28. ECOLOGICAL EFFECTS OF CHEMICAL CONTROL OF RODENTS AND JACKALS IN ISRAEL

H. Mendelssohn

Israel, situated where several zoogeographical regions overlap, has a relatively rich fauna, notwithstanding its small area of approximately 20,000 square kilometers. The impact of modern development on the fauna has been conspicuous, influencing many species adversely by changing the environment by pollution and by pesticides, and by favoring other, adaptable species, some of which have become pests. The present paper will mainly consider the northern and central parts of Israel which have a Mediterranean climate, becoming arid toward the south. They have been much more influenced and changed by development than has the southern desert.

Among the twenty-eight species of rodents occurring in Israel, three species of field mice showed cyclic population changes in the past. In certain areas, mass populations of these rodents occasionally caused heavy damage to agricultural crops.

Prior to 1950, thirty-six species of diurnal birds of prey occurred regularly in Israel. Field mice were the main food for twelve species, most of which could be considered as common or very common. The population density of birds of prey was especially high in winter and spring, coinciding with the main reproductive season of the field mice.

As agricultural development opens hitherto uncultivated regions and intensifies the use of the other farm areas, the control of pests becomes a major concern. Thallium sulfate-coated wheat, for example, has been used in Israel for rodent control and has had a heavy impact on the populations of diurnal birds of prey. Predation by these birds of prey on rodent populations is discussed. A jackal-eradication campaign, impinging on other predators and on prey species,

is also discussed.

Wheat coated with thallium sulfate, which had been used on a small scale for field mice control before 1950, was applied in large quantities over large areas several times during the winter of 1950-51, when a mass reproduction of field mice occurred. This large-scale application of poisoned grain was continued during the following years until recently, even when no increase of field mice populations was apparent.

After every application of thallium-wheat, dead and paralyzed birds of prey were found in the fields. All specimens checked for thallium contained large amounts of this metal. Birds of prey killed as a result of other causes, even in areas where thallium had not been used, were also found to contain thallium.

Captive birds of prey, fed experimentally on mice poisoned with thallium sulfate wheat, displayed the same form of paralysis as birds found in the field.

By 1955-56, breeding, as well as wintering populations of those species of birds of prey which fed mainly on rodents, had been almost entirely exterminated. Other species, which feed only occasionally on rodents or on grain-eating birds, were slower to disappear. Only one species, *Circaetus gallicus,* which feeds exclusively on reptiles, was not affected at all, and its population density did not decrease. Populations of mammal predators of field mice were also affected by secondary poisoning by thallium, but to a lesser degree.

After the continuous application of poison and the disappearance of the predators, regular cyclic population changes of field mice were no longer observed. Mass increase of field mice and sometimes also of other species of rodents occurred irregularly and took place also in areas in which this phenomenon had not been observed previously.

During the years 1964 to 1965, campaigns were carried out to exterminate jackals. Chicks poisoned with fluoracetamide were used as bait and widely distributed in large amounts. Populations of jackals as well as of other mammal predators, especially mongooses, were drastically reduced. Two consequences were conspicuous: a mass increase of hares, which began in 1966 and is still continuing, and a slower, but steady, increase of vipers and of snake-bite cases.

The influence of thallium and fluoracetamide on other forms of wildlife, as well as the general influence of other pesticides, is also conspicuous.

FIELD MICE, THALLIUM AND BIRDS OF PREY

Among the 28 species of rodents in Israel, one species, the levant vole *(Microtus guentheri guentheri* Dunford and Alston, 1880)[1] has displayed regular cycles of mass reproduction. Two other species, Tristram's jird *(Meriones tristrami* Thomas, 1892) and the house mouse *(Mus musculus praetextus* Brants, 1827), also participate to a certain degree in these cycles (Bodenheimer, 1949). It was probably *Microtus guentheri* whose mass reproduction was mentioned in the Bible. The same species was the object of ecological studies carried out by Bodenheimer (1949, 1953, 1957) and by Bodenheimer and Dvoretzky (1952). Bodenheimer stated that *Microtus guentheri* displayed ten-year cycles of mass reproduction and three-year to five-year cycles in

[1] *Microtus guentheri philistinus* Thomas, 1917, does not seem to be different morphologically from *Microtus g. guentheri,* if variability in size and color in populations from northern and southern Israel is considered.

between.[2]

In order to estimate the possible role of predators and their influence on the populations of field mice in Israel, the biology of *Microtus guentheri* should first be considered. *Microtus guentheri* inhabits open country on heavy alluvial soils in plains and valleys, which in winter absorb large amounts of rainwater and in summer dry on top, forming large surface cracks, but retaining a certain amount of humidity in the deeper layers. *Microtus guentheri* prefers humid soils and is able to dig its burrows even in soil which the winter rains have turned to mud. It prefers to feed on green food, but takes also a certain amount of grain. It may reproduce all year round, but its main reproductive season is from November to April, and population density is generally highest in spring. Its fertility is greatly reduced and even interrupted for six to eight months during the summer in dry areas (Bodenheimer, 1953). In spring, when the winter grain crops are being harvested, most of the annual vegetation has dried up and the voles rely to a large extent on grain, which they collect and store in their burrows. As the food intake of each specimen is small, the damage caused by this species is, therefore, generally restricted to years of mass populations and to areas of heavy alluvial soil, which is at the same time the best agricultural soil. Some damage may also be caused to alfalfa, vegetables and occasionally to fruit trees by gnawing their roots.

The other two species of rodents which participate in the mass increase together with *Microtus guentheri,* generally at the same time, but to a lesser degree, inhabit lighter and drier soil and also hilly areas, whereas the vole is restricted to level ground. *Meriones tristrami is* the more important of these two species, causing damage sometimes also in the south-central part of Israel, where *Microtus guentheri* is rare.

In Israel, the larger part of the grain crops is grown in wide open plains, which are cultivated mechanically. The density of field-mice populations in these fields is generally low in normal years, amounting to about one to five specimens per 1000 square meters (Bodenheimer, 1949). The method used by Bodenheimer (1949) for estimating populations of field mice was to plug the burrow openings and check the reopened burrows. The number of reopened burrows was used as an indication of the number of voles present. As one burrow of *Microtus* may have several openings, this method cannot be considered as accurate. According to personal observations, an average population of 1 vole per 1000 square meters in grain fields appears to be closer to reality in normal years. During years of mass reproduction, the population density may reach up to 25 specimens per 1000 square meters in spring or even more; according to Bodenheimer (1949), even 500 per 1000 square meters in some cases. Only under these circumstances is real damage caused by these field mice.

The question arises how much predation would be able to influence the population density of field mice in Israel and in this way prevent the development of damage. Bodenheimer (1949) took the barn owl as a model of predation, the composition of whose food in Pales-

[2] Bodenheimer discusses the development of mass reproduction and the crash with which these mass reproduction cycles generally end, in Israel as well as elsewhere (Elton, 1942; Lack, 1954). He discusses also the role of predation in regulating populations of this vole and of the two other species of field mice participating in the cycles and arrives at the conclusion that the role of predation is negligible. Elton (1942) and Lack (1954), summarizing other authors, maintain as well that predation is generally not an important factor regulating populations of small rodents. Other authors (Chitty and Phipps, 1966; Errington, 1943; Golley, 1960; Kalabukhov and Raevskii, 1933; Klimov, 1931; Pearson, 1964, 1966; Pitelka *et al;* 1955) found that predation may, under certain circumstances, and generally in combination with other factors, have an influence on rodent populations. Bodenheimer and Dvoretzky (1952) arrive at a similar conclusion.

tine has been studied by Dor (1947). Bodenheimer came to the conclusion that the influence of the barn owl on rodent populations is negligible, even though the food of the barn owl contains about 70 per cent voles and other mice. This conclusion is correct for several reasons. The barn owl nests and roosts in buildings and generally does not forage at a distance of more than 1 km from its nest or roost. It feeds mostly in and around settlements, where it preys on house mice, young rats, sparrows and shrews; voles, which may represent 50% of its food, are collected only in the surroundings of the villages. Therefore, the barn owl makes little use of the open fields, where *Microtus* are common.

Bodenheimer mentioned only incidentally the mammalian predators, whose food intake is much larger than that of the barn owl, but which also do not generally feed much in the open fields, where no hiding or resting places are available. Bodenheimer, however, did not mention at all the possible influence of diurnal birds of prey, many species of which feed in open country. The relation between diurnal birds of prey and another subspecies of *Microtus guentheri* has been mentioned by Harting (1893) for *M. g. hartingi* Barrett-Hamilton, 1903, in Thessaly, Greece.

It would have been worthwhile, however, to study this influence because Israel had a very rich fauna of diurnal birds of prey. The list comprised thirty-eight species, part of which were winter visitors, part summer breeders. A third group could be called residents, even though with some species apparently the breeding populations were at least partly different from the wintering populations. Some of the winter visitors were very common and occurred in high population densities.

From the point of view of a possible biological control of field mice, the important species of birds of prey which live in open country and feed mainly on small rodents, especially the most common eight species of winter visitors and four species of summer breeders. By examinations of crop and stomach contents it was found that mice were the staple food of these eight winter visitors which are also very common in spring migration, until May. During summer, however, mice were represented to a lesser extent in the food of the four common species of mice-feeding summer breeders, as reptiles and insects were now included in the diet of the diurnal birds of prey. Availability of prey species was generally reflected in the crop and stomach contents.

The availability of mice as food is apparently an important factor in the predator-prey relation. After fields are sown in autumn, rodents living in these fields have no cover and are vulnerable to predation. This situation continues when the grain starts to germinate after the first winter rains and until the plants have developed sufficiently to provide the rodents with cover, which is not before February. Thus, mice were generally the prominent food of birds of prey, living in the open fields until the end of February or even until the first half of March, depending on precipitation. During March and April, mice were in many cases less conspicuous in the food of the birds of prey which were collected in the fields, and more reptiles and insects appeared in the food with the onset of activity in heliothermic reptiles and the increasing populations of larger insects. In May and June, after the harvest, rodents are again deprived of cover and appear to a larger extent in the food of the birds of prey, which now feed their young also on rodents. An important difference between winter and summer is that the population density of the breeding birds of prey is lower than that of the wintering species.

The mainly, but not exclusively, nocturnal activity of the field mice does not prevent their being preyed upon by diurnal birds of prey. Even the mole rat *(Spalax ehrenbergi* Nehring,

1898), a subterranean rodent of much lower density than voles and other field mice, appeared surprisingly often in the food of diurnal birds of prey, especially the Egyptian vulture and the black kite. These victims were mostly sub-adult specimens which, prior to establishing territories of their own, appear more on the surface than do territory owners.

Among the diurnal birds of prey occurring in winter, eight species have been common enough to have affected field-mice populations. These species include the eagles *Aquila clanga* and *Aquila pomarina,* which in the present paper will be considered as one species, as it is difficult to distinguish between them in the field. The wintering populations of the somewhat rarer *Aquila heliaca* also subsisted mainly on mice. The buzzards *Buteo b. buteo* and *Buteo v. vulpinus,* the black kite *Milvus m. migrans,* the harrier *Circus macrourus,* and the kestrel *Falco tinnunculus* were the other important predators. Other species were less common, but for instance a *Buteo rufinus* could take the place of an *Aquila pomarina,* or a *Circus cyaneus* that of a *Circus macrourus.*

On the basis of fifteen counts conducted during the years 1933 to 1945 it may be supposed that the average population of wintering mice-feeding diurnal birds of prey per 10 square kilometers of grain-field area was two eagles, ten buzzards, four kites, four harriers and twelve kestrels. The counts were made in the vicinity of the town of Afula in northern Israel, about 35 kilometers southeast of Haifa. Afula is situated in a vast plain, typical *Microtus guentheri* country. In this uniform, open country, counting the birds was not very difficult. Counts were made on three consecutive days along transects 300 meters broad.

In order to ascertain the average daily food consumption of these birds when feeding on small rodents, captive birds of these species were fed on mice and rats of 20-90 grams weight. It was found that the average daily food intake for birds which kept their normal weight for ten to fourteen days was: for eagles, 200 grams; for buzzards and kites, 90 grams; for harriers, 60 grams; and for kestrels, 40 grams. According to these observations, the total food consumption of the diurnal birds of prey living on an area of 10 square kilometers would be 2380 grams of food per day. Because it is based on birds kept in captivity, this food consumption must be considered as minimal; birds in nature are more active and probably have larger food consumption. On the other hand, even though these birds feed mainly on mice, they take a certain amount of other food as well.

The average weight of the Levant vole in nature may be taken as 30 grams, as few of them reach an age of one hundred days and a weight of 40 grams (Bodenheimer, 1949). The thirty-two birds of prey living on an area of 10 square kilometers would therefore consume 79 voles per diem or 2370 voles per month. As during an average year the vole population per 1000 square meters was about 1, and on 10 square kilometers therefore, 10,000, the removal of 2370 voles per month by birds of prey constitutes an influence on the vole population which, together with predation by other predators and other mortality factors, may participate in regulating the population in winter and prevent or decelerate increase. Nothing is known about the reproduction rate of the Levant vole in nature, either in normal or cycle years. Bodenheimer (1949) and Bodenheimer and Dvoretzky (1952) assumed that even a slight change in reproduction rate may cause increase or decrease of vole populations. Predation such as that described here can be important only if the rate of increase of the rodent population is not too high.

Thus, the regulatory influence of predation on field-mice populations is likely to be effective only during normal years. As soon as the reproduction rate of the mice rises and a mass increase develops, the role of predation de-

creases relatively. Even though areas of a mass outbreak of field mice attract all kinds of predators, and the increase in diurnal birds of prey is very conspicuous, still the increase in their population density is much less than the increase in mice populations. During the height of the ten-year cycle of *Microtus guentheri,* vole populations may increase twenty-five times their normal density or more whereas the increase in population density of birds of prey was found to be not more than three to four times the average density. The influence of predation on field-mice populations is, therefore, relatively negligible during a mass outbreak. Bodenheimer and Dvoretzky (1952) and Pearson (1966) state that predation is relatively more important during times of low population density and negligible during times of high density.

A mass outbreak of the Levant vole occurs generally over large areas and may even extend over the whole of the Near East (Bodenheimer, 1949). The populations of the wintering diurnal birds of prey were more or less constant and did not change much from year to year. Their populations could, therefore, shift to areas of denser mice populations, but no larger concentrations of these predators could be expected. The situation may be different if a local increase of voles takes place, while their density remains low in surrounding areas. This occurred in alfalfa fields, which offer especially favorable conditions to *Microtus guentheri.* So, for instance, in March, 1952, an alfalfa field of 100 acres was found to be heavily infested with *Microtus,* with an estimated density of 200-300 per acre. Around each burrow the plants were grazed down to the ground on several square meters, exposing the voles to predation. Eight eagles, 11 buzzards, 13 kites, 3 harriers, and 7 kestrels were counted on these 100 acres. Some of these birds, however, may have been migrants which stopped during migration at this ample source of food.

The influence of mass outbreaks of voles and other field mice on the reproduction rate of predators may be considerable. During the 1949-50 outbreak it was found that mongoose *(Herpestes i. ichneumon* Linnaeus, 1758) and wild cat *(Felis lybica tristrami* Pocock, 1944) had not only one litter in spring, as usual, but also a second one in summer. Barn owls were found to nest almost the year round, rearing larger broods than usual, and, probably because of lack of proper nesting sites, were found to nest in unconventional places such as on the ground in dense thickets. Up to nine nestlings were found in a family, whereas generally barn owls in Israel rear only four to five nestlings. Long-eared owls *(Asio otus)* and short-eared owls *(Asia flammens),* which generally do not breed in Israel, do so almost regularly during mass outbreaks of field mice. All these predators, reproducing in Israel, had much less influence, because of their local distribution, than the wintering birds of prey with their high density.[3]

The connection between populations of field mice and diurnal birds of prey has been well demonstrated by the influence of field-mice poisoning on these birds (Mendelssohn, 1962). Thallium sulfate-coated wheat was recommended by Bodenheimer (1949) for field-mice control, and different concentrations were tried, containing between 1.2 to 1.7 per cent thallium sulfate in the wheat bait. Bodenheimer eventually recommended a preparation containing 2 per cent thallium sulfate, and this was used until 1964. This preparation was prepared locally and used for the first time during the vole outbreak in 1930-31. It was also used during the

[3] The influence of the increase of rodent populations on the reproduction rate of predators has been summarized by Elton (1942) and by Lack (1954). Dawaa (1961) reports on the increase of *Aquila rapax, Buteo hemilasius* and *Vulpes corsac* in relation with the increase of *Microtus brandti* populations.

outbreak in 1939-40 but still on relatively restricted areas and only during the outbreak. Another large outbreak occurred in 1949-50, when field-mice control using thallium sulfate-coated wheat was recommended by the Plant Protection Department of the Ministry of Agriculture and carried out on a large scale. The poison baits were distributed repeatedly over large areas. The original instructions were to put up to twelve poisoned grains in every occupied burrow, whereas actually one or two poisoned grains alone contained the lethal dose. Soon the poison bait was, however, distributed wholesale over the fields, at first manually and later on mechanically or by planes. Whereas, according to the directions, not more than 1600 grams of bait per acre should be distributed, equivalent to about 15 poison grains per square meter, evidence showed that generally much larger quantities were used. This very dense distribution of the thallium sulfate-coated grain made it possible for the mice to ingest much larger amounts than the minimum lethal dose.

Thallium is a poison which is only slowly excreted by the body. It works slowly, causing paralysis and finally killing the mice after several hours and up to two days. As the poisoned mice move slowly on the surface of the ground, and have difficulty in reaching their burrows, they are easy victims of birds of prey and other predators.

The field-mice-control actions actually attracted larger than ordinary concentrations of diurnal birds of prey to the fields on which the poison had been distributed, as larger numbers of mice were to be seen on the ground and were easily caught. Beginning from the fifth day after the distribution of thallium bait, paralyzed and dead birds of prey were found in the fields. The development of the thallium paralysis in birds of prey presents a very typical picture. First the flight of the birds is labored and unsteady, and then they are unable to fly but still are able to stand. Later they are unable to keep their wings in the normal posture and the wings droop. Then the leg muscles become paralyzed; the bird is unable to stand; it squats on the tarso-metatarsus, leaning on the drooping wings and the tail. Soon it is unable to lift its head and eventually it lies prostrate on the ground and soon dies. Full development from the first external signs of poisoning to death will take between three to ten days depending on the amount of poison ingested. Partially paralyzed birds, which are already unable to stand, may still recover if artificially fed. In the field, however, probably all birds which start to develop paralysis eventually succumb because even partly paralyzed birds are unable to feed or to adopt the proper posture if it rains; they become soaked, are unable to keep up thermoregulation and die of exposure.

Birds found paralyzed or dead in the fields after distribution of thallium sulfate were examined and found to contain large amounts of thallium. Even birds of prey which did not display external signs of thallium poisoning and were tested for thallium were also found to contain certain amounts of it.

Captive birds of prey, fed experimentally on thallium-poisoned mice, developed the same form of paralysis as observed in the field and eventually died. Experimental birds fed continually on thallium-poisoned mice took more time to develop paralysis than the time interval between thallium application and appearance of paralysis in birds in the field. Buzzards and kites used in these experiments generally refused food on the eighth day of the experiment and displayed the first signs of paralysis the next day. There may be two reasons for this difference; the food consumption of birds in the field may be larger than in the laboratory, and they will therefore ingest larger amounts of thallium in less time. They may not ingest lethal amounts of thallium after one control action, but accumulate increasing amounts of this slowly excreted poison during successive control actions, until the lethal level is reached.

trol actions, until the lethal level is reached.

Before 1949-50, poison bait was distributed only during an actual field-mice outbreak; but after the outbreak of 1949-50, poisoning was repeated several times every year in most areas. The reason for this activity may not have been real need, but rather that during the outbreak of 1949-50 a department for field-mice control was established and continued active even when no subsequent damage was caused.

Whereas prior to 1949-50 the influence of the thallium sulfate on populations of diurnal birds of prey had not been conspicuous, afterward this influence was felt increasingly. The larger part of the wintering populations of birds of prey was eliminated by secondary poisoning during the years 1950 to 1955-56. Several years later the most common species of mice-feeding birds of prey had disappeared almost entirely, because field-mice control by repeated intensive application of highly concentrated thallium bait was selectively destructive to field-mice predators.

As most of the field-mice control actions were carried out during the winter, wintering birds of prey, whose staple food was small rodents, were most severely affected. During the summer, fewer actions against field mice were carried out, and therefore the breeding birds of prey were less affected and were slower to disappear.

In Table 28-1 an attempt is made to compare the populations of birds of prey prior to the extensive field-mice-control campaigns and after them. When considering the table it should be kept in mind that in Israel there is almost none of the animosity toward birds of prey which is such a strong tradition in many other countries. Shooting of birds of prey has, therefore, no influence on their population. Besides, all birds of prey, like most other wild birds, are strictly protected by law in Israel and trespassers are fined.

Besides the already mentioned connection between the application of thallium-poisoned wheat and the occurrence of thallium poisoning among birds of prey, some unusual cases should be mentioned. During the autumn migration of 1961, a cinereous vulture *(Aegypius monachus)* was found with typical signs of thallium paralysis in Eilat on the shore of the Gulf of Aqaba. This case was considered to be strange, as no agriculture existed then in these desert surroundings. Upon investigation, it was found, however, that in the agricultural settlement of Yotvata, 35 kilometers to the north, thallium bait had been applied a week earlier. This case well demonstrated the slow action of the thallium and its consequently wide spatial influence. Another unusual case concerns a population of lappet-faced vultures *(Torgos tracheliotus).* A small resident population of this species exists in the Arava valley in southern Israel, entirely isolated from the main distribution area in Africa. This small resident population, which was estimated at about twenty-five pairs and about thirty to forty immature specimens, displayed a steady decline after 1950. It was found that part of the population was feeding on poisoned field mice in the area north and west of Beersheba, 90 to 150 kilometers to the west and northwest of the main distribution area of this population; poisoned birds were found there in the fields. Large vultures are supposed to feed on carcasses of large mammals. Feeding on poisoned, small rodents has, however, been reported also for the California condor (Koford, 1953).

Other birds, which occasionally also feed on mice, were also found to be poisoned by thallium, for instance cattle egrets (Bubulcus ibis) and purple herons (Ardea purpurea). Of the latter species, a considerable part of the breeding population of the Hula Nature Reserve was exterminated in June, 1960, and it was found that prior to this mass mortality of adult birds and nestlings, thallium had been distributed in the

Table 28-1

LIST OF FALICONIFORMES FOUND IN ISRAEL AND THERE POPULATION STAUS

SPECIES	PRIOR TO 195O				RECENT SITUATION			
	RESIDENT	SUMMER BREEDER	WINTER VISITOR	MIGRANT	RESIDENT	SUMMER BREEDER	WINTER VISITOR	MIGRANT
Pernis apivorus				Very common				Very common
Milvus migrans	Common and increasing		Extremely common	Extremely common	No recent observations		Very rare	Extremely common
Milvus milvus			Very rare				No recent observa-tions	
Accipiter gentilis			Very rare				No recent observa-tions	
Accipiter brevipes			Rare				No recent observa-tions	
Accipiter nisus			Very common	Common			Very rare	Common
Buteo rufinus		Common	Common	Common		Extremely rare	Extremely rare	Common
Buteo vulpinus			Very common	Very common			Very rare	Very common
Buteo Buteo			Common				Very rare	
Hieraëtus fasciatus	Common				Very rare (only in southern desert)			
Hieraëtus pennatus			Rare	Not Rare			Very rare	Not Rare
Aquila heliaca	Very rare (only-in southern desert)		Very common	Common	Very rare (only in southern desert)		Extremely rare	Common

Table 28-1 (continued)

SPECIES	PRIOR TO 195O				RECENT SITUATION			
	RESIDENT	SUMMER BREEDER	WINTER VISITOR	MIGRANT	RESIDENT	SUMMER BREEDER	WINTER VISITOR	MIGRANT .
Aquila nipalensis			Fairly common	Common			No recent observations	Common
Aquila clanga	Rare		Very common	Common	No recent observations		Extremely rare	Common
Aquila pomarina			Very common	Common			Extremely rare	Common
Aquila verreauxei	Occasional				Occasional			
Haliaëtus albicilla	Very rare				No recent observations			
Torgos tracheliotus	Not rare in southern desert				Rare			
Aegypius monachus			Not Rare	Rare			No recent observations	Rare
Gyps fulvus	Common			Not Rare	Quite rare			Not Rare
Neophron percnopterus		Very common		Not Rare		Extremely rare		Not Rare
Gypaëtus barbatus	Very rare				Very rare			
Circus cyaneous			Not common				Extremely rare	
Circus macrourus			Very common				Extremely rare	
Circus pygargus			Rare				Extremely rare	

Table 28-1 (continued)

SPECIES	PRIOR TO 195O				RECENT SITUATION			
	RESIDENT	SUMMER BREEDER	WINTER VISITOR	MIGRANT	RESIDENT	SUMMER BREEDER	WINTER VISITOR	MIGRANT
Circus aerugiosus	Not rare (local)		Very common		No recent observations		Rare	
Circaëtus gallicus		Common		Not Rare		Common		Not Rare
Pandoin haliaëtus			Fairly Common				Very rare	
Falco biarmicus feldeggi		Not rare				No recent observations		
Falco biarmicus tanypterus	Fairly common				Rare (only) in shouthern desert	Not rare		
Falco cherrug			Fairly Common				No recent observations	
Falco peregrius		Very rare	Common			Very rare	Very rare	
Falco subbuteo		Fairly Common						
Falco eleonorae			Occasional				Occasional	
Falco concolor		Very rare						
Falco columbarius			Fairly Common		Very rare (only in southern desert)		No recent observations	
Falco vespertinus				Rare				No recent observations
Falco naumanni		Extremely Common	Fairly Common	Common	Very rare (only in southern desert)	No recent observations	No recent observations	Common
Falco tinnunculus	Extremely Common		Common		Quite rare, lately increasing		Rare	

fields of the Hula Valley.

The decline of populations concerns all species of birds of prey in Israel except one. This one species, which succeeded in keeping its numbers at about the same level, is the short-toed eagle *(Circaetus gallicus),* who feeds exclusively on reptiles, mostly snakes. Reptiles are apparently little influenced and contaminated by pesticides. It would, of course, be possible for snakes to feed on thallium-poisoned mice after field-mice-control action during the summer. The food intake of snakes is, however, much lower than that of endothermic animals and seems, therefore, to effectively prevent any considerable accumulation of thallium in their bodies. The short-toed eagle seems even to have increased in some areas. This might perhaps be explained by lack of competition for nesting sites after other birds of prey disappeared. Another reason could be the disappearance of the long-legged buzzard *(Buteo rufinus),* who perhaps competed formerly with the short-toed eagle for food, as it feeds partly on reptiles.

The changed status of birds of prey in Israel, before and after the widespread application of thallium, is summarized in Table 28-1. In the column "migrant," only those species are mentioned which are conspicuous during migration. Breeding species which survived in reduced numbers after introduction of thallium did so mainly in mountainous areas or in the southern desert, where thallium was not used much.

The influence of other pesticides, especially the persistent organochlorine compounds, cannot of course be ruled out, as these pesticides have been used extensively in agriculture in Israel since about 1950. The exaggerated use of pesticides in Israel is corroborated by the high amount of residues in human tissues (Wassermann, 1967). The influence of insecticides is probable in birds like the lesser kestrel *(Falco naumanni),* which feeds mostly on insects, and has disappeared entirely as a breeding bird. This bird was the most common of birds of prey breeding in Israel prior to 1949-50. Other birds of prey may also have been influenced by persistent pesticides other than thallium, but there was then no possibility in Israel to examine carcasses for other pesticide residues besides thallium. The influence of thallium is, however, proved not only by the results of post-mortem examinations and by feeding experiments, but also by the temporal relation between the application of thallium in the field and mortality of birds of prey. The influence of persistent organochlorine insecticides on birds of prey, causing mortality as well as lowering fertility, is well known by now (Ames, 1966; Lockie and Ratcliffe, 1964; Moore, 1964; Moore and Walker, 1964; Prestt, 1965, 1966; Ratcliffe, 1965, 1967). Fertility may also be influenced adversely already in mice, the second link in the food chain leading to birds of prey (Bernhard and Gaertner, 1964).

After the large vole outbreak of 1949-50, the tendency for cyclic mass reproduction was obscured by the large-scale application of poison baits in all agricultural areas. However, field-mice populations obviously tended to build up large populations at irregular intervals and irregularly in different areas, in which favorable conditions prevailed. This accords with Elton's (1942, p. 59) assumption that "partial reduction of the population may prolong the plague at a lower, though still formidable, level." It seems that the almost complete elimination of one extermination factor, that of predation, upset the balance existing between the mice population and its extermination factors.

In the semiarid areas of the western Negev, other species of mice, especially Tristram's jird *(Meriones tristrami),* were increasing periodically and occasionally causing damage to grain crops. Here the formerly mentioned wintering birds of prey occurred in less dense

tering birds of prey occurred in less dense populations, but three other species were common predators of field mice in winter: *Aquila rapax orientalic, Buteo rufinus* and *Falco cherrug.* Thallium was applied and birds of prey were exterminated by secondary poisoning in this area, too. Because of the irregular precipitation, growing of grain crops without irrigation has been discontinued in recent years in the more arid parts of this area and, therefore, field-mice control was discontinued as well. In 1965-66 there occurred an unprecedented mass increase of all the gerbil species inhabiting the area: *Meriones tristrami, Meriones sacramenti, Gerbillus pyramidum* and in parts of the area also *Gerbillus allenbyi.* This mass increase was probably made possible by the absence of the birds of prey which previously had wintered here and by the discontinuation of poison bait. The dense populations of mice, vulnerable to predation because of the thin plant cover, attracted large concentrations of migrant birds of prey, mostly black kites *(Milvus migrans)* but also long-legged buzzards *(Buteo rufinus)* and Egyptian vultures *(Neophron percnopterus).* Whereas in former years few birds of prey occurred in this area in summer, many immature birds of the mentioned species, especially kites, did not migrate and remained. In July, 1966, it was found that a relatively large number of burrows were deserted. Lack of food may have been one reason for the decline of these mice populations, as in many places actually all the plants were collected near the burrow entrances and deprived of all their seeds. Predation, however, was also conspicuous, as remnants of these jirds and gerbils were found in the pellets regurgitated by these birds, proving that they actually fed on these rodents.

INFLUENCE OF THALLIUM AND OTHER PESTICIDES ON BIRDS

The wholesale use of thallium bait had, of course, also affected the grain-eating birds. The collared dove *(Streptopelia decaocto),* for instance, which in Israel is not anthropophilous as it is in Europe but lives in open fields, was most conspicuously injured. The populations of this bird increased considerably after reduction of hunting pressure, but later the population decreased again in direct correlation with the increasing application of thallium. In contrast a related bird, the palm dove *(Streptopelia senegalensis),* which in Israel lives only in towns and villages and does almost no feeding in fields, increased continuously and is still doing so. Other birds were harmed as well; for instance, in January, 1960, in the Hula Nature Reserve, hundreds of starlings and dozens of mallards were found dead after application of thallium in the fields surrounding the nature reserve. Both starlings and mallards were found to contain large amounts of thallium. Chukar partridges (Alectoris graeca), which are very common in Israel, were not much affected by thallium, as they live mainly in hilly areas and do little feeding in the plains where thallium is mostly applied. However, some partridges which were found dead contained large, probably lethal, amounts of thallium. Other specimens which were shot during the open season were found to contain small amounts of thallium. In Israel the Chukar partridge is the main food of the Bonelli's eagle *(Hieraëtus fasciatus),* which has been the only common resident eagle. The disappearance of this eagle between 1955 and 1965 is probably due to slow thallium poisoning via the Chukar partridge. As relatively little thallium is found in Chukar populations, its influence on Bonelli's eagles may have developed very slowly. No dead eagles of this species

were found, and therefore no examination for thallium could be made on carcasses. However, a bird with typical first-stage signs of thallium poisoning was observed in spring 1955, and thereafter the populations began slowly to disappear. One nesting site after another became deserted; even earlier only one chick was reared instead of the ordinary two, or no young were reared at all. Small flocks of the European crane *(Megalornis grus)* which were wintering in plains inhabited by *Microtus guentheri* were also almost entirely exterminated by thallium during 1956-1959. They displayed the typical form of paralysis; thallium was found in one bird examined after its death. As cranes may feed on grain as well as on mice, it is not known if the cranes were killed by direct or by secondary poisoning. The same uncertainty holds for the wintering populations of rooks *(Corvus frugilegus)* and jackdaws *(Corvus monedula),* which might feed on poisoned grain as well as on poisoned mice. Wintering rooks disappeared entirely from Israel, and jackdaw populations were reduced to a small percentage of the huge flocks wintering here in former years.

As already mentioned, it is very possible that pesticides other than thallium, especially the persistent organochlorine insecticides, played a certain role in the disappearance of birds of prey. The long-lived, late-maturing birds of prey are apparently more vulnerable to the influence of these pesticides, as they may accumulate high concentrations of residues even before they mature. Some other earlier-maturing birds did not display the same influence of pesticides on their populations; or perhaps they may be able to withstand higher concentrations in their tissues.

Another case concerns the cattle egret *(Bubulcus ibis),* which established breeding colonies in Israel in highly contaminated agricultural areas after 1950 and thereafter increased, notwithstanding its living and feeding in areas in which pesticides are constantly applied. Cattle egrets, which feed on small vertebrates, including rodents, as well as on insects, were occasionally found to have been poisoned by thallium; specimens affected with tremors and convulsions were also found, indicating acute poisoning by DDT or related compounds. Still the size of their populations was not affected. One important factor may be that cattle egrets mature when one year old, not like most birds of prey, which mature at the age of two or more. It should also be noted that notwithstanding their continual exposure to pesticide contamination, the fertility of cattle egrets has not been adversely influenced; three nestlings still are generally reared from each clutch, and breeding continues from March to August and in some colonies even in winter.

Two other species of birds which apparently are not affected by pesticides, even though they live in agricultural areas, are the white-breasted kingfisher (*Halcyon smyrnensis)* and the hoopoe (*Upupa epops).* Both species feed extensively on mole crickets *(Gryllotalpa),* which build up dense populations in irrigated areas. Mole crickets are a bad pest to agriculture and are controlled more or less successfully in Israel by dieldrin application. Even though the kingfisher and the hoopoe feed in many cases on dieldrin-poisoned mole crickets, their populations are still not affected; no poisoned birds have been found and the populations of the hoopoe have increased considerably in recent years. Another case concerns the bulbul *(Pycnonotus capensis),* which lives in orchards and feeds on fruit that is constantly sprayed with pesticides. But still populations are not affected; on the contrary, the bulbul has increased to such a degree that it has become an important pest.

JACKAL CONTROL

Among the mammals, one species which adapted excellently to the conditions existing in agricultural areas and near dense human populations is the jackal *(Canis aureus).* Jackals built up large populations, especially in the densely populated coastal plain of Israel. In many areas they reached a density of several specimens per square kilometer. Jackals are omnivorous, mainly scavengers, but they also prey on many kinds of animals up to the size of hares or lambs. Their influence on populations of other animals is especially prominent when their own populations are dense. Around the settlements on the north end of the Dead Sea, jackals built up a population which grew from a few specimens in 1933 to several hundred in 1946. This jackal population fed mainly on the garbage of the settlements, but had by 1945 almost completely exterminated the formerly very common sand rat *(Psammomys obesus),* whose populations decreased in proportion to the increase of jackals. As jackals fed also on a variety of fruits and vegetables, they caused damage to agriculture. They were also supposed to play a role in the epidemiology of rabies, although the main source of rabies in Israel is feral dogs. For almost fifty years attempts were made to control jackal populations by application of poisoned baits, mainly strychnine. Success was only moderate and jackal populations continued to increase. The use of strychnine was more conspicuous in the decrease of the numbers of griffon vultures *(Gyps fulvus).* Both species fed on strychnine-poisoned bait, but griffon vulture populations were much more affected because of their low reproduction rate and late maturation. Griffons lay their first egg when five or six years old and rear one chick; jackals have their first litter when one or two years old and rear four to eight cubs. Jackal populations are therefore much better able to withstand losses.

In 1964 and in 1955 the Plant Protection Department undertook an extensive campaign to eradicate jackals by distributing bait in which a 15 per cent fluoroacetamide solution was injected. These poison baits were distributed wholesale; uneaten baits were not collected, and no care whatsoever was taken to prevent poisoning of animals other than jackals. The influence of this action was extremely disastrous, as small chicks were used as bait and proved to be attractive for many animals. Jackals disappeared almost entirely, but so did other small mammal predators as well: mongooses, wild cats, and foxes. Some birds also decreased conspicuously, especially the hooded crow *(Corvus corone),* which had been very common in the same areas as the jackal. Along with the crows, the crested cuckoo *(Clamator glandarius),* which parasitizes the hooded crow in Israel, became very rare.

The most conspicuous result of the disappearance of the jackal was, however, an enormous increase of hares *(Lepus europaeus)* which in 1967-68 reached a density of one or even more per acre in some areas, a density unprecedented prior to jackal extermination. The damage done by the hares to agriculture in many cases was greater than that done earlier by jackals.

The results of the jackal extermination campaign were felt also in the increase of the populations of a reptile, the Palestine viper *(Vipera xanthina palaestinæ).* This venomous snake takes well to agricultural settlements, where it finds more moisture in summer than in natural surroundings, where moisture is apparently suboptimal for this snake. An ample supply of food in the form of mice and rats is also available to the snakes in agricultural settlements. Therefore, vipers had developed well-established populations in and near agricultural settlements. Viper populations seemed to increase considerably after the jackal extermination campaign, and this is probably connected

with the concomitant disappearance of the mongoose *(Herpestes ichneumon),* which preyed to a large extent on reptiles, including vipers. Possibly, mongooses kept the viper populations in check, as mongooses had been also common near settlements.

DISCUSSION

The disastrous influence of pesticides on birds of prey is apparent in many countries. There are two obvious reasons for the vulnerability of these predators: they are located at the end of food chains and they mature late, especially the larger species. The latter have a low reproduction rate as well. Generally the chlorinated hydrocarbon pesticides are supposed to be the cause of the decline in the populations of birds of prey. In this paper, secondary poisoning by thallium has been demonstrated. It is highly possible that a more sparse application of thallium in lower concentrations could effectively control field mice and prevent damage without causing secondary poisoning and thus selectively destroying biological control. The intense application of thallium, as described in this paper, was favored by the Plant Protection Department "in order to eradicate field mice entirely all over Israel" (Y. Naftali, personal communication). This aim has not been reached. So far, mice populations still increase and decrease; increase has to be stopped by application of poison.

If they are compared to some other birds which are also on the end of food chains, it is somewhat difficult to understand the vulnerability of birds of prey to secondary poisoning. In North America, gulls were found to carry very high amounts of pesticide residues (Stickel, 1968). In England, populations of the heron *(Ardea cinerea)* were less affected than birds of prey (Prestt, 1966), and this was also found to be the case in Israel with the cattle egret, the hoopoe and the white-breasted kingfisher. Besides, these last three species live in highly contaminated surroundings, whereas some birds of prey lived in little-contaminated areas and still were reached by pesticides. Possibly, the actual physiological vulnerability toward pesticides is different in different families of birds.

Biological control of pests among vertebrates seems to be rare. Apparently such a relation existed between field mice and wintering birds of prey in Israel. It is highly probable that the birds of prey which wintered in Israel depended for long periods mainly on the rodent species living in open fields for their staple diet. It is now impossible to study this relation thoroughly, and the situation can only be considered retrospectively. This case, however, demonstrates how easily a relatively well balanced situation may be upset by a single individual, if ecological considerations are not taken into account. Quite recently a similar case occurred when, in an attempt to eradicate the jackal populations, all species of mammalian predators were heavily decimated, causing an increase of prey species which became pests.

From 1964 on, thallium sulfate was replaced by fluoracetamide as field-mice poison. Wheat soaked in a 0.2 per cent solution is now being used as poison bait, being applied and distributed according to the same regulations laid down for thallium sulfate. In laboratory experiments it was found that fluoracetamide, in the same concentration as that used for field-mice control, did not cause secondary poisoning to birds of prey, but proved to be dangerous to mammals fed on fluoracetamide-poisoned mice. It is, however, not known if there are any long-term effects on birds of prey.

Recently experiments were performed in order to test whether effective field-mice control could be obtained by applying smaller amounts of poison per area than those recommended by the Plant Protection Department. The experi-

ments were carried out by Z. Zook-Rimon of the Nature Protection Research Institute of Tel-Aviv University. The test animal was the jird, *Meriones tristrami,* and the populations were checked by trapping, marking and re-trapping. It was found that one wheat grain soaked in a 0.2 per cent fluoracetamide solution and containing 0.08-0.1 milligram of the poison, was sufficient to kill a jird.

For control experiments in the field, the same poisoned wheat was used. On three experimental plots of twelve acres each with 10 grains per square meter, the following different mixtures were used: only poisoned grains, poisoned grains mixed with unpoisoned ones in ratios of 1 to 5 and of 1 to 10. In all three cases, the same measure of control was obtained, proving that 1 poisoned grain per square meter is as effective as the 15 poisoned grains per square meter recommended by the Plant Protection Department. Secondary poisoning of predators is, however, less probable if the field mice ingest only the minimum lethal dose by feeding on one poisoned grain among a number of unpoisoned ones than by feeding on poisoned grains only and ingesting several times the lethal dose. The disastrous effects of thallium and the destruction of the biological control of field mice in Israel could probably have been avoided by a more careful application of the poisoned bait.

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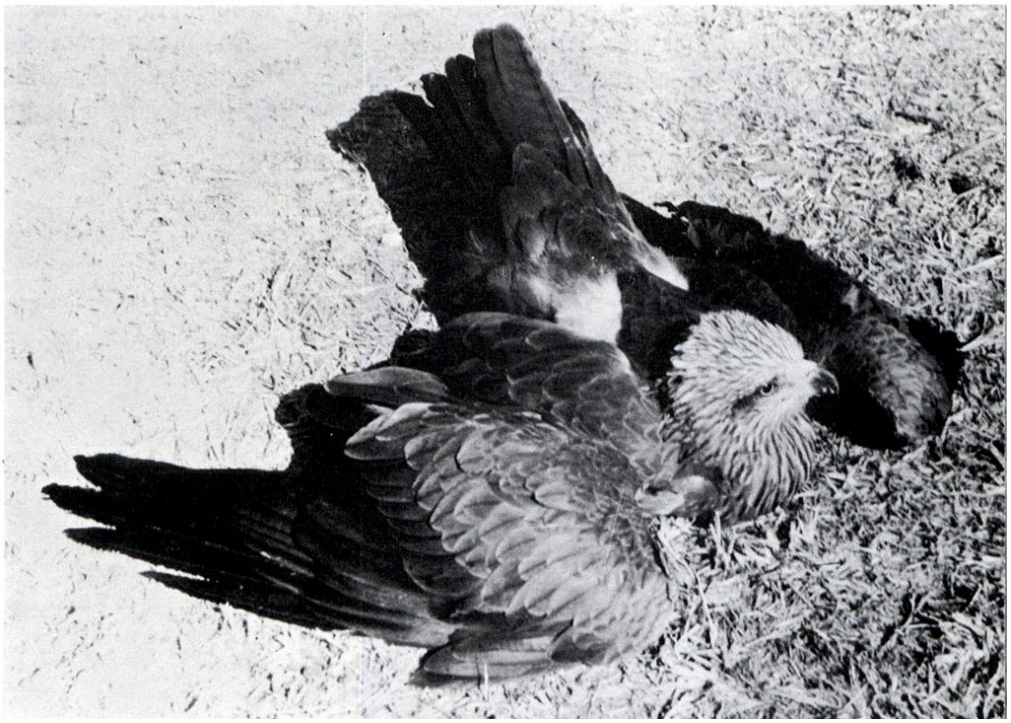
Diurnal birds of prey were common in Israel prior to 1950. Their main food was field mice. In his paper **ECOLOGICAL EFFECTS OF CHEMICAL CONTROL OF RODENTS AND JACKALS IN ISRAEL** (Page 527), Dr. Mendelssohn explains the widespread effects of the use of thallium sulfate-coated wheat to control field mice. The application of large quantities of thallium sulfate was repeated every year until recently, even though there was no apparent increase of field mice population. One unanticipated result of this application was the death and paralysis of birds of prey in the fields. Even in areas where thallium was not used, the dead birds of prey were found to contain thallium. The photos show two lappet-faced vultures *(Torgos tracheliotus)*— one dying, one dead— found in 1957 after distribution of thallium bait in Bet Qama, about 20 kilometers north of Be'er Sheva.

28-1



28-2