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# ECOLOGICAL EFFECTS OF CHEMICAL CONTROL OF RODENTS AND JACKALS IN ISRAEL

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## INTRODUCTION

Israel is situated in an area in which several zoogeographical regions overlap. Thus, it has a relatively rich fauna, notwithstanding its small area of approximately 20,000 km.$^2$. The impact of modern development on the fauna has been conspicuous, influencing many species adversely, due to changing of the environment, by pollution and by pesticides, and favoring other, adaptable species, some of which have become pests. In the present paper mainly the northern and the central parts of Israel will be considered. These areas have a mediterranean climate, which turns arid towards the south. They have been much more influenced and changed by development than has the southern desert.

## FIELD MICE, THALLIUM AND BIRDS OF PREY

Among the 26 species of rodents occurring in Israel, one species, the levant vole (*Microtus quentheri quentheri* Dunford and Alston, 1880)* has displayed regular cycles of mass reproduction, with two other species, Tristram's jird (*Meriones tristrami* Thomas,

* *Microtus quentheri philistinus* Thomas, 1917 does not seem to be different morphologically from *Microtus q. quentheri*, if variability in size and color in populations from northern and central Israel is considered.

1892) and the house mouse (*Mus musculus praetextus* Brants, 1827) participating to a certain degree in these cycles (Bodenheimer, 1949). It was probably *Microtus guentheri* whose mass reproduction was already mentioned in the Bible and which 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 3 to 5 year cycles in between.

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). Bodenheimer (1949) 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.

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 in their upper parts, forming large cracks on the surface, but retaining a certain amount of humidity in the deeper layers. _Microtus guentheri_ prefers humid soils and is able to survive and 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 6 to 8 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 now for food 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 one of these two species, causing damage sometimes also in the southern 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 $m^2$ (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. 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 $m^2$ 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 $m^2$ in spring or even more; according to Bodenheimer (1949) even 500 per 1000 $m^2$ in some cases. Only under these circumstances is real damage caused by these field mice.

The question arises how far 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 Palestine 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% 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; and 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 38 species, part of which were winter visitors, whereas others were 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, those species are important which live in open country and feed mainly on small rodents. Important as well are those among them which were common; these are 8 species of winter visitors and 4 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. During summer, however, mice were represented to a lesser extent in the food of the four 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 population density than voles and other field-mice, appeared surprisingly often in the food of diurnal birds of prey, especially of the Egyptian vulture and the Black Kite. These victims were mostly the young of the year, 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, 8 species have been common enough to be considered to have had a certain influence on field-mice populations. These species are: 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, of which the second one has been more common than the first one; the black kite Milvus m. migrans; the harrier Circus macrourus and the kestrel Falco tinnunculus. 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 15 counts which were 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 $km^2$ of grain-field areas was: two eagles, including Aquila heliaca, Aquila pomarina and Aquila clanga, ten buzzards, four kites, four harriers (mostly Circus macrourus) and 12 kestrels. The counts were made in the vicinity of the town Afula in northern Israel, about 35 km southeast of Haifa. Afula is situated in a vast plain, which is typical Microtus guentheri country. In this uniform, open country, counting of the birds was not very difficult. Counts were made on three consecutive days along strips 300 m. broad.

In order to ascertain the average daily food consumption of these birds when feeding on small rodents, experiments were carried out with captive birds of these species, which were fed on mice and rats of 20-90 gr. weight. It was found that the average daily food intake for birds which kept their normal weight for 10 to 14 days was: for eagles 200 gr., for buzzards and kites 90 gr., for harriers 60 gr. and for kestrels 40 gr. According to these observations food consumption of the diurnal birds of prey living on an area of 10 $km^2$ would be 2380 grams of food per day. This food consumption must be considered as minimal, as it is based on birds kept in captivity, whereas birds in nature are more active and probably have a 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 considered as being 30 gr., as few of them reach an age of 100 days and a weight of 40 gr. (Bodenheimer, 1949). The 32 birds of prey living on an area of 10 $km^2$ would therefore remove per diem 79 voles from this area or 2370 voles per month. As during an average year the vole population per 1000 $m^2$ was about 1, and on 10 $km^2$ therefore, 10,000 , the removal by birds of prey per month of 2370 voles 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 deccelerate increase.

Nothing is known about the reproduction rate of the levant vole in nature, neither in normal nor in 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 possible regulatory influence of predation on field mice populations holds good only during normal years. As soon as the reproduction rate of the mice rises and a mass-increase develops, the role of predation decreases relatively. Even though areas of a mass-outbreak of field-mice attract all kinds of predators, among which the increase in diurnal birds of prey is very conspicuous because of their diurnal activity, still the increase in their population density is much less than the increase in mice populations. During the height of the 10-year cycle of Microtus guentheri, vole populations may increase 25 or even more times their normal density, whereas the increase in population density of birds of prey was found to be not more than 3 times the average density and generally not more than two times. The influence of predation on field-mice populations is, therefore, really 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, whereas in the surroundings their density remains low. 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 9 nestlings were found in a family, whereas generally barn-owls in Israel rear only 4 to 5 nestlings. Long-eared owls (Asio otus) and short-eared owls (Asio 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. 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.

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 outbreak in 1939/40 but still on relatively restricted areas and only during the outbreak. Another large outbreak occurred in 1949/50. Now field-mice control using thallium sulfate-coated wheat was propagated and carried out on a large scale. The poison baits were distributed repeatedly over large areas. The original instructions were to put several poison grains in every occupied burrow. Soon the poison bait was, however, distributed wholesale over the fields, at first manually and later 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 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 causes the death of the mice after several hours or 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 prey to birds of prey. Actually the field-mice control actions 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 than usual 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, 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 death soon follows. Full development from the first external signs of poisoning to death may take between 3 to 10 days. 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, as even partly paralyzed birds are unable to feed. Besides, paralyzed birds are unable to adopt the proper posture in case it rains; they become soaked, are unable to keep up thermoregulation and die of exposure.

Birds which were found paralyzed or dead in the fields after distribution of thallium sulfate, and which were examined, were 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.

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 the birds in the field may be larger than in the laboratory and they will, therefore, ingest larger amounts of thallium in less time. On the other hand, 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.

Contrary to the situation prior to 1949/50, when poison bait was distributed only during an actual field-mice outbreak, after the outbreak of 1949/50, poisoning was continued several times every year in most areas. The reason for this activity may have been not so much one of real need, but the fact that during the outbreak of 1949/50 a department for field-mice control was established, which continued to be active even when no damage was caused after this outbreak.

Whereas prior to 1949/50 the influence of the thallium sulfate on populations of diurnal birds of prey had not been conspicuous, now this influence was felt increasingly from year to year. The larger part of the wintering populations of birds of prey were eliminated by secondary poisoning during the years 1950-1955/56. Several years later the most common species of mice-feeding birds of prey had disappeared almost entirely, as this way of 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 rodenst, were most intensively affected. During the summer less actions against field-mice were carried out, and therefore the breeding birds of prey were less intensively affected and were slower to disappear.

In Table 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 towards 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 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 km. to the north, thallium bait had been applied a week earlier. This case demonstrated well the slow action of the thallium and its 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 as being composed of about 25 pairs and about 30-40 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 Beer Sheva, 90 to 150 km. to the west and north-west of the main distribution area of this population; poisoned birds were found there in the fields (Fig. 1). 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, as 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 fields of the Hula Valley.

The decline of populations concerns all species of birds of prey in Israel besides 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 a field-mice control action undertaken 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 status of birds of prey in Israel, before and after the widespread application of thallium, is summarized in Table 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 only in mountainous areas or in the southern desert, where thallium was not used much.

The influence of other pesticides, especially the persistent organochlorine compounds, can of course not be ruled out, as these pesticides are 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. This bird was the most common of birds of prey breeding in Israel prior to 1949/50 and has disappeared entirely as a breeding bird. 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; Moore, 1964; Moore and Walker, 1964; Prestt, 1965, 1966; Ratcliffe, 1963). Fertility may 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. There was, however, an obvious tendency in field-mice populations to build up large populations at irregular intervals and irregularly in different areas. This is in accordance 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 may well be that the almost complete elimination of one extermination factor, of predation, working during the main reproductive season, upset the temporary balance existing during winter between the increase of mice populations and the different extermination factors.

In the semi-arid 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 populations, but three other species were common predators of field mice in winter: Aquila nipalensis, 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 withoug irrigation has been discontinued in recent years in this area and, therefore, field-mice control was discontinued as well. In 1965/66 there occurred here 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 (Fig. 2). This mass increase was probably made possible by the absence of the birds of prey, which earlier had wintered here, and by the discontinuation of applying poison bait. The dense populations of mice, vulnerable to predation because of the thin plant cover, attracted large concentrations of 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 a reason for the decline of mice populations, as in many places actually all the plants were collected near the burrow entrances and deprived of all their seeds (Fig. 3). Predation was, however, conspicuous also, 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, some direct influence as well on 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 influenced. The populations of this bird increased considerably after reduction of the hunting pressure, but later the population decreased again in direct correlation with the increasing application of thallium. On the other hand, 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 more or less influenced 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. Starlings as well as 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 were found to contain 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 resident eagle that has been fairly common. The disappearance of this eagle, which took place between 1955-1965, 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 much more 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 prior to this only one young 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 1956-59. They displayed the typical form of paralysis, and thallium was found in one bird examined after its death.

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

One case concerns the cattle egret (Bubulcus ibis), which established breeding colonies in Israel in highly contaminated agricultural areas after 1950 and the population increased, notwithstanding their living and feeding in areas in which pesticides are constantly applied. Cattle egrets, which feed on small vertebrates as well as on insects, were occasionally found to have been poisoned by thallium; specimens were also found affected with tremors and convulsions, indicating acute poisoning by DDT or related compounds. Still their populations as such were not affected. One important factor may be that cattle egrets mature when one year old, and not like most birds of prey at the age of 2 or more years. It should be noted that notwithstanding their continual exposure to pesticide contamination, the fertility of cattle egrets is not adversely influenced, as three nestlings 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 with more or less success in Israel by application of Dieldrin. 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 increased considerably in recent years. Another case concerns the bulbul (Pycnonotus capensis) which lives in orchards and feeds on fruit which is constantly sprayed with pesticides, but still populations are not affected. On the contrary, the bulbul increased to such a degree that it became 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 sq. km. Jackals are omnivorous, mainly scavengers, but 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 was mainly based on the garbage of the settlements, but had in 1945 already almost completely exterminated the formerly very common sandrat (Psammomys obesus), whose populations decreased in proportion to the increase of jackals. As jackals feed also on a variety of fruits and vegetables, they cause damage to agriculture. They were also supposed to play a role in the epidemiology of rabies. The main source of rabies in Israel, however, is feral dogs. For almost 50 years attempts were made to control jackal populations by application of poisoned baits, mainly using strychnine. Success was only moderate and jackal populations continued to increase. The use of strychnine was more conspicuously felt 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 1965 the Plant Protection Department undertook an extensive campaign to eradicate jackals by distributing bait in which a 15% 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, which proved to be attractive for many animals. Jackals disappeared almost entirely, but so did other small mammal predators as well: mongoose, wild cats, foxes, and also some birds decreased conspicuously, especially the hooded crow (Corvus corone), which had been very common in the same areas in which the jackal was common. Together with the crows, the crested cuckoo (Clamator glandarius) which parasitises 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 palaestinae*). 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, mongoose kept the viper populations in check, as mongoose 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 cause a 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 so 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 having to be stopped by application of poison.

It is somewhat difficult to understand the vulnerability of birds of prey to secondary poisoning, if they are compared to some other birds which are also on the end of food chains. In England, populations of the heron (Ardea cinerea) were less affected than birds of prey (Prestt, 1966), and the same was 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 towards pesticides is different in different families of birds.

Biological control of pests among vertebrates seems to be rare. Perhaps such a relation existed between field-mice and wintering birds of prey in Israel. 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 has 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.

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SUMMARY

Thallium-sulfate-coated wheat has been used in Israel for rodent control. Its influence on the populations of diurnal birds of prey is described. The possible influence of predation by birds of prey on rodent populations is discussed. The influence of a jackal eradication campaign on other predators and on prey species is described.

ZUSAMMENFASSUNG

Thalliumsulfatweizen wurde in Israel zur Nagerbekaempfung verwendet. Die Auswirkungen dieser Methode auf die Populationen der Tagraubvoegel werden beschrieben. Der moegliche Einfluss der Raubvoegel auf Nagerpopulationen wird besprochen. Der Einfluss einer Schakalvernichtungsaktion auf andere Raubsaeuger und auf Beutetiere wird erwaehnt.

TABLE 1

LIST OF FALCONIFORMES FOUND IN ISRAEL AND THEIR POPULATION STATUS

| Species | Prior to 1950 | | | | 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 observations | |
| Accipiter gentilis | | | Very rare | | | | No recent observations | |
| Accipiter brevipes | | | Rare | | | | No recent observations | |
| 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 | Fairly common | | | Very rare | Fairly common |
| 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 |

List of Falconiformes (con't)

| Species | Prior to 1950 | | | | 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 cyaneus | | | Not common | | | | Extremely rare | |
| Circus macrourus | | | Very common | | | | Extremely rare | |
| Circus pygargus | | | Rare | | | | Extremely rare | |

List of Falconiformes (con't)

| Species | Prior to 1950 | | | | Recent Situation | | | |
|---|---|---|---|---|---|---|---|---|
| | Resident | Summer breeder | Winter visitor | Migrant | Resident | Summer breeder | Winter visitor | Migrant |
| Circus aeruginosus | Not rare (local) | | Very common | | | | Rare | |
| Circaëtus gallicus | | Common | | Not rare | Common | | | Not rare |
| Pandion haliaëtus | | | Fairly common | | | | Very rare | |
| Falco biarmicus feldeggi | | Not rare | | | | No recent observations | | |
| Falco biarmicus tanypterus | Fairly common | | | | Rare (only in southern desert) | | | |
| Falco cherrug | | | Fairly common | | | | No recent observations | |
| Falco peregrinus | | Very rare | Common | | | No recent observations | Very rare | |
| Falco subbuteo | | Fairly common | | | | Not rare | | |
| Falco eleonorae | | | Occasional | | | | Occasional | |
| Falco concolor | | Very rare | | | | Very rare | | |
| Falco columbarius | | | Fairly common | | | | No recent observations | |
| Falco vespertinus | | | | Rare | | | | No recent observations |
| Falco naumanni | | Extremely common | Fairly common | Common | | No recent observations | No recent observations | Common |
| Falco tinnunculus | Extremely common | | Common | | Quite rare lately in- | | Rare | |

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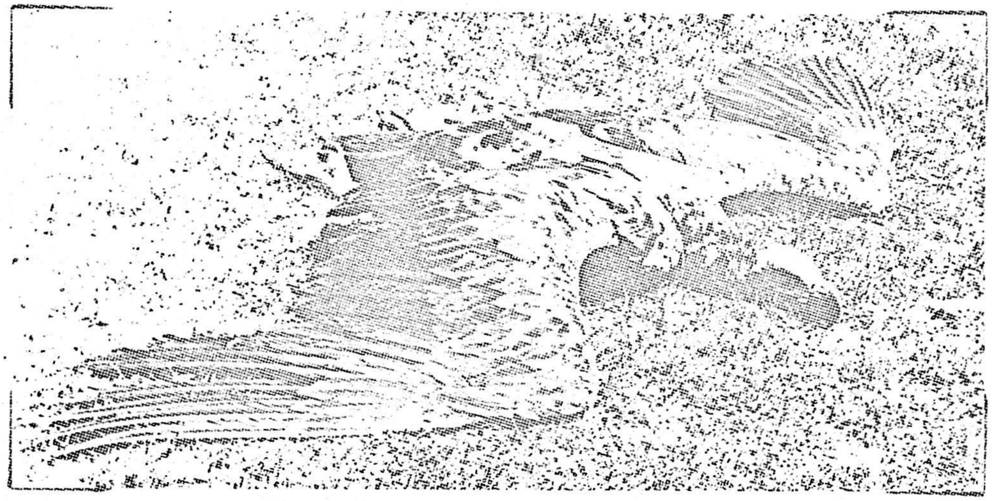

Fig. 1. Lappet-faced vulture (<u>Torgos tracheliotus</u>) found dying after distribution of thallium bait. Bet Qama (ca. 20 km. north of Be'er Sheva), September, 1957.

Fig. 2. Burrows of dense population of <u>Meriones tristrami</u>.
Urim (ca. 25 km. west of Be'er Sheva), 17.VII.1966.

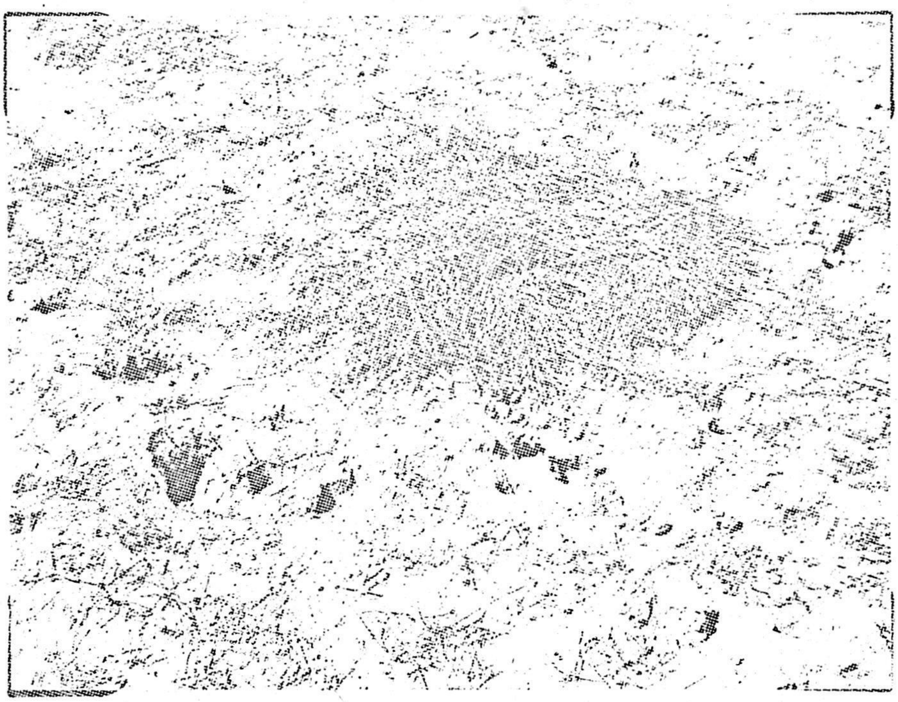

Fig. 3. Heap of food plants (mostly Erucavia boviana) stripped of their seeds, near burrow entrance of Meriones tristrami. Urim, 17.VII.1966.

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