CROP PROTECTION PROGRAMME

Models of Quelea movements and improved control strategies

R6823 (ZA0183)

FINAL TECHNICAL REPORT

1 October 1996 - 31 March 1999

Prof R.A.Cheke
Natural Resources Institute

Project R6823 (ZA0183) Final Technical Report   Period of funding 01/10/96 - 31/03/99
Project Leader: Prof. R. A. Cheke

Models of quelea movements and improved control strategies

Executive Summary

The Project Purpose was to develop a forecasting methodology for the economically important migrant pest, the Red-billed Quelea *Quelea quelea*, in southern Africa, to be used to improve management strategies of national pest control authorities, thereby reducing crop losses and environmental contamination by pesticides.

Research activities included: (a) the production of a data-base to record information on quelea occurrences, breeding and roosting activities and crop damage in 10 countries; (b) collation of environmental information to derive relationships between rainfall and timing of quelea movements and breeding; (c) gathering of information on the degree of isolation of different sub-populations in each country, based on plumage polymorphisms and DNA; (d) production of a geographically-referenced PC information management system to predict zones suitable for quelea at different times of the year, in relation to rainfall and vegetation indices and (e) testing the possibility that fungi could be used to breakdown fenthion residues in contaminated soil.

It was found that the sub-species *Quelea quelea spoliator*, thought by some to have a separate migration system from *Q. q. lathamii*, and thus to need a separate control strategy, cannot be considered a valid taxon. Experiments using orientation cages also failed to provide any firm evidence of the existence of a migratory divide. Means of ageing juvenile quelea birds have been established, to assist in tracking dispersal from breeding colonies, and methods for typing Quelea birds using microsatellite DNA have been developed. A data-base of historical records of quelea has been compiled and used in developing forecasting tools including a prototype PC-based predictive model. It was found that the fungus *Phanerochaete chrysosporium* was a promising bioremediation candidate for breaking down fenthion residues.

The project has contributed towards DFID’s goal of “Improved strategies for the control of avian pests, particularly quelea, developed and promoted” within the wider context of Purpose 4 of the Crop Production Programme’s Semi-arid Production System “Impact of migrant pests on crop production minimised”. The contributions include a better understanding of the factors governing quelea migrations in Southern Africa and a framework with which to predict their movements, thereby permitting control interventions to be planned in good time and more efficiently. Steps have also been taken to develop techniques to minimise the environmental damage that such control engenders by research on a bioremediation mechanism, which has been shown to have much promise.

Background

The Red-billed Quelea bird *Quelea quelea* is a major pest of small-grain cereal crops, attacking millet seed heads, mature sorghum seeds and other crops, affecting both small producers and commercial growers, throughout semi-arid areas of Africa. US$5.4 million worth of grain loss was attributed to quelea damage in Kenya and Tanzania in 1978-79 (FAO 1981) and annual losses in Africa have been estimated as US$ 45 million (Elliott 1989).

Quelea birds regularly perform long distance migrations from one affected area or country to another. The migratory routes and timing of movements of the different sub-species of *Q. quelea* occurring in southern Africa and the influence of environmental variables on them are not fully understood. Not only are the routes unclear but even the taxonomic status of one of the sub-species thought to be involved is uncertain. These were two of the researchable constraints that the project addressed. Another was the lack of any existing forecasting model or system.

Research on quelea migrations, and the integration of knowledge into a model framework would improve forecasting and allow member countries of IRLCO-CSA (the international control organisation charged with quelea control in the region) to benefit from advanced warnings. Combined with more efficient control technologies, forecasts incorporating relevant climatic and ecological data would lead to substantial benefits in terms of increased crop yields, reductions in pesticide usage and improved control strategies.

Quelea migrations are determined by weather patterns and vegetation as the birds feed on grass seeds. These suddenly become no longer available at the start of the rainy season when they germinate. The birds are then forced to move out of the early rains areas to where it has not yet rained. When the rain eventually reaches their new sites and grass seed germinates there too, the birds feed on alternative but ephemeral food sources, such as the termites that are abundant after rains. Such a diet provides opportunities for the birds to accumulate reserves of migratory fat and allows them to emigrate *en masse* in “early rains migrations”. These movements take the birds away from their “dry season quarters”, back through the zones where rain had fallen earlier in the season, until they reach an area where fresh seeds are already available. This will be six to eight weeks after the first rains, which forced them away at the beginning of the cycle. Next, the birds gradually return to their dry season quarters during a “breeding migration”, so called because they pause to nest during the journey. The numbers of times that they can breed during this period will be dependent on the prevailing conditions, with good rains tending to permit more breeding attempts. It is the young birds, which fledge from successful colonies at these periods when millet or sorghum is about to be harvested, that are responsible for most cases of damage to subsistence agriculture. The prediction of such events was a researchable constraint.

The two subspecies involved in southern Africa are *Q. q. lathamii* and *Q. q. spoliator* but the taxonomic validity of the latter is in doubt, another researchable constraint addressed by the project. *Q. q. lathamii* breeds in Angola, Botswana, Malawi, Mozambique, Namibia, South Africa and Zimbabwe. The long distance movements of queleas between countries have been confirmed by ringing recoveries. For instance, many birds ringed in South Africa have been recovered in Zimbabwe, a bird ringed in Namibia has been recovered in Malawi and two South African-ringed birds have been found in Namibia and another two in the Democratic Republic of the Congo. As queleas have easily recognisable plumage polymorphisms, one way of investigating their migration routes is to examine male specimens for the relative frequencies of different morphs in different populations. This approach should be complemented at the molecular genetic level by seeking information on DNA polymorphisms using blood samples, but as yet no research had been done on this aspect, so development of appropriate techniques was an additional researchable constraint.

Existing data-sets on quelea occurrences and abundance had not been analysed in relation to environmental variables, another researchable constraint addressed in order to improve predictions of migration routes and the timing of quelea movements. This research follows previous studies using satellite imagery in Eastern Africa (Dreiser 1993, Meinzingen 1993, Wallin *et al*. 1992). For instance, Wallin *et al*. (1992) established a relationship between quelea colony initiation date and the start of the growing season, with the latter derived from Normalized Difference Vegetation Index (NDVI) data obtained by satellite. A more direct measure of the start of the growing season, rainfall, can be estimated from cold cloud duration (CCD) data recorded by the Meteosat satellite. Satellite imagery could also provide information on areas where grasses were or were not germinating, to help to identify areas suitable for queleas and likely control zones.

Demand for the project was identified because, without control, queleas can cause economically significant damage to cereal crops. For example, they can destroy up to 50% of a wheat crop with a value of Z$5000 per hectare in Zimbabwe (P.J. Mundy minute to Chief Warden, National Parks HQ Mar 1996). The Zimbabwean Problem Bird Control Unit and its predecessors have been collecting data on quelea outbreaks for many years but had done no research on them since 1985 and requested a proper analysis. Similarly, a representative of the Ministry of Agriculture, Water and Rural Development of Namibia had stated (FAX of 5 June 1995) that "Losses as a result of the quelea can have a big economic impact on crop production, but very little is actually known about the damage, crop lost and economic importance of the quelea in Namibia. No research was done in the past on the quelea". Also, recent reports on quelea control concluded that an early warning system would allow an assessment to be made of the threat to crops. It was pointed out that such a system would allow time to prepare for a control programme, and that the data gathered would need to be combined with similar data collected from other countries (Allan 1994, 1997).

Project Purpose

The Project Purpose was to develop a forecasting methodology for quelea in Zimbabwe and neighbouring countries, to improve the quelea management strategies of the national pest control authorities, thereby increasing crop production and reducing environmental contamination by pesticides.

Research Activities

1. ***Production of a data-base to record information on quelea occurrences, breeding and roosting activities and crop damage in 10 countries*.**

An electronic data-base has been re-compiled from the Quelea Archives originally assembled in the early 1970s (Magor & Ward 1972, COPR unpubl.). The original electronic data-base on magnetic tape was lost but one hard copy of the print-out was preserved. It was from this that 3,543 separate entries concerning SADC countries have been keyed into an Access data-base (Venn *et al.* 1999), a version of which is attached to this report (Figure 1 shows the initial menu screen). The data-base extends from 1836 and includes data from Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe. The most useful information is available only from the early 1950s, detailing precisely located colonies where the dates of egg-laying are known but the data-base also contains details of dry-season roosts, control operations, and reported crop damage.

The way in which the data-base can be used to summarise information is illustrated in Figures 2-7. These show the positions of quelea breeding colonies recorded in different months of the quelea breeding season in southern Africa (December-May), during the period 1911-1972. It is clear from the figures that in December most breeding is restricted to South Africa and southern Mozambique, by January most records occur further northwest in Botswana, Zambia and Zimbabwe, and by February any country in the region may be affected. By March, the overall distribution contracts south-eastwards; in April, the major concentrations in Botswana and Zimbabwe have disappeared elsewhere and by May the only breeding is back in South Africa. These general patterns mask the considerable year-to-year variation, which can be illustrated by examples from Botswana. Figure 8 shows different breeding colonies in that country by month during the 1958-98 period. Figures 9 and 10 show contrasting distributions of breeding colonies, and the areas likely to be damaged by birds from them, in a zone of northeast Botswana in 1970 and in 1998.

2. ***Collation of environmental information to derive relationships between rainfall and timing of quelea movements and breeding*.**

Rainfall data were obtained from the Zimbabwean Meteorological Services for selected synoptic weather stations from all the relevant countries except Angola, Lesotho and Swaziland. Supplementary data were gathered from the World Climate Global Climatic Change Data CD-ROM (Chadwyk-Healey Ltd., Cambridge). In addition Cold Cloud Duration (CCD) data, from which rainfall can be estimated, and vegetation indices based on the NDVI were obtained from Meteosat satellite imagery.

Analyses of migration events and rainfall showed that if the first rainfall at the start of the wet season exceeds 60-70mm within a 10-day period, sufficient widespread germination of seeds would follow and stimulate quelea populations to initiate their early-rains migrations. The birds will then move to areas where previous rains have permitted conditions good enough, for long enough, and a sufficient length of time earlier, for grasses to have produced seeds in the destinations. Only then will the birds be able to breed successfully. Further analyses suggest that a threshold of 300mm of rain needs to have fallen at such candidate sites since October of the relevant season. The way in which such rainfall regimes determine different migration patterns can be illustrated by the contrasting examples of the three consecutive seasons of 1965/66, 1966/67 and 1967/68. In 1965/66, breeding began in Mozambique in December, by January it was concentrated along the South Africa/Mozambique border, southwest of the initial sites. By February a north-eastwards shift spread the birds around Mozambique, and by March all activity was in the Francistown region of Botswana (Figure 11). Breeding there would have been facilitated by the heavy rain which fell around Francistown during January and February (see Table, Figure 11). In 1966/67 breeding began earlier, following substantial rain in South Africa before December, with the heavy rain in Botswana during that month allowing widespread breeding there in January and February (Figure 12 and Table). There were drought conditions throughout much of the region during 1967/68, but following initial breeding in South Africa, it was sufficient only in Mozambique to permit widespread breeding there, with rainfall in Botswana inadequate and too late. It only reached the 300 cumulative threshold by the end of April (Figure 13 and associated Table) and no breeding occurred there that season.

The areas receiving rain and indications of the amounts falling were estimated from the CCD data. Figure 14 illustrates data for 8 November 1998, building up to the 60-70 mm threshold being exceeded by mid-November when an early-rains migration away from the Harare area in Zimbabwe was observed.

3. ***Gathering of information on the degree of isolation of different sub-populations in each country, based on plumage polymorphisms and DNA.***

Based on comparison with the dorsal coloration of museum specimens, males from breeding colonies in Zimbabwe in March 1998 were scored as *spoliator, lathamii*, or intermediate, and their breeding plumage morphs were recorded. These data showed that the whole range of dorsal coloration, from *spoliator* to *lathamii*, was represented among males in the same breeding colonies well within the supposed breeding range of *Q. q. lathamii*. These same males were also scored for the polymorphisms in their breeding plumage to see whether there was any association between morph frequencies and dorsal coloration. A Principal Components Analysis of these data showed no discrete clusters of individuals associated with the prior classification into *spoliator*- or *lathamii*-type and that the category means are indistinguishable from each other in the centre of the distribution (Figure 3 of Jones *et al*. 1999).

The morphological data on plumage polymorphisms collected from breeding colonies at widely separated localities in Zimbabwe, in Botswana, Namibia and South Africa are being analysed in conjunction with DNA markers (DNA microsatellites), identifiable by using a variety of primers specially developed for this research (Dallimer 1999). At present it is too early to report on the results of this aspect of the research, which is being brought to a conclusion with funding from another source. However, on the basis of present evidence, the preliminary conclusion is that, because "*spoliator*" individuals cannot be separated from *lathamii* on morphological criteria in either breeding or non-breeding plumage, and because all colour variants breed in the same places at the same time, the subspecies *Q. q. spoliator* does not reflect any significant phylogenetic division (Jones *et al*. 1998, 1999). Once this has been confirmed by the DNA analyses, it will then be possible to refine interpretations of the data to see what other molecular genetic differences may occur. These could be between sub-populations across the southern African region, and might indicate sufficiently discrete entities to warrant more individually targeted management actions.

4. ***Production of a geographically-referenced PC information management system to predict zones suitable for quelea at different times of the year, in relation to rainfall and vegetation indices***.

The quelea breeding data were imported from the Access Data-base into a geographically-referenced PC information management system, programmed in ARCVIEW. Overlays of rainfall data and NDVI vegetation indices (Figure 15) allow assessments and forecasts to be made, using a rule-based approach, to predict breeding possibilities in relation to logical “if-then” algorithms. The model is not concerned with off-season wanderings or dry-season roosting activities as these seldom have any damaging effects on subsistence agriculture.

At the start of the season, breeding will be deemed to be unsuitable in any degree-square for 6 weeks after a threshold of 60mm of rain has fallen within the previous 10 days, this threshold being that known to initiate the “early-rains migration”. All those degree-squares where quelea breeding is known to have occurred (and thus assumed to have suitable habitat within them) are next treated as candidate breeding zones, provided that: (1) the NDVI images indicate suitable vegetation ; (2) at least 6 weeks have elapsed since the 60mm threshold was exceeded; (3) there has been > 300mm of rain since that time and (4) there are no existing, nearby, squares in the “early-rains” quarters, permitting the birds to remain there without needing to move. Queleas may then breed in the grid-square provided there are not equally suitable areas already fulfilling these conditions available in the direction of the early-rains migration, i.e. in the early-rains quarters. If there are, then breeding birds will be occupied there for the duration of a breeding attempt (5 weeks + 1 further week to regain breeding condition) before they can move elsewhere, though this period may be shorter if the breeding attempt is already partly completed or colonies fail. Only after earlier breeding attempts are completed can birds occupy grid-squares of later rainfall but, even then, because breeding conditions are ephemeral and the window of opportunity in any one place is very short, they will do so only if the area has only recently become suitable. If the grass seed has already matured and fallen from the seed heads, it becomes much less readily available to queleas and, by this time, caterpillars and nymphal grasshoppers have become adults and are unavailable as prey. Queleas seeking new nesting areas will by-pass such places and move on further along the line of the breeding migration to areas of even later rainfall. Such a leap-frogging process will continue until no more areas are suitable to receive birds that are ready to make a further breeding attempt, and the breeding season comes to an end.

5. ***Testing the possibility that fungi could be used to breakdown fenthion residues in contaminated soil.***

Apart from explosives ignited under quelea roosts or colonies, the main means of controlling the birds is by spraying, usually from the air, with the avicide Queletox®, the active ingredient of which is fenthion. For instance, during the 1997/98 season more than 5,000 litres of a commercial formulation (Queletox®) were sprayed at 7 l/ha to protect wheat, sorghum, millet and sunflower crops in South Africa (Geertsema 1998). After application, fenthion and its toxic degradation products, particularly the sulphone and sulphoxide derivatives, can be persistent, depending on environmental conditions (Minelli *et al.* 1996; Rotunno *et al.* 1997, Lacorte *et al*.

1997). In addition, off-target drift for 3km has been detected, at a sampling height of 6m, 20 hours after application and at 9m after 64 hours (van der Walt *et al*. 1998, van der Walt 1999). Also, as fenthion has weak knock-down properties, birds which have collected a lethal dose of the avicide may be able to disperse and contaminate other sites up to 30km distant, resulting in secondary contamination. Both primary and secondary contamination have been detected in non-target birds such as raptors (van der Walt *et al*. 1998) and recent reports suggest that fenthion persists in the soil for at least 54 days after spraying (van der Walt 1999). Control methods which are less damaging to the environment are urgently sought, therefore, with remediation of contaminated sites being a priority. For this reason, research was conducted to test whether a known bioremediation agent, the white-rot fungus *Phanerochaete chrysosporium,* was active against fenthion. If so, it would become a promising candidate for development as a means of reducing poisoning in environments where quelea had been controlled.

Laboratory tests showed that fenthion was metabolised by *P. chrysosporium* in liquid culture when applied to the limit of its solubility in aqueous media (7.2μM). Using GC-NPD, no evidence for either adsorption or accumulation of intracellular components was obtained and after 5 days culture, less than 1% of the original sample remained in the extracellular medium. Fenthion did not inhibit spore germination at the concentrations supplied, but appeared to inhibit the rate of spread of the fungus on solid media. Fenthion was oxidised by lignin peroxidase but enzyme turnover was dependent on the concentration of H_2O_2 supplied, with inhibition accompanying the formation of an inactive intermediate Compound III at higher H_2O_2 concentrations. Available evidence suggests that fenthion was metabolised via the fungal ligninolytic system using lignin peroxidase (LiP) as oxidant. Thus, there is good evidence that *P. chrysosporium* is active against fenthion, and so a promising bioremediation agent has been identified (Zacchi *et al*. 1999).

Outputs

(1) The sub-species *Quelea quelea spoliator*, thought by some to have a separate migration system from *Q. q. lathamii,* and thus to need a separate control strategy, cannot be considered a valid taxon on the basis of morphological research conducted during the project. Thus control plans and forecasting do not need to assume the existence of two separate migration routes within the southern African system. Experiments using orientation cages also failed to provide any firm evidence of the existence of a migratory divide.

(2) Means of ageing juvenile quelea birds have been established to assist in tracking dispersal from breeding colonies.

(3) Methods of typing Quelea birds using microsatellite DNA have been developed in conjunction with known plumage polymorphisms, which will assist in establishing migratory routes of different sub-populations within southern Africa and the extent to which such populations might remain geographically discrete.

(4) A data-base of historical records of quelea has been compiled, for use in developing forecasting tools including a predictive model using rainfall and NDVI data for Zimbabwe.

(5) A promising method for the bioremediation of sites contaminated by fenthion, the avicide used against quelea birds, has been identified and shown to be able to break down fenthion in the laboratory.

(6) A prototype model for predicting areas where quelea could breed has been developed.

All the anticipated outputs were achieved, but output 6 remains to be formulated in a formal way for widespread dissemination and output 3 will not yield definitive results until further analyses have been completed.

Dissemination Outputs

The following have been or will shortly be published, and copies of each are appended to the report (hardcopy held at NRInt).

Dallimer, M. (1999) Cross-species amplification success of avian microsatellites in the redbilled quelea *Quelea quelea*. *Molecular Ecology* 8: 685-702.

Jones, P. J., Cheke, R. A. & Mundy, P. J. (1998) Migration patterns of Red-billed Queleas *Quelea quelea* in southern Africa and the validity of *Q. q. spoliator*. In : Adams, N. J. & Slotow, R. H. (eds.) Proc. 22 Int. Ornithol. Congr., Durban. *Ostrich* 69: 402-403. (Abstract of Poster, full version of which included here).

Jones, P. J., Cheke, R. A., Mundy, P. J., Dallimer, M. & Venn, J. (1999) Quelea populations and forecasting based in southern Africa. In Cheke, R. A., Rosenberg, L. J. & Kieser, M. (eds.) *Proceedings of a Workshop on Research Priorities for Migrant Pests of Agriculture in Southern Africa*, Plant Protection Research Institute, Pretoria, South Africa, 24-26 March 1999. Natural Resources Institute, Chatham.

Jones, P.J., Dallimer, M., Cheke, R.A. & Mundy, P.J. (2000) The validity of the subspecies *spoliator* of the Red-billed Quelea *Quelea quelea* in southern Africa. *Ostrich* (to be submitted).

Jones, P. J., Elliott, C.C.H., & Cheke, R.A. (2000) Methods for ageing juvenile Red-billed Quelea *Quelea quelea*. *Ostrich* (to be submitted).

Venn, J., Cheke, R. A. & Jones, P. J. (1999) *Quelea Bird-pest Database: Southern Africa Data*. Chatham: Natural Resources Institute.

Zacchi[1], L., Cox[2], J. R., Cheke[2], R. A., van der Walt[3] , E. & P. J. Harvey[1*] (1999) Biodegradation of Fenthion by *Phanerochaete chrysosporium.* In Cheke, R. A., Rosenberg, L. J. & Kieser, M. (eds.) *Proceedings of a Workshop on Research Priorities for Migrant Pests of Agriculture in Southern Africa*, Plant Protection

Research Institute, Pretoria, South Africa, 24-26 March 1999. Natural Resources Institute, Chatham

The database (Venn *et al*. 1999) has been made available in electronic form to appropriate plant protection authorities in Botswana, Namibia, South Africa and Zimbabwe.

Contribution of Outputs

The outputs have contributed to DFID's developmental goal of eliminating poverty and, also, to a production system goal of minimising the impact of migrant pests on resource-poor farmers in semi-arid farming systems in southern Africa. The outputs have improved the ability of the Problem Bird Control Unit of Zimbabwe, and similar organisations in other southern African countries, to respond to quelea attacking crops by enhancing their understanding of quelea ecology. Specifically, project personnel and target country collaborators noted extensive quelea breeding in Botswana and Zimbabwe, which led to the appearance of important quelea colonies in Namibia. Immediate advice on appropriate measures was made available by email, followed by on-site visits by project personnel. The Quelea Data-base, compiled as one of the project outputs, has been distributed to national agricultural organisations, and provides information on quelea breeding sites (some of which are traditional). These data, coupled with a prototype computer model driven by remote-sensed data on rainfall and vegetation conditions, will permit forecasting of zones where quelea are expected to occur.

The immediate beneficiaries are national agricultural organisations in southern Africa. These have lacked any support or research capabilities on quelea for many years, although they recognise the severity of the problems caused by the birds. Only FAO, GTZ and SADC have made any contributions at all since the 1960s and the project has stimulated much interest amongst target institutions in methods of dealing with the quelea bird problem. During the project, quelea control strategies have been rationalised, by showing that the possible need to consider two subspecies in the region is unsubstantiated and by devising a framework for a forecasting model. A system of DNA markers, with much potential for future research has been developed, and substantial progress has been made towards devising a method for reducing environmental contamination caused by quelea control operations. A network of collaborating scientists and practitioners has now been established and a staff member of the Botswana Ministry of Agriculture has received extensive training in quelea biology and monitoring, as have field staff of the appropriate Zimbabwean and Namibian Ministries.

The 'end-user' beneficiaries are rural communities in southern Africa, dependent on cereal crop production, who gain from improvements in the efficiency of control methods against quelea birds. Follow-up research to promote the findings of the project should include testing and refining of forecasts, based on model outputs, with real-time events in southern Africa and the development of the prototype model into a form for general dissemination e.g. for use by IRLCO-CSA. If these tests proved to be successful, then the model could be adapted for use in other countries in Africa affected by other subspecies of the pest. Information generated by the project was disseminated to target institutions, including IRLCO-CSA, through a CPP Workshop on Migrant Pests (Project A0813 / ZA0274).

References

Allan, R. (1994) Final technical report of the quelea consultant. Unpublished report on Project C0200, Natural Resources Institute, Chatham, Kent.

Allan, R. (1997) *The grain-eating birds of sub-Saharan Africa: identification, biology and management.* Natural Resources Institute, Chatham, Kent.

Dallimer, M. (1999) Cross-species amplification success of avian microsatellites in the redbilled quelea *Quelea quelea*. *Molecular Ecology* 8: 685-702.

Dreiser, C. (1993) *Mapping and monitoring of Quelea habitats in East Africa*. Berliner Geographische Studien Band 37, Berlin.

Elliott, C. C. H. (1989) The quelea as a major problem in a food-deficient continent. pp.90-99. in *Africa's Feathered Locust* (Ed. by P. J. Mundy & M. J. F. Jarvis).Baobab Books, Harare, Zimbabwe.

FAO (1981) An assessment of the bird pest problem in Sudan, Ethiopia, Somalia, Kenya, Tanzania. Unpubl. report. FAO/UNDP. Rome. Italy.

Geertsema, L. (1998) Redbilled Quelea. Annual Report for the Directorate Agricultural Resource Conservation of the National Department of Agriculture, Republic of South Africa. Pretoria (unpublished report).

Jones, P. J., Cheke, R. A. & Mundy, P. J. (1998) Migration patterns of Red-billed Queleas *Quelea quelea* in southern Africa and the validity of *Q. q. spoliator*. In : Adams, N. J. & Slotow, R. H. (eds.) Proc. 22 Int. Ornithol. Congr., Durban. *Ostrich* 69: 402-403. (Abstract of Poster, full version of which included here).

Jones, P. J., Cheke, R. A., Mundy, P. J., Dallimer, M. & Venn, J. (1999) Quelea populations and forecasting based in southern Africa. In Cheke, R. A., Rosenberg, L. J. & Kieser, M. (eds.) *Proceedings of a Workshop on Research Priorities for Migrant Pests of Agriculture in Southern Africa*, Plant Protection Research Institute, Pretoria, South Africa, 24-26 March 1999. Natural Resources Institute, Chatham.

Lacorte, S., Jeanty, G., Marty, J-L., & Barcelo, D., (1997). Identification of fenthion and temephos and their transformation products in water by high-performance liquid chromatography with diode array detection and atmospheric pressure chemical ionisation mass spectrometric detection. *J. Chromatog*. 777 99-114.

Magor, J. I. & Ward, P. (1972) Illustrated descriptions, distribution maps and bibliography of the species of *Quelea* (weaver-birds: Ploceidae). *Tropical Pest Bulletin* no.1. Centre for Overseas Pest Research, London.

Meinzingen, W. F. (ed.) (1993) *A guide to migrant pest management in Africa*. FAO, Rome.

Minelli, E.V., Cabras, P., Angioni, A., Garau, V., Melis, M., Pirisi, F.M., Cabitza, F., and Cubeddu, M (1996). Persistence and metabolism of fenthion in orange fruit. *J. Agric. Food Chem.* 44, 936-9

Rotunno T., Di Caterina,R., & Argenti, L. (1997) Decay of Fenthion in green table olives. J. Agric. Food Chem. 45, 3957-60.

van der Walt, E. (1999) *Quelea* research at ARC. Abstract. In Rosenberg, L. J. & Kieser, M. (eds.) *Migrant Pests of Agriculture in Southern Africa. Research Priorities. Workshop on* Plant Protection Research Institute, Pretoria, South Africa, 24-26 March 1999.

van der Walt, E., Meinhardt, H. R., Venter, A. J. & Bouwman, H. (1998) Primary and secondary effects of Red-billed Quelea *Quelea quelea* control in South Africa. In Adams, N. J. & Slotow, R. H. (eds.) Proc. 22 Int. Ornithol. Congr., Durban. *Ostrich* 69: 456.

Venn, J., Cheke, R. A. & Jones, P. J. (1999) *Quelea Bird-pest Database: Southern Africa Data*. Chatham: Natural Resources Institute.

Wallin, D. O. , Elliott, C. C. H., Shugart, H. H., Tucker, C. J. & Wilhelmi, F. (1992) Satellite remote sensing of breeding habitat for an African weaver-bird. *Landscape Ecology* 7: 87-99.