As initial samples were not obtained until the day after treatments were made to plots, residues could have degraded and disappeared. As droplet counts on plots 2 (5/cm²) and 9 (6/cm²) were similar to those on malathion plot 4 (7/cm²), initial residues similar to those on plot 4 (2.8 ppm) might have been expected. The half-life of dichlorvos in soil and on vegetation was only hours long in other studies as it rapidly disappeared due to hydrolysis and volatilization (FDA 1982). Results of tests in this study where field samples were fortified (spiked) with dichlorvos suggested residues may have been lost from samples during storage and transport of samples to the Casablanca Laboratory.

Drift of malathion from plot 1 may have contaminated plots 2 and 3. Malathion residues were found in soil from plot 2 when soil was sampled after dichlorvos application. If insecticide drift of such proportions occurred in this study, posttreatment information from study plots may reflect effects of more than just assigned treatments. Such a situation could cause greater variation in sampling results and further inhibit clear interpretation of treatment effects.

No important biological effects were documented on birds and mammals. Moussier's Redstart decreased significantly on dichlorvos plots, but numbers involved in the analysis were low. A general decrease in the abundance of this species was suggested by data collected from all plots (Table 29). Posttreatment levels of cholinesterase activity in brains of birds did not suggest intense exposure to insecticides or the potential for mortality in populations on plots. A significant decrease was found in brain cholinesterase levels of *G. theklae* on malathion plots after treatments. However, cholinesterase depression was only 18 percent. Previous studies have shown that mortality in birds does not usually occur until depression exceeds 50 percent (Hill and Fleming 1982).

Cholinesterase measurements in birds served as a bioassay of plot contamination with insecticides. Most (8 of 10) *G. theklae* collected from malathion plots came from plot 7. These larks came from the only plot to received satisfactory insecticide application and they were the only group to show significant cholinesterase depression. Treatments of other plots were poor, and birds from those plots did not show significant reduction in cholinesterase levels.

O. moesta ate fewer ants on malathion plots after treatments. Only one of nine birds (11 percent) had eaten ants, while 54 and 64 percent of wheatears from dichlorvos and control plots, respectively, had ants in their gizzards. Entomologists documented a decrease in ant activity on malathion plots and evidently wheatears did not as often find ants to eat on malathion plots. *O. moesta* also had eaten a lower proportion (68 percent) of animal foods on plots treated with dichlorvos than on control plots (89 percent), and this was the only other effect of treatments on the foods of vertebrates.

Treatments had no significant effects on the abundance or activity of rodents. There were decreases in capture rates on malathion (26 percent) and dichlorvos (32 percent) plots after treatments, while there was an increase of 33 percent on control plots (Table 31). In addition, rodent activity in burrow systems on malathion plots appeared to decrease 35 percent (Table 32), but these apparent treatment effects were not supported by analyses of data. Decreases in abundance were possible, as in one other study rodent populations in forests were reduced temporarily by application of 810 g/ha of malathion (Giles 1970).

Neither cholinesterase measurements, nor radiotelemetry monitoring suggested any mortality or movements of vertebrates. Population sampling, in contrast, gave some indication of treatment effects on bird and mammal numbers.

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 the organisms most obviously affected by malathion and dichlorvos applications. Numbers found dead or debilitated during searches after treatments grossly reflected relative insecticide deposits measured on plots during treatments. However, population sampling did not conclusively show effects of treatments on beetles. Pitfall trapping weakly indicated ($p = 0.09$) decreases due to dichlorvos, but did not even suggest effects of malathion. Pitfall trapping also did not show significant effects of malathion on ants. Likewise, transect counts only indirectly (by comparison with controls) indicated decreases ($p = 0.02$) due to malathion in numbers of *Adesmia dilatata*, the most common species found dead during searches on plots. Transect counts suggested orthoptera decreased markedly after malathion treatments ($p = 0.03$). These were the target organisms of malathion and dichlorvos applications in Morocco, but no effects of dichlorvos on orthoptera were shown in this study.

In conclusion, results obtained in this study were compromised by inadequate treatment of plots with insecticides. This is regrettable as the scientific quality of sampling data, and the industry and efforts of the scientists gathering data were of the highest quality. The ultimate purpose of this project and of the field research was to prepare Moroccan scientists to conduct future ecotoxicology studies. Based on their performance in this study, they are well-prepared to conduct further evaluations of pesticide effects on wildlife and the environment.

CONTRIBUTORS

Administrative support for this project and the research conducted in 1992 was provided by Generale H. Benslimane (Coordonnateur National de la Lutte Antiacridienne, Gendarmerie Royale), A. Arifi (DPVCTRF, Ministry of Agriculture and Agrarian Reform), T. Ben Halima (Centre National de la Lutte Antiacridienne, Ministry of the Interior), Joe Kitts (USAID, Morocco), and Richard Bruggers (Denver Wildlife Research Center, USDA).

James Keith, H. El Addami, and M. Charhbili selected the study area. John McConnell and a survey team from the Direction Provinciale d'Agriculture, Guelmim, located study plots and marked boundaries of plots and sampling areas. John McConnell and workers from the Centre National de la Lutte Antiacridienne established the tent camp at which biologists and chemists were lodged. The workers provided all meals and other necessities and coordinated purchases with John McConnell, Joe Kitts, and A. Muhim.

Michael Avery, Keith LaVoie, Patricia Matteson, Lawrence Kolz, and James Keith provided field training in research methods, especially during training sessions at Aït Baha in October 1990 and October 1991. In cooperation with Moroccan counterparts, they developed and tested most methods used in this research. Richard Engeman advised on the experimental design, sampling, and statistical analyses.

The Centre National de la Lutte Antiacridienne supplied pesticides and a team to load material into the helicopter. The Poste de Commandement Central (Gendarmerie Royale) provided the helicopter and a pilot and mechanic to apply insecticides.

Participants listed in Table 9 collected data during the study period. John McConnell obtained historic weather records, and in addition to his other duties, he worked on a rodent team. Michael Avery designed methodology for plant inventory and collected data on four plots in October 1991; measurements on other plots were taken by James Keith and A. El Hani in January 1992. Richard Engeman advised on sampling strategies and data entry into laptop computers. He later analyzed field data for statistical inference and contributed to manuscript preparation. John McConnell and Lynwood Fiedler helped retrieve data from computers, and John compiled all data gathered on birds and insects.

James Keith, as Study Director, organized the preparation of this report and prepared sections other than those written by research teams. Sections prepared by teams were:

Birds:	Richard Bruggers
	A. El Hani
Mammals:	Lynwood Fiedler
	H. Arroub
Insects and Bees:	Patricia Matteson
	S. Ghaout
Radiotelemetry:	Robert Phillips

Patricia Matteson determined contents of bird gizzards and rodent stomachs; James Keith compiled data and reported results.

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