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REVIEW OF HAZARDS TO RAPTORS FROM PEST CONTROL IN SAHELIAN AFRICA

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Abstract.—Pesticides applied to control pests sometimes kill raptors. One region receiving frequent and heavy pesticide treatments is the Sahel that lies between the Sahara Desert and tropical forest areas of northern Africa. Plagues of locusts, grasshoppers, birds and rodents periodically develop in the Sahel when heavy rainfall follows periods of drought. Insecticides, avicides and rodenticides are applied over millions of hectares at rates known to kill birds. Observations indicate that many pesticide applications in the Sahel do not cause serious mortality. Only minimal raptor losses were reported following applications of malathion, fenitrothion, chlorpyrifos and other insecticides for control of locusts and grasshoppers scattered over about 14 million acres in northern Africa. Similarly, applications of zinc phosphide bait on 430 000 ha in Sudan did not cause known losses of raptors. In contrast, use of fenthion to control Red-billed Quelea (*Quelea quelea*) in breeding colonies often killed or debilitated nontarget vertebrates, including raptors. A more specific avicide should be developed for quelea control. Until then, nontarget birds should be kept out of colonies for several days following avicide applications and dead quelea should be removed from treated areas.

Key Words: *Raptors; pesticides; locust control; quelea control; rodent control; Africa.*

Resumen de amenazas para las aves rapaces a partir del control de plagas en el Sahel, Africa

Resumen.—La utilización de pesticidas puede ocasionar la muerte de aves rapaces. Una de las regiones en donde se utilizan estas substancias con frecuencia y volúmenes importantes es el Sahel entre el desierto de Sahara y los bosques tropicales del norte de Africa. Periódicamente después de la sequía y con las fuertes lluvias ocurren erupciones de langostas, saltamontes, aves y roedores. Insecticidas, avicidas y rodenticidas son aplicados en millones de hectáreas en concentraciones que pueden eliminar a las aves. Algunas observaciones indican que muchas de las aplicaciones de pesticidas en el Sahel no causan una mortalidad importante. Algunos casos de aves rapaces han sido reportados después de la aplicación de malathion, fenitrothion, chlorpyrifos y otros insecticidas para el control puntual de langostas y saltamontes en una extensión de 14 millones de acres en el norte del Africa. En forma similar la utilización de cebos de fosfato de zinc en 430 000 hectáreas en Sudán no causó pérdidas conocidas en aves rapaces. En contraste, el uso del fenthion para el control de *Quelea quelea* en sus colonias de anidación ha ocasionado la muerte y/o afectado algunos vertebrados incluyendo a las aves rapaces. Se debe evitar la presencia de aves rapaces por varios días en las colonias después de aplicar el avicida, como también se debe remover las Quelea muertas de estas áreas.

[Traducción de César Márquez]

The Sahel is a strip of arid country that lies south of the Sahara Desert and north and east of the forests of central Africa. The area includes most of the farming and grazing lands across Africa between 10°–17°N latitude and south to about 5°S latitude in East Africa. Soils are poor and annual precipitation is low (10–90 cm), but the area has been farmed and grazed by indigenous peoples for thousands of years. The vegetative cover includes the grasslands of the subdesert, the shrubsteppes, and the thornbush and woodland savannas of the Sahelian and Sudanian bioclimatic zones.

After prolonged droughts, rains support vegetative growth, which stimulates population irruptions of the desert locust (*Schistocerca gregaria*) and the Senegalese grasshopper (*Oedaleus senegalensis*) (Rowley 1993), as well as the multimammate rat (*Praomys natalensis*), the Nile rat (*Arvicanthis niloticus*), and other desert species (Fiedler 1994). Red-billed Quelea (*Quelea quelea*) also increase with the rains as the birds will breed only when precipitation is sufficient to produce the insects and grass seeds they need to raise young (Jones 1989). All of these animals can become serious pests when huge populations decimate forage for livestock and cultivated crops.

The advent of synthetic pesticides has introduced new methods to kill these pests. The use of pesticides often creates hazards to nontarget organisms and there is a potential for undesirable effects on nontarget wildlife such as raptors from pest control programs. Because there is little objective information available on impacts of pesticides on raptors in the Sahel, this paper will describe the nature, frequency, and spatial extent of control programs for acridids (locusts and grasshoppers), birds and rodents in the Sahel and what is known about their effects on African raptors.

Some 93 species of raptors are either resident or seasonal visitors to sub-Saharan Africa. Included are 21 species of eagles, 17 falcons, 14 sparrowhawks and goshawks, eight vultures, seven buzzards, six kites, six harriers, the Osprey (*Pandion haliaetus*), the Secretary-bird (*Sagittarius serpentarius*) and 12 owls (Brown et al. 1982, Pickford et al. 1989). Of those, 17 Palearctic migrants and 60 Afrotropical species frequent the Sahel. Fifty-eight of the 77 species are uniquely adapted to the open, arid habitats of the Sahel and eastern Africa and many specialize their feeding on the pests that occur there.

CONTROL OF LOCUSTS AND GRASSHOPPERS AND ITS EFFECT ON RAPTORS

Between 1908–70, locust populations irrupted four times in the Sahel, with each plague lasting from 7–13 yr (Rowley 1993). The Sahel suffered a severe and prolonged drought from 1970–85. Rains began in 1985 and were heavy in 1987. Locust populations responded, became mobile, and invaded 43 countries in northern Africa and Asia comprising more than 20% of the earth's land surface. Plagues were characterized by numerous large swarms of flying adult locusts and bands of hopping immatures scattered thinly throughout infested areas. Swarms migrated between seasonal breeding areas by flying with strong winds enabling them to cover up to 1000 km in a week (Symmons 1992). Between outbreaks, scattered locust aggregations persisted in small recessional areas of wetter habitat. Grasshopper populations increased with rains, but they were not migratory and caused less damage. From 1986–90, applications of insecticides for locust control were made to almost 14 million ha in northern Africa (Everts 1990). About one-half of the area treated was in North Africa from Morocco to Egypt. The rest was in the Sahel from Mauritania and Senegal to Ethiopia. While most applications for locust control were made in relatively small areas (1–12 km^2), larger areas ($\sim$100 km^2) were treated for control of grasshopper populations. Both organophosphate and carbamate insecticides were used and persisted for only a few days in the desert environments (Everts 1990).

Table 1. Number of avian species that are major predators of Sahelian pests.[a]

FAMILY	DESERT LOCUSTS	QUELEA	RODENTS
Accipitridae	8	19	11
Falconidae	5	3	4
Strigidae	8	2	6
Other	80	17	1

[a] From Brown et al. (1982), Steedman (1988), Pickford et al (1989).

Migrating locusts represent one of the largest biomasses of insects ever to congregate on earth. In Somalia, one plague area was estimated to contain 1.6 billion locusts weighing 50 000 tons (Rowley 1993). Such concentrations attract large numbers of resident and migratory birds that often travel with swarms of locusts. Smith and Popov (1953) observed thousands of eagles and falcons feeding for days on a swarm containing tens of millions of locusts. Many raptors feed on locusts (Table 1) and the African Cuckoo Falcon (*Aviceda cuculoides*), Montagu's Harrier (*Circus pygargus*), Red-footed Falcon (*Falco vespertinus*), Amur Falcon (*Falco amurensis*), and Lesser Kestrel (*Falco naumanni*) are considered locust and grasshopper specialists (Steedman 1988, Pickford et al. 1989).

Of the estimated 15 million liters of insecticides used in the recent outbreak of locusts in the Sahel, most was the organophosphate insecticide, fenitrothion (Symmons 1992). The recommended rate of fenitrothion application (250–300 g/ha) was near that shown to cause mortality in birds (Steedman 1988). Toxicity data (Smith 1987) suggested that at rates of 250 g/ha chlorpyrifos, a widely used carbamate insecticide, might also pose hazards to birds. Organophosphate and carbamate insecticides kill animals by decreasing levels of the neurotransmitter acetylcholinesterase (ChE). Measurement of ChE activity in brain and blood can indicate the intensity of exposure of animals to the insecticides, and reductions of 50% or more in brain levels may cause mortality (Hill and Fleming 1982). Controlled studies of the environmental effects of locust control are not possible during operational applications of insecticides to moving swarms of locusts. However, several experimental applications of insecticides to large study plots have been evaluated.

In 1989, experimental applications were made of fenitrothion (485 and 825 g/ha) and chlorpyrifos (270 and 387 g/ha) to four large (6 km^2) plots in a 400 km^2 study area located in the savanna of northern Senegal (Mullié and Keith 1993). A few individuals of 18 raptor species were identified in or near the study area. Fourteen species were of Afrotropical origin and four were Palearctic migrants. None of the raptors were known to be exposed to or affected by treatments. Mortality of other birds was negligible (seven dead, 12 debilitated) on study plots, but numbers of birds showed significant decreases (up to 43%) on all treated plots. Decreases probably were due to movements from plots following a reduction in the insect food supply of birds. For instance, Singing Bushlarks (*Mirafra cantillans*) on the high dosage fenitrothion plot ate only about one-half the amount of insects after treatments as larks on the control plot. Experimental applications of the organophosphate insecticides malathion (750 g/ha) and dichlorvos (200 g/ha) were made to six large (3 km^2) plots in southern Morocco in 1992 (Keith et al. 1995). These two insecticides were the primary ones used against locusts in Morocco between 1987–89. Three Long-legged Buzzards (*Buteo rufinus*), two Eastern Marsh Harriers (*Circus spilonotus*), and 20 Eurasian Kestrels (*Falco tinnunculus*) were seen on or near the 160 km^2 study area, but there was no indication that they or any other birds or mammals were killed or debilitated by the insecticides. Sixteen Little Owls (*Athene noctua*) were captured and fitted with radios so that their movements and mortality could be monitored before and after treatments. No owls died and neither their home ranges (<10 ha), their daily movements (20–460 m), nor their foods (largely beetles) changed following insecticide applications.

The absence of heavy bird mortality in Senegal on fenitrothion plots treated with 485 and 825 g/ha was surprising. Applications to forests in Canada at 300 g/ha and higher most often killed small passerines (Busby et al. 1983). Mortality and decreases in bird abundance followed applications of 210–410 g/ha of fenitrothion to rangelands in the western U.S. for grasshopper control (McEwen 1982). During the 1986–89 locust outbreak in the Sahel, raptor mortality was reported in areas operationally sprayed with fenitrothion (W. Mullié pers. comm.) and with dichlorvos (A. El Hani pers. comm.), but documented losses were minimal (one to five birds) and infrequent in occurrence (four cases). Keith (1994) discussed possible reasons why large numbers of birds were killed in Canada but not in the Sahel following fenitrothion applications.

We concluded that locust control with most organophosphate and carbamate insecticides did not result in serious mortality of nontarget vertebrates. Experimental studies of fenitrothion, chlorpyrifos and malathion did not show any mortality. Likewise, there were no reports of excessive avian kills following operational applications of those insecticides. Some mortality of vertebrates was reported following dichlorvos applications in Morocco, which was the only country in which it was used. Dichlorvos should not be used for locust control. Its only advantage is a quick knockdown of locusts, but this is offset by its high toxicity to vertebrates.

CONTROL OF RED-BILLED QUELEA AND ITS EFFECT ON RAPTORS

Irruptions in quelea populations are more subtle. Quelea are numerous every year and can be found scattered throughout their range where habitats are relatively stable, such as near marshes, lakes and irrigated agriculture. Their numbers, however, fluctuate considerably with environmental conditions (Jones 1989). During droughts lasting for several years, fewer young quelea are produced. When annual rainfall increases to 20–45 cm, conditions improve sufficiently to support breeding (Jaeger et al. 1989). With good rains, quelea populations increase and can become irruptive. The birds can breed two or three times in one year and thereby increase populations to plague proportions in a single breeding season (Jarvis and Mundy 1989).

The most common method of quelea control is ground or aerial application of Queletox(r) (60% fenthion) to breeding colonies and night roosts (Elliott and Allan 1989). Queletox(r) is most often applied at a volume of 4 l/ha in a ULV formulation, but amounts applied vary (2–8 l/ha), with smaller areas (<5 ha) receiving the highest rates (Meinzingen et al. 1989). Four liters of Quele-

Table 2. Nontarget avian species found dead in treated quelea colonies.

Avicide and Location	Raptors Killed		Other Birds Killed	Reference[a]
	No.	Species		
Parathion				
South Africa	46	Black Kites	409	1
	16	Tawny Eagles		
		Steppe Eagles (*Aquila nipalensis*)		
	1	Wahlberg's Eagle		
Mali	400	Black Kites	—	2
Fenthion				
Sudan	100	Unknown	—	2
Tanzania	1	Goshawk	15	2
South Africa	6	Common Buzzards	8	3
Kenya	5	Tawny Ealges[b]	44	4
	1	Pearl-spotted Owlet[b]		
Kenya	24	8 species	>100	5
Botswana	56	Common Buzzards	—	6
	8	Steppe Eagles		
	6	Wahlberg's Eagles		

[a] 1-Tarboton (1987), 2-Meinzingen et al. (1989), 3-Colahan and Ferreira (1989), 4-Bruggers et al. (1989), 5-Thomsett (1987), 6-R Bruggers (unpubl. data).
[b] Seriously debilitated, but fate unknown.

tox(r) per ha equals a fenthion rate of 2.4 kg/ha (2.14 lb/ac). This is the highest application rate of fenthion for any use anywhere in the world.

Elliott (1989) estimated the breeding population of quelea in Africa at 753 million birds and the total area of colonies used by 249 million birds was 4145 ha. Proportionately, 753 million birds would use about 12 500 ha. Therefore, if all colonies in Africa were treated at one time, only 125 km^2 would be involved. Colonies can develop in most months of the year in response to seasonal rains (Jaeger et al. 1989). This extends the period of fenthion applications, but reduces the probability of raptors continuously intercepting treated areas containing contaminated habitats and dead quelea. In a local area, however, raptors will move from colony to colony as they are sequentially treated (Bruggers et al. 1989).

Thiollay (1989) listed 80 species of avian predators in 15 families that have been observed in quelea breeding colonies. He considered 41 species in nine families to be major predators (Table 1). Of those, 24 were raptors and included eight species that specialize in feeding on quelea: the Black Kite (*Milvus migrans*), Shikra (*Accipiter badius*), Wahlberg's Eagle (*Aquila wahlbergi*), Tawny Eagle (*Aquila rapax*), Dark Chanting-Goshawk (*Melierax metabates*), Gabar Goshawk (*Melierax gabar*), African Harrier-Hawk (*Polyboroides typus*), and Lanner Falcon (*Falco biarmicus*). Predator numbers increase in colonies when quelea eggs hatch, and are greatest when flightless young leave nests to perch on branches several days before fledging. Up to 1200 eagles can gather at a colony at that time (Pienaar 1969). Raptor densities at colonies often can exceed those in the adjacent countryside by 70–500-fold. Small raptors can eat four to eight young per day and larger raptors can eat 15–20 per day. In Mali, Thiollay (1989) estimated 678 and 763 avian predators ate 8000 and 10 000 young quelea from two colonies, respectively.

Fenthion applications often cause some nontarget mortalities of smaller passerines and raptors (Table 2). Fenthion is an organophosphate insecticide, and applications kill and contaminate many invertebrates in treated areas. This creates an abundance of dead and dying insects that attracts insectivorous birds to treated sites. Insects collected in treated quelea colonies have contained up to 7.2 ppm of fenthion (Bruggers et al. 1989). Likewise, up to 90% of quelea die in colonies that contain millions of dead and dying quelea, each of

Table 3. ChE levels found in blood of raptors in or near areas sprayed with fenthion[a].

SPECIES	PRE-TREAT-MENT	UNEX-POSED	EXPOSED
Tawny Eagles	1416	1300	840
	1418	1820	583
	1437		335
			200
			136
Pygmy Falcons	—	1264	623
			888
			661
Pale Chanting-Goshawks	—	—	513
			627
			785
Gabar Goshawks	—	—	632
			663
Bateleur Eagles	—	2260	—
		2025	
		1450	

[a] Units are mU/ml of blood, from Bruggers et al. (1989).

which can contain as much as 45 to 92 ppm of fenthion (Jaeger and Elliott 1989). The acute oral toxicity of fenthion ranges from 2.0–25 mg/kg for nonraptor species (Smith 1987) and is 1.3 mg/kg for American Kestrels (*Falco sparverius*) (Schafer 1972), the only raptor against which fenthion is known to have been tested. Therefore, a meal of insects or quelea killed with fenthion contains sufficient residues to be lethal to raptors (Bruggers et al. 1989).

In two Kenyan colonies sprayed with fenthion (Bruggers et al. 1989), blood from 13 of 22 raptors examined exhibited low ChE activity (Table 3). Five Tawny Eagles were sufficiently debilitated that their survival was of concern; ChE levels in blood were 41, 59, 76, 86, and 90% below normal. No raptors other than Tawny Eagles were tested before spraying to determine normal ChE levels in blood; therefore, the degree of inhibition in other raptors could not be calculated. After spraying, three Pygmy Falcons (*Polihierax semitorquatus*), three Pale Chanting-Goshawks (*Melierax canorus*), and two Gabar Goshawks had low ChE levels. Some of the raptors ultimately may have died, but no dead raptors were found within 5 d of treatments. Brain tissue from a moribund Pearl-spotted Owlet (*Glaucidium perlatum*) contained 6.3 =l mol/g of ChE activity, which indicated serious fenthion exposure. Three Bateleur Eagles (*Terathopius ecaudatus*) had high ChE levels after spraying and apparently did not feed on dead or debilitated quelea. Nine of 10 species of smaller birds found dead or debilitated showed average brain ChE inhibition of 15–76%.

Thomsett (1987) observed mortality of raptors near Mt. Kenya following aerial and ground spraying of fenthion at high rates on wheatfields and quelea roosts. Water troughs used by quelea also were poisoned with fenthion. Twenty-four raptor carcasses were recovered including those of a Secretary-bird, two Black Kites, four Black-shouldered Kites (*Elanus caeruleus*), four Tawny Eagles, seven Augur Buzzards (*Buteo augur*), a Gabar Goshawk, three Cape Eagle-owls (*Bubo capensis*), and two Verreaux's Eagle-owls (*Bubo lacteus*). Counts taken on 4800 ha of farmland before and after treatments suggested decreases of 85% in five of the eight species affected. Surveys conducted along the Nairobi-Naivasha road in 1974 were repeated after fenthion applications in 1986. Results indicated decreases of 93% in Augur Buzzards, Long-crested Eagles (*Lophaetus occipitalis*), and Black-shouldered Kites (Thomsett 1987).

As fenthion is very toxic to most birds, it should either be replaced with an avicide more specific to quelea or used so as to minimize nontarget hazards. In South Africa, exploders are set out to disperse raptors and other birds from quelea colonies before they are treated. In addition, quelea carcasses are removed from colonies to prevent secondary poisoning (G.H. Verdoorn pers. comm.). These practices should be followed in the Sahel. Raptors should be razed from colonies before and during a 48-hr period after applications. Bruggers et al. (1989) found that fenthion residues on grasses and debilitated quelea were high the day after spraying, but decreased 75–80% by the second day after spraying. Thus, after 2 d raptors and other birds should be able to safely return to treated areas. Fenthion is much less toxic to mammals than to birds (Smith 1987), but its effects on mammalian predators and scavengers are not known.

CONTROL OF RODENTS AND ITS EFFECT ON RAPTORS

Rodent populations irrupt when food is abundant because they have short reproductive cycles and multiple generations in a year. Fiedler (1994) reported 10 irruptions of the multimammate and Nile rat, each lasting 1–2 yr between 1951–89 in Sudan, East Africa and Zimbabwe. Multimammate and Nile rats live in areas with loam or clay soils and good vegetative cover. They cause damage to crops of groundnuts, sesame, sorghum, fruits and vegetables. In contrast, arid-tolerant species of Jirds (*Meriones* spp.), Jerboas (*Jaculus* spp.), and Gerbils (*Tatera* spp. and *Gerbillus* spp.) inhabit semidesert country with sandy soils and sparse vegetation, and consume the seeds of millet and sorghum planted by farmers at the beginning of the rainy season. Irruptions of these latter species occurred in 1962, 1977, and 1986–87.

Irruptions of rodents seriously affected agricultural areas throughout the Sahel in 1986 and 1987. In nine crop areas of Chad, rodent densities were estimated from 360–2290 per ha in 1987 (Fiedler and LaVoie 1992). In the Sudan, the rodent problem was recognized throughout the country in 1986, a state of emergency was declared, and international donors supplied most of the zinc phosphide used in the 1987 control program. The program conducted there from June–August 1987 was the largest ever attempted in a country. About 1300 metric tons of a 1.0% zinc phosphide bait (sorghum) was prepared and distributed by the government and applied by farmers to about 430 000 ha infested with rodents (Fiedler and LaVoie 1992).

Some 21 raptor species in the Sahel rely on rodents for much of their diet (Table 1). Eight of those species specialize on rodent prey (Brown et al. 1982, Pickford et al. 1989): the Augur Buzzard, Common Buzzard (*Buteo buteo*), Black-shouldered Kite, Montagu's Harrier, Pallid Harrier (*Circus macrourus*), Barn Owl (*Tyto alba*), African Grass Owl (*Tyto capensis*), and White-faced Scops Owl (*Otus leucotis*). Raptors congregate in areas where rodents are abundant during irruptions and readily take animals poisoned during control campaigns. As with dead and moribund locusts and quelea, the affected rodents pose potential hazards to raptors and other predators. The critical factors are the susceptibility of predators and their exposure to poisons used to kill the pests. Rodenticides also differ in their toxicity to secondary consumers and exposure of scavengers can be mediated by conditions in the field.

Rodenticides can kill nontarget animals that eat poisoned bait. In addition, rodents are eaten by numerous predators, and secondary poisoning seems almost unavoidable. Still, the impact of rodent control on raptors can vary with the poison used, where baits are placed, whether rodents die in their burrows or on the surface, and how raptors eat the poisoned rodents.

The control of rodents in the Sudan in 1987 with zinc phosphide on sorghum baits was a well-conducted program with minimal effects on nontarget animals. Training was conducted for all personnel including farmers, and baits were prepared, transported, and in most cases, stored and applied safely. Rodent activity was reduced an estimated 90% throughout the area of infestation. Several goats and chickens died from eating bait, but farmers admitted deaths were due to their failure to isolate animals from stored bait and to the poor placement of bait in rodent burrows. Wild rabbits and unknown gallinaceous birds (reported as "wild hens") were killed, again because bait was poorly placed in burrows. Village leaders corrected these problems when they occurred.

Black Kites and Tawny Eagles were seen in large aggregations feeding on poisoned rodents in treated areas. Farmers observed avian predators regurgitate rat intestines containing zinc phosphide bait, but claimed most birds removed the intestines from rodents before eating them. In our searches, we did not see dead avian scavengers and none were reported to us by villagers or technicians who readily related problems they observed with the control program.

Trials to evaluate the secondary toxicity of zinc phosphide have been run on foxes, dogs, cats, mustelids, rats, mongooses, owls, eagles, kestrels, vultures, turtles, alligators and snakes. Results show little potential for secondary poisoning (Johnson and Fagerstone 1994). Zinc phosphide does not accumulate in animal tissue. Tests have shown that 90% of the zinc phosphide on bait eaten by ground squirrels was metabolized before the animal died. In the presence of water and weak acid in the stomach, zinc phosphide releases phosphine gas, which is absorbed into the blood and causes heart, liver, lung and kidney failure. Poisoning of scavengers can occur from ingestion of bait remaining in the gastrointestinal tracts of rodents. Most scavengers and predators, when given a choice, refused to eat the tracts of poisoned animals (Johnson and Fagerstone 1994). Studies and anecdotal evidence from field observations show zinc phosphide can kill nontarget animals that consume baits, but the probability of secondary poisoning is low.

Zinc phosphide is used for rodent control in some areas of Egypt (Mullié and Meininger 1985).

There were reports of mass mortalities of raptors due to zinc phosphide, but no details were presented. Numbers of nine breeding species and 12 wintering species of raptors have decreased in Egypt. Mullié and Meininger (1985) felt this was due to changes in agricultural practices, habitat destruction and use of pesticides. They considered rodenticides as an important factor preventing recovery in raptor populations.

Raptors have been killed by other rodenticides used in Africa. In 1967, Klerat(r), a wax-block bait containing 0.005% brodifacoum, was used by the Plant Protection Department in Chad to protect maturing rice from rodents. In doing so, a large number of raptors was killed by secondary poisoning (Fiedler and LaVoie 1992). Thallium sulfate (Mendelssohn 1972) and azodrin (Mendelssohn and Paz 1977, Mullié and Meininger 1985) have killed raptors after their use in rodenticide baits.

CONCLUSIONS

Pesticides used in agriculture often cause raptor mortality (Balcomb 1983, Henny et al. 1985, Smith 1987, Goldstein et al. 1996). Indirect effects on raptors from pesticides are not well-known. In the Sahel, locust insecticides reduced insect food supplies and thereby lowered reproductive success in nonraptorial birds. Raptors following locust swarms face food shortages after swarms are sprayed with insecticides. In addition, exposure to pesticides can cause sublethal debilities by adversely affecting physiological processes controlling reproduction and longevity. There is the potential for hormonal disruptions in animals exposed to insecticides and other environmental contaminants (Colborn et al. 1996).

On the surface it appears that control of acridids, quelea and rodents has a great potential to cause losses of resident and migratory raptors in the Sahel. Every pest killed contains residues that could cause secondary poisoning. Still, studies do not indicate the likelihood of serious primary or secondary poisoning of raptors if control programs are intelligently conducted. Hazards to raptors become real if use protocols are not followed, if economics and expediency are given priority over environmental safety, and if efforts are not made to change existing programs when improvements are clearly needed.

LITERATURE CITED

BALCOMB, R. 1983. Secondary poisoning of Red-shouldered Hawks with carbofuran. *J. Wildl. Manage.* 47: 1129–1132.

BROWN, L.H., E.K. URBAN AND K. NEWMAN. 1982. The birds of Africa. Volume 1. Academic Press, London, U.K.

BRUGGERS, R.L., M.M. JAEGER, J.O. KEITH, P.L. HEGDAL, J.B. BOURASSA, A.A. LATIGO AND J.N. GILLIS. 1989. Impact of fenthion on nontarget birds during quelea control in Kenya. *Wildl. Soc. Bull.* 17:149–160.

BUSBY, D.G., P.A. PEARCE, N.G. GARRITY AND L.M. REYNOLDS. 1983. Effects of an organophosphorus insecticide on brain cholinesterase activity in White-throated Sparrows exposed to aerial forest spraying. *J. Appl Ecol.* 20:255–263.

COLAHAN, B.D. AND N.A. FERREIRA. 1989. Steppe Buzzards poisoned in the course of quelea spraying in the Orange Free State, South Africa. *Gabar* 4:17.

COLBORN, T., D. DUMANOSKI AND J.P MEYERS. 1996. Our stolen future. Penguin Books, New York, NY U.S.A.

ELLIOTT, C.C.H. 1989. The pest status of the quelea. Pages 17–34 *in* R.L. Bruggers and C.C.H. Elliott [EDS.], *Quelea quelea*—Africa's bird pest. Oxford Univ Press, New York, NY U.S.A.

——— AND R.G. ALLAN. 1989. Quelea control strategies in action. Pages 317–326 *in* R.L. Bruggers and C.C.H. Elliott [EDS.], *Quelea quelea*—Africa's bird pest. Oxford Univ. Press, New York, NY U.S.A.

EVERTS, J.W. [ED.]. 1990. Environmental effects of chemical locust and grasshopper control: a pilot study. Project Report. Project ECLO/SEN/003/NET. FAO/UN Rome, Italy.

FIEDLER, L.A. 1994. Rodent pest management in eastern Africa. FAO Plant Protection and Production Paper 123. FAO/UN. Rome, Italy.

——— AND G.K. LAVOIE. 1992. Solving rodent pest problems in the Sahel. Pages 349–353 *in* l'Institut du Sahel [ED.], Deuxième Séminaire sur la Lutte Intégrée Contre les Ennemis des Cultures Vivrières dans le Sahel. Jan. 1990. Bamako, Mali.

GOLDSTEIN, M.I., B. WOODBRIDGE, M.E. ZACCAGNINI, S.B. CANAVELLI AND A. LANUSSE. 1996. An assessment of mortality of Swainson's Hawks on wintering grounds in Argentina. *J. Raptor Res.* 30:106–107.

HENNY, C.J., L.J. BLUS, E.J. KOLBE AND R.E. FITZNER. 1985 Organophosphate insecticide (famphur) topically applied to cattle kills magpies and hawks. *J. Wildl. Manage.* 49:648–658.

HILL, E.F. AND W.J. FLEMING. 1982. Anticholinesterase poisoning of birds: field monitoring and diagnosis of acute poisoning. *Environ. Toxicol. Chem.* 1:27–38.

JARVIS, M.J.F. AND P.J. MUNDY. 1989. Current policies and future plans. Pages 142–147 *in* P.J. Mundy and M.J.F. Jarvis [EDS.], Africa's feathered locust. Baobab Books, Harare, Zimbabwe.

JAEGER, M.E. AND C.C.H. ELLIOTT. 1989. Quelea as a resource. Pages 327–338 *in* R.L. Bruggers and C.C.H Elliott [EDS.], *Quelea quelea*—Africa's bird pest. Oxford Univ. Press, New York, NY U.S.A.

JAEGER, M.M., R.L. BRUGGERS AND W.A. ERICKSON. 1989

Formation, sizes, and groupings of quelea nesting colonies. Pages 181–197 *in* R.L. Bruggers and C.C.H. Elliott [EDS.], *Quelea quelea*—Africa's bird pest. Oxford Univ. Press, New York, NY U.S.A.

JOHNSON, G.D. AND K.A. FAGERSTONE. 1994. Primary and secondary hazards of zinc phosphide to nontarget wildlife—a review of the literature. DWRC Res. Rep. 11-55-005. USDA/APHIS/ADC, Washington, DC U.S.A.

JONES, P.J. 1989. Factors determining the breeding season and clutch size. Pages 158–180 *in* R.L. Bruggers and C.C.H. Elliott [EDS.], *Quelea quelea*—Africa's bird pest. Oxford Univ. Press, New York, NY U.S.A.

KEITH, J.O. 1994. Insecticides: why are animals killed only some of the time? Pages 4–13 *in* I.D. Thompson [ED.], Proc. Internatl. Union Game Biologists XXI Congress. August 1993. Halifax, Nova Scotia, Canada.

———, R.L. BRUGGERS, P.C. MATTESON, A. EL HANI, S. GHAOUT, L.A. FIELDER, E.H. ARROUB, J.N. GILLIS AND R.L. PHILLIPS. 1995. An ecotoxicological assessment of insecticides used for locust control in southern Morocco. DWRC Res. Rep. 11-55-006. USDA/APHIS/ADC, Washington, DC U.S.A.

MCEWEN, L.C. 1982. Review of grasshopper pesticides versus rangeland wildlife and habitat. Pages 362–382 *in* J.M. Peak and P.D. Dalke [EDS.], Proc. Wildlife-livestock Relationships Symposium. April 1981. Univ. Idaho, Moscow, ID U.S.A.

MEINZINGEN, W., E.S.A. BASHIR, J.D. PARKER, J.-U. HECKEL AND C.C.H. ELLIOTT. 1989. Lethal control of quelea. Pages 293–316 *in* R.L. Bruggers and C.C.H. Elliott [EDS.], *Quelea quelea*—Africa's bird pest. Oxford Univ. Press, New York, NY U.S.A.

MENDELSSOHN, H. 1972. The impact of pesticides on bird life in Israel. ICBP Bull. 11:75–104. Gland, Switzerland.

——— AND U. PAZ. 1977. Mass mortality of birds of prey caused by Azodrin, an organophosphorus insecticide. *Biol. Conserv.* 11:163–170.

MULLIÉ, W.C. AND P.L. MEININGER. 1985. The decline of bird of prey populations in Egypt. Pages 61–92 *in* I. Newton and R.D. Chancellor [EDS.], Conservation studies on raptors. ICBP Tech. Publ. No. 5. Gland, Switzerland.

——— AND J.O. KEITH. 1993. The effects of aerially applied fenitrothion and chlorpyrifos on birds in the savannah of northern Senegal. *J. Appl. Ecol.* 30:536–550.

PICKFORD, P., B. PICKFORD AND W. TARBOTON. 1989. African birds of prey. Cornell Univ. Press, Ithaca, NY U.S.A.

PIENAAR, V. DE V. 1969. Observations on the nesting habits and predators of breeding colonies of Red-billed Quelea, *Quelea quelea lathami,* in the Kruger National Park. *Bokmakierie 21* (Suppl.):11-15.

ROWLEY, J. 1993. Grasshoppers and locusts—the plague of the Sahel. The Panos Institute, London, U.K.

SCHAFER, E.W., JR. 1972. The acute toxicity of 369 pesticidal, pharmaceutical, and other chemicals to wild birds. *Toxicol. Appl. Pharmacol.* 21:315–330.

SMITH, G.J. 1987. Pesticide use and toxicity in relation to wildlife: organophosphorus and carbamate compounds. Fish Wildl. Serv. Resour. Publ. 170. USDI, Washington, DC U.S.A.

SMITH, J.D. AND G.B. POPOV. 1953. On birds attacking desert locust swarms in Eritrea. *Entomologist* 86:3–7.

STEEDMAN, A. [ED.]. 1988. Locust handbook. Overseas Development Natural Resources Institute, London, U.K.

SYMMONS, P. 1992. Strategies to combat desert locust. *Crop Prot.* 11:206–212.

TARBOTON, W. 1987. Red-billed Quelea spraying in South Africa. *Gabar* 2:38–39.

THIOLLAY, J.-M. 1989. Natural predation on quelea. Pages 216–229 *in* R.L. Bruggers and C.C.H. Elliott [EDS.], *Quelea quelea*—Africa's bird pest. Oxford Univ. Press, New York, NY U.S.A.

THOMSETT, S. 1987. Raptor deaths as a result of poisoning quelea in Kenya. *Gabar* 2:33–38.

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