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A review of the impacts of control operations against the red-billed quelea (*Quelea quelea*) on non-target organisms

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SUMMARY

Spraying with the organophosphate fenthion has been the predominant means to control the red-billed quelea (*Quelea quelea*), a major bird pest throughout semi-arid regions of sub-Saharan Africa, for more than forty years. A review of known effects of fenthion and other control measures used against *Q. quelea* on non-target organisms, provides a basis for comparisons with any alternative chemical control agents. Birds of prey, owls and passerines have been commonly reported casualties of spraying with fenthion over land. Moreover, fenthion is known to have negative effects on aquatic invertebrates, in particular on populations of crustacea, which predicates against its use near water bodies. Non-target species may be affected directly by spraying, but predatory birds, scavenging birds and even mammals can be contaminated by secondary poisoning when they eat *Quelea* carcasses found up to 20 km or more from the primary control site. To avoid secondary poisoning, where possible quelea carcasses should be removed from a site after spraying. The use of explosions to kill roosting quelea birds has similar effects to those of fenthion in terrestrial habitats, killing non-target species including birds of prey and owls. Another control method, harvesting quelea as a source of protein, is benign and could contribute to local nutritional and economic needs. However harvesting is unlikely to reduce quelea populations substantially. Integrated pest management (IPM) approaches are recommended to minimize environmental damage, but until these are successfully adopted, standardized procedures for comparative assessments of the effects of quelea control are required.

Keywords: red-billed quelea, *Quelea quelea*, Africa, non-targets, fenthion, explosives

INTRODUCTION

The red-billed quelea (*Quelea quelea*) is a granivorous ploceid weaverbird occurring throughout the semi-arid zones of sub-Saharan Africa (Magor & Ward 1972). Arguably the most abundant land-bird in the world, quelea can occur in huge flocks (breeding colonies may harbour 60 000 adults ha^{-1}) that are capable of devastating small-grain crops such as millet, sorghum, wheat and rice (Bruggers & Elliott 1989; Mundy & Jarvis 1989). Accorded major pest status throughout its range, millions of queleas are destroyed annually by most nations that have this species within their borders. The most common form of quelea control involves ground or aerial application of Queletox® (60% fenthion, usually at 4–5 l ha^{-1} in ultra low volume [ULV] formulation) to breeding colonies and night roosts (Elliott & Allan 1989). A second control technique, the use of firebombs and explosives, has long been an alternative methodology, particularly in West Africa during the 1960s and 1970s and more recently in Kenya and South Africa (Meinzingen *et al*. 1989; Allan 1997). Both methods have negative environmental impact and mortality to non-target species, but in South Africa there has been particular concern for avian conservation over the use of chemical sprays (Verdoorn 1999) and greater use of explosives has been adopted (Elliott 2000). Here we review the effects of control with fenthion or explosives on non-target organisms in the field.

One of the manufacturers of fenthion, Bayer, announced in March 2003 that they would cease production of the pesticide. However, although alternative suppliers exist, other chemicals are likely to be developed for quelea control. Thus, it is timely to review fenthion's effects for comparisons with alternatives, such as cyanophos, a pesticide that may be used extensively in future quelea control programmes. Currently, cyanophos is being used widely (on a trial basis) by the South African National Department for Agriculture (NDA); however, its environmental impact remains to be fully evaluated and is not discussed here (but see Mullié *et al*. 1999). Our review of the effects of fenthion on the environment will also serve as an appropriate comparison with any newly developed (and needed) alternative strategies and methodologies, such as agronomic control strategies, which reduce crop damage and also limit the environmental impact of quelea control operations (Jones 1972; Ward 1972, 1973, 1979; Elliott & Allan 1989; Elliott & Craig 1999).

There are three strategies to reduce non-target mortality that could be implemented immediately: avoiding unnecessary control, strategic timing of justified control and avoiding control in high species diversity habitats.

(1) Control should be restricted to only those sites where economic damage to crops actually occurs. In this context,

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it is generally agreed that large breeding colonies or roosts are unlikely to threaten vulnerable crops further away than 10 and 50 km, respectively (Elliott & Allan 1989).

(2) Where control cannot be avoided it has to be timed to occur before young birds fledge and increase numbers of poisoned birds available as prey-items to non-target species after spraying. Control is also recommended as being much more effective during the earlier breeding stages because the adults return to the site more quickly after a spray aircraft passes (C.C.H. Elliott, personal communication 2003). Currently, in view of the increasing realization that chemical control of quelea causes substantial mortality to other wildlife, integrated pest management (IPM) approaches have been advocated, involving: crop substitution, modification of crop husbandry and planting times, as well as bird scaring or exclusion netting (Elliott & Craig 1999). More research is needed to develop such techniques into practical solutions.

(3) The potential impact of quelea control operations on non-target birds in South Africa is well illustrated by an analysis of quelea distribution in relation to bird diversity, with emphasis on wetland and predator/scavenger species (Allan *et al*. 1995). Allan *et al*. (1995) stress the need to avoid spraying in wetland sites, which support a wide variety of waterfowl and other species, and at breeding colonies that attract large numbers of predators.

Research is still urgently required to develop safer technologies for quelea control and limit the environmental impacts (Elliott 2000). This review of fenthion and of explosives on non-target organisms in the field is provided for comparative purposes and to inform future control planners in the hope that environmental damage can be minimized. An understanding of the environmental effects of fenthion is needed to provide a base line against which other control methods can be measured. Regrettably, in the absence of alternative environmentally benign methods of controlling Africa's 'feathered locust', chemical and explosive control measures cannot be abandoned yet.

EFFECTS ON NON-TARGET ORGANISMS

Chemical control with fenthion

Extent of spraying operations

Between 1988 and 2000 in South Africa, an average of 52 658 000 quelea were estimated to have been controlled per annum over a mean annually treated area of 1243 ha (Willemse 2000). The number of control operations averaged 173 per year and by 1999/2000 the average quelea kill per colony (mean size 7 ha) was 385 000 birds. In Zimbabwe, an estimated 13.5 million birds were sprayed with Queletox in 1988 (Mundy 2000); in Ethiopia and Sudan, annual control averaged 37 (mean size 41 ha) and 145 (mean size 205 ha) sites, respectively (Elliott 2000).

Non-target exposure to fenthion

Owing to the extent and density of quelea colonies, many non-target species can be affected by control operations, either as original occupants of the same habitat or when attracted as predators. Concentrations of quelea can number millions in very dense breeding colonies (up to 30 000 nests ha^{-1}; Allan 1997) or roosts. A night roost may contain as many as 25 million quelea on 10 ha, and breeding colonies incorporate up to 100 ha of acacia bush (Manikowski 1988) or, as in the case of a colony in March 1998 at Malilangwe in Zimbabwe, cover an area as long as 20 km and 1–2 km wide (Dallimer 2000). Such sites, apart from harbouring resident wildlife, sometimes attract numerous predators, of which the most visible are birds of prey. Thus, Thiollay (1989) has recorded 80 species of predatory birds at breeding colonies in western and central Africa. At risk are some 93 raptor species that are resident or seasonal migrants in sub-Saharan Africa (Keith & Bruggers 1998). Snakes and monitor lizards also prey on eggs or nestlings and it is known that queleas are eaten by a wide variety of mammals, ranging from genets (*Genetta genetta*) and baboons (*Papio* spp.) to hyaenas (*Crocuta crocuta* and *Hyaena* spp.) and even lions (*Panthera leo*) (Pienaar 1969; Thiollay 1989).

Not only is the diversity of predator species high at quelea congregations (see above) but also the absolute numbers of predators can be staggering. For example, in South Africa's Kruger National Park, it was estimated that over 1000 birds of four large eagle species were present at one quelea colony (Biggs 2001) and Pienaar (1969) judged that up to 1200 eagles (mainly *Aquila rapax* and *A. wahlbergi*) and about 300 Marabou storks (*Leptoptilos crumeniferus*) attended another colony in the park. Scores of vultures and many smaller birds of prey were also observed in both studies (some 19 species of predatory birds between both sites). Since predation rates on nests can be significant (at one of the Kruger colonies, 60% of nests had been torn open; Pienaar 1969) and since colonies are huge, a colony can clearly support a large and diverse population of predators.

Since quelea densities are so high, an efficient control operation can result in about 1500 kg ha^{-1} of poisoned birds on a site (Manikowski 1988). This, of course, provides an abundant food source to scavengers and predators, which themselves become prone to debilitation and death from secondary poisoning. Thus, Thiollay (1989) found more carcasses of predators within a 2 km radius of a fenthion-sprayed colony in Chad than actually inside the colony.

Field studies

The few systematic field studies of the impact of control on non-target wildlife at quelea colonies that have been carried out (Bruggers *et al*. 1989; Keith *et al*. 1994; Mullié *et al*. 1999, van der Walt 2000) confirm that fenthion, being an insecticide, is highly toxic to terrestrial invertebrates. In Kenya, Bruggers *et al*. (1989) recorded extensive mortality in 14 families of insects and spiders, with particularly high residues found on Carabidae, Acrididae, Gryllidae,

Table 1 Non-target birds killed or debilitated after quelea control with fenthion, except ‡mostly killed by parathion. *N. ind.* = number of individual birds, *N. spp.* = number of species. * From database of records of incidents reported during 1993–1999. †From database of records of incidents reported since the 1980s. (n) denotes number of sites examined, if reported.

Location	*Birds of prey poisoned*		*Other birds poisoned*		*Reference*
	N. ind.	*N. spp.*	*N. ind.*	*N. spp.*	
Botswana					
Kgatleng	?	Eagles and buzzards	?	?	Camara-Smeets (1987)
Kgatleng	?	Eagles, kites, owls			Simmons (1987)
Maun (7)	155	2			Liversedge (1990)
Tuli Block (1)	28	2			McWilliam (1996)
Tuli Block (1)	9	2	7	5	McWilliam (1996)
Francistown	‘Large numbers’				Tyler (1998)
Francistown	70	3			Bruggers *et al.* (1989)
Kenya					
Mt Kenya	41	9	> 100		Thomsett (1987)
Galana (2)	6	2	44	17	Bruggers *et al.* (1989)
Njoro			61	14	Keith *et al.* (1994)
Gicheha			22	8	Keith *et al.* (1994)
Senegal					
Senegal (no location given)			?	> 7	Mullié *et al.* (1991)
Senegal River (2)	2	1	45	> 10	Mullié *et al.* (1991)
Somalia					
Various locations (7)			17	50	Becker & Amir (1993)
South Africa					
Transvaal (16)‡	63	3	409	68	Tarboton (1987)
Soetdoring	6	1	9	6	Colahan & Ferreira (1989)
Nylsvlei	> 62	raptors, owls, waterbirds and passerines			Trendler *et al.* (1992), Yeld (1993), Verdoorn (1999)
Dwaalboom	> 150	> 10	?	> 4	McAllister (1993), Yeld (1993), Verdoorn (1999)
Countrywide	7	3	> 107	3	Bouwman & Lötter (1998)
Orange Free State (2)	3	?			van der Walt (2000)
Countrywide*	3509 non-target kills of birds of prey and other species (1674 from sprays and 1835 from explosions) from 150 control operations				Lötter & Kieser (2001)
Sudan					
Gedarif	> 100	?			Meinzingen *et al.* (1989)
Tanzania					
Shinyanga	1	1	15	11	Meinzingen *et al.* (1989)
Zimbabwe					
Zimbabwe (no location given)			?	Waterfowl	La Grange & Jarvis (1977)
Dichwe			157	42	Talbot (1977)
Bindura			23	54	Jarvis & La Grange (1989)
Countrywide	267 non-target kills of 26 species from 11 control operations				Stiles (1995)
Aisleby				Crowned crane (*Balearica pavonina*)	Townsley (2000)
Countrywide†	26	6	> 1817	> 82	Couto (2002)

Tettigonidae and Mantidae. In Senegal, ants, carabid and tenebrionid beetles were most notably affected (Mullié *et al.* 1999) and, in South Africa, residues persisted for up to 42 days in soil invertebrates (van der Walt 2000). Thus, invertebrates are also a source of fenthion toxicity to insectivorous predators, particularly birds, in sprayed areas. As fenthion is not highly toxic to mammals (US Environmental Protection Agency 2001), these studies have principally concentrated on the impact of both direct and secondary poisoning on birds. However, dead jackals (*Canis* sp.) and hyaena (*Hyaena* sp.) have been found near spray sites in Botswana (Liversedge 1990; Simmons 1987).

Table 1 summarizes the numbers of poisoned birds found in the above studies, together with other records from the literature. This demonstrates that, although unlikely to be of concern to non-target birds on an Africa-wide scale, resident populations of susceptible species (especially predators that accumulate fenthion from poisoned prey) do suffer mortality. This could lead them to become locally scarce after years of repeated spraying, as suggested by Thomsett (1987). He reported that 41 raptors died of organophosphate poisoning after quelea roosts were sprayed on a farm in Kenya, and road counts spanning a ten-year period before and after widespread control showed a marked decline in numbers of three susceptible raptor species (Thomsett 1987).

Technical considerations

Fenthion is currently applied by spraying at ULV, resulting in the production of a chemical mist. Aerial drift of small droplets has long been regarded as a problem of ULV application (Manikowski 1988), since more non-target animals are exposed over a wider area, leading in turn to a greater incidence of secondary poisoning when these are eaten by predators.

Recent technical monitoring of aerial spraying at a quelea roost site, with ULV fenthion at 3 l ha^{-1} (concentration of 64% [m/v] and droplet size volume median diameter [VMD] of 90 μm), found off-target drift extended up to 3 km (van der Walt *et al*. 1998; van der Walt 2000). There was very uneven coverage of target sites (deposition rates varying from 0.01 to $>$ 550% of expected) and further lack of exposure was caused by poor canopy penetration. In addition, persistence was longer than previously reported, at 64 hours in air and 46 days in soil (van der Walt *et al*. 1998; van der Walt 2000).

R. Allan observed (reported in Elliott 2000) that larger droplets were produced when fenthion was first used in a 50:50 diesel mixture, and this resulted in a much greater kill efficacy. Indeed, Willemse (2000) reported recently that greater efficacy was achieved by increasing the droplet size from a VMD of 90 μm to 180 μm (and the volume rate to 8.7 l ha^{-1}). Improved kill efficacy also implies that fewer debilitated quelea are able to fly off and increase the area in which secondary poisoning of predators can occur.

Recommendations

We make the following recommendations in order to reduce the non-target deaths that occur as a result of quelea control operations:

(1) As fenthion is very toxic to most bird species and insects, an alternative avicide needs to be developed that is more specific for quelea.
(2) Research is needed into methods that increase the efficiency of knock down (perhaps the addition of surfactants) so that secondary poisoning is reduced at least outside the sprayed area.
(3) Sites that attract many raptors or other predators (such as Marabou storks) should not be sprayed. Alternatively, where possible, non-target birds should be scared from colonies before control and kept away for two days following treatment while residue levels decline. In Zimbabwe, reed beds that were well populated by water birds and other species were disturbed with beaters in late afternoon before aerial spraying. After spraying, no non-target birds were found in a search that yielded 26 400 dead quelea (Mundy & Packenham 1988).
(4) In order to limit secondary poisoning, as many dead quelea as possible should be removed from accessible sprayed sites and incinerated by control personnel wearing suitable protective clothing.

Control with explosives

Non-target exposure

Controlling quelea with explosions or firebombs also results in significant mortality of non-target species. Unfortunately, published data on their impact are as yet inadequate to make an informed judgement on the relative environmental costs compared with those attributable to fenthion. However, although non-target mortality is generally under-reported, the Directorate of Land Use and Soil Management in South Africa conducted an unpublished evaluation. It was concluded, from an analysis of 3509 non-target kills (1674 from spraying and 1835 from explosions) recorded from 150 out of a total of 799 control operations, that there was extensive non-target mortality after explosions (Lötter & Kieser 2001). The species involved differed from those at sprayed sites since explosions were more common in wetland areas where no sprayings took place, although birds such as cattle egret (*Bubulcus ibis*) and barn owl (*Tyto alba*) succumbed under both circumstances. Red data species, such as the white-backed night heron (*Gorsachius leuconotus*) and marsh owl (*Asio capensis*) were also involved and mass mortalities (1050 from chemical sprays and 1358 from explosions) were reported for red bishops (*Euplectes franciscanus*). Furthermore, these data were derived from a database of only what was reported and so are likely to have underestimated the true toll. Occasionally this may be very worrisome, for instance in excess of 100 black-shouldered kites (*Elanus caeruleus*) were incinerated after one fuel-explosion in South Africa, which also polluted and destroyed the habitat (van der Walt 2000), but, in general, explosions should be less damaging than sprays as the areas affected are more restricted.

Meinzingen *et al*. (1989) considered firebombing the least environmentally damaging control technique. Only one bird (a black-shouldered kite) was found after 10 firebomb operations in Kenya where eucalyptus trees were not permanently damaged, recovering within two months. However, as few non-target birds use eucalyptus trees anyway these results were unsurprising. In contrast, Meinzingen *et al*. (1989) also reported many birds of prey were sometimes killed in Nigeria at control explosions in acacia bush, although this work was done in the 1960s when arguably the environment was of less concern. Allan (1997) advocates a refinement of the technique, particularly for wetlands, that has yet to be field-tested, involving the deployment of smaller, but more closely spaced, explosive packages.

Nevertheless, because incidents of wildlife poisoning have been more frequently reported after chemical spraying, and sometimes involve the deaths of hundreds of non-target birds, the South African authorities made a policy decision to use explosives wherever possible (L. Geertsma, as reported in Elliott 2000). Thus, half of all control operations currently use firebombs which, although more expensive than chemical control, kill more quelea and are thus more cost-effective. However, the applicability of this method is limited to smaller roosts of about 4 ha in eucalyptus and 2 ha in reed beds.

After a comparative cost analysis of control at roosts or breeding colonies with fenthion, explosives, repellents or mechanical destruction (by tractor), Garanito *et al.* (2000) concluded that mechanical control was by far the most cost-effective method. But mechanical clearance will only displace quelea to neighbouring areas (and perhaps have no impact whatever on crop damage levels) and, by destroying the habitat, it will contribute to the mortality of resident non-target species.

CONTROL IN ECOLOGICALLY SENSITIVE AREAS

Aquatic habitats

Aquatic habitats appear to be highly susceptible to fenthion. Although not intentionally sprayed on water, there is evidence both from studies of the non-target impact of mosquito control in America and quelea control in Africa that some faunal assemblages in aquatic habitats suffer significant exposure.

In particular, marked chronic effects have been noted on Crustacea and other smaller invertebrates. A study of sand fiddler crabs (*Uca panacea*), in simulated aerial spraying of ULV-grade fenthion (at 50% of the field rate application for mosquito control), found that larvae were no longer produced at the end of the third hatching cycle and the mortality of adult crabs at the surface had reached 20%. Three weeks after the final application, survival of adult crabs was only 3% (Schoor *et al.* 2000).

Water fleas and shrimps appear to be the most sensitive invertebrate taxa, with reproductive impairment recorded in the laboratory at concentrations as low as $1\,\mathrm{ng\,l^{-1}}$ in the cladoceran *Daphnia pulex* (Roux *et al.* 1995). This study demonstrated that, following aerial spraying of quelea in South Africa, fenthion persisted in dams at concentrations sufficient to have marked effects on the survival and reproduction of *D. pulex* for several months after spraying. Thus, acutely toxic concentrations (to the lethal concentration LC_{50} of $1.3\,\mu\mathrm{g\,l^{-1}}$) were estimated to have lasted between 10 and 86 days, and a decay time of 185 days to the no effect concentration (NOEC) of $0.6\,\mathrm{ng\,l^{-1}}$ was estimated for the most polluted dam.

For rivers, van Dyk *et al.* (1975) used hand-net samples to develop a protocol relating to aerial control of quelea on the Orange River in South Africa. This protocol used declines in the total population density of crustacea and aquatic insects (Odonata, Ephemeroptera, Hemiptera, Coleoptera and Diptera) as a sensitive indicator of fenthion pollution. In effect, water sampling of population density acted as a proxy for residue analysis of the chemical, recovery taking up to 20 days depending on rates of water flow. The presence or absence of Odonata best indicated fenthion pollution, and Ephemeroptera and Hemiptera were also particularly sensitive. Palmer (1994) also reported the detrimental effects of fenthion on rheophilic benthic macroinvertebrates in the Orange River after quelea control. The aerial spraying of quelea roosts in reed beds induced mortality among at least 17 taxa (over half the taxa present), mayfly nymphs and midge larvae being particularly sensitive.

Although fenthion is not highly toxic to amphibians, it has been shown experimentally that wild-caught tadpoles can bioconcentrate sufficient fenthion (averaging 62×) to poison mallard ducks (*Anas platyrhynchos*) (Hall & Kolbe 1980). A summary of aquatic toxicity data, and a risk assessment for fenthion (Joint Meeting of the FAO/WHO [Food and Agricultural Organization of the United Nations/World Health Organization] Panel on Pesticide Residues in Food and the Environment 1996), concluded that there was no direct risk to fish at the dose rate of $5\,\mathrm{l\,ha^{-1}}$ recommended for quelea control.

Assessing the environmental impact of controlling quelea with fenthion at wetland roosts, Keith *et al.* (1994) found that although amphibians and fish were not affected, populations of a variety of aquatic invertebrates (particularly dytiscid and notonectid beetles) were largely eliminated in an adjacent dam. However, some recovery was observed within six days and eventual repopulation would be expected. Unsurprisingly, given the large numbers of reports of non-target bird casualties already cited, the rich non-target bird life in these wetland roosts was damaged. Although the general abundance of waterfowl, waders and other birds appeared to be unaffected, in Kenya 61 birds of 14 species at Njoro dam and a further 22 birds of eight species at Gicheha were killed or severely debilitated. As is commonly the case, fenthion residues on dead birds were sufficient to cause secondary poisoning to scavengers and predators (Keith *et al.* 1994).

Fenthion used in mosquito control has been implicated in several avian kills in America (Smith *et al.* 1986). Zinkl *et al.* (1981) reported fenthion poisoning of wading birds where wind and wave action was thought to have concentrated poisoned food items. Severe mortality of birds following mosquito control of wet meadows with fenthion was linked to depressed brain cholinesterase activity from organophospate poisoning of individual birds, and subsequent declines in population numbers (De Weese *et al.* 1983). Even dead mammals (marmosets, rabbits and squirrels) were found, despite their lower sensitivity to fenthion.

It is clear that quelea control with fenthion should not be carried out near water bodies. Indeed wetland habitats are not sprayed now in South Africa, owing to the established toxicity of fenthion to aquatic organisms (Bouwman & Lötter 1998), and at aquatic sites (mainly reed beds) control of quelea is now conducted with firebombs.

Honey bee colonies

As it is an insecticide, fenthion should never be sprayed within the vicinity of bee colonies, particularly if they are managed for honey collection. Nine colonies of honeybees, exposed to relatively low levels of fenthion (56 g ha^{-1}) after a single aerial application, lost their queens (Nunamaker *et al*. 1984).

IMPLICATIONS FOR USE OF QUELEA AS A FOOD SOURCE FOR THE RURAL POOR

Food shortages are prevalent in Africa and many arid areas prone to famine are occupied seasonally by concentrations of quelea in millions that potentially provide a good source of food. Thus, colonies and roosts in the middle Awash River Valley of Ethiopia were estimated to contain some eight million quelea (Jaeger & Erickson 1980), providing about 37 tonnes of dried carcasses (Jaeger & Elliott 1989).

The nutritional content of quelea is high, with a greater calorific value than dried mammalian meat and around five times the protein found in staple cereals (Jaeger & Jaeger 1977). The most widespread and easiest method of harvesting quelea is the collection of nestlings from breeding colonies, which is most productive just before they fledge (as carried out in Zimbabwe; Jarvis & Vernon 1989). Approximately 500 rural people were able to harvest some 3.5 tonnes of quelea chicks from a large colony in a wildlife conservancy (Pelham 1998), a control method that may be cost effective locally as there is no burden on the exchequer and it provides an important food supplement in drought-prone areas.

Although rural people traditionally collect and eat quelea throughout Africa, even after spraying operations, commercial markets are only well developed in Cameroon and Chad, where flying birds are intensively trapped by teams with hand-held cast-nets and large stationary nets (Mullié 2000). Trapping and selling quelea for food is an important economic activity in rural Chad, and it was estimated that in one area around N'Djamena the income from some seven million quelea sold annually comes to within 40% of the maximum capitalized crop loss experienced by farmers (Mullié 2000).

As a control method, however, even this substantial off-take of 5–10 million birds will have no impact on the population of about 200 million quelea birds in the Chad basin, which, in any case, has a natural annual mortality of about 50% (Mullié 2000). Nevertheless, if trapping activities could be targeted at roosts responsible for depredations of crops, then Mullié (2000) anticipates that the value of quelea as a natural bush product could at least match grain losses.

Collection of dead quelea for food after fire-bombing is normally safe and, following such control in dense roosts in Kenya, local people were able to collect birds by the sackful (Meinzingen *et al*. 1989). This method could be further exploited for local provision of food if decoy or trap roosts, established by planting stands of Napier grass (*Pennisetum purpureum*; Jarvis & La Grange 1989), could be fire-bombed instead of sprayed, as normally practised in Zimbabwe. However, combustion needs to be efficient, as otherwise pollution occurs from unburnt fuel (van der Walt 2000).

Consumption of birds killed by fenthion is not recommended, as the acceptable daily intake is only 0.001 mg kg^{-1} of body weight (FAO/WHO 1980). Even allowing for a 100-fold margin of error, this would only permit consumption of 1.25 treated birds by an adult (Jaeger & Elliott 1989). Apart from being potentially more dangerous to children and pregnant or nursing women, metabolites of fenthion appear to be more toxic than the active ingredient itself. Practically, to be eaten fresh, quelea would need to be collected soon after control and the risk of poisoning for people that gather recently-sprayed quelea may be higher than for consumers (Manikowski 1988). Thus, as a precaution to limit exposure, re-entry into colonies is not recommended for several days after spraying except by wearers of protective clothing, although preventing local people from accessing the site can be problematic (Jaeger & Elliott 1989).

PROTOCOLS FOR ASSESSING NON-TARGET IMPACT

Given the lack of any systematic methodology for monitoring the environmental impact of quelea control on non-target wildlife, it is recommended that a standardized set of protocols should be developed and tested in the field. The methods would need to distinguish between the effect of the pesticide application from other site-related and environmental variables and so facilitate pre-spray and post-spray comparisons of the population abundance of non-target species. In addition, mortality rates arising from direct contact or secondary poisoning would need to be estimated. Carcass searches and standard transect-survey techniques for assessing bird and reptile numbers could be adapted for statistical validity under operational conditions, together with employing sweep-netting, malaise, pitfall and canopy traps for estimating the relative abundance of invertebrates following pesticide knockdown. In order to confirm that any vertebrate mortality can be attributed to organophosphate poisoning, exposure would need to be confirmed through the selective use of cholinesterase assays and residue analyses carried out by trained government monitoring teams.

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