1 DFID-sponsored Migrant Pest Research, 1989–99

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ABSTRACT

In 1989 the UK Government’s Overseas Development Administration (ODA), now the Department for International Development (DFID), launched its Renewable Natural Resources Research Strategy (RNRRS) for the allocation of funds in support of development priorities. This scheme included an initiative on pest control, the Integrated Pest Management Strategy Area (IPMSA), which funded projects on the biology and control of migrant pests. The Crop Protection Programme (CPP) followed in 1995 and was based on different production systems reflecting differences between agro-ecological zones. The CPP has continued to support work on migrant pests, but with increasing emphasis on southern Africa.

Given the current focus of research programmes on discrete communities of beneficiaries or on localised improvements in livelihoods, it is necessary to align them with the need for international initiatives on pests, which eschew boundaries as spectacularly as do locusts or quelea birds. Migrant pests are also difficult to reconcile with some bilateral aid programmes when their control in one country may benefit that country’s neighbours more than the community bearing the control costs.

The species constituting migrant pests, which qualify as targets within the RNRRS, are briefly described. The ways in which DFID-supported projects on migrant pests have sought, during the 1989–99 period, to increase knowledge of their biology, means of controlling them, ways of coping with environmental effects of control measures, the economics of control, monitoring their environments and modelling and forecasting outbreaks are reviewed. Finally, thoughts on future research priorities within the developmental context of southern Africa are considered.

INTRODUCTION

The UK Aid Programme, in its various guises, has supported research into the biology and control of migrant pests in Africa for much of this century. The discussion here will be restricted to the period from 1989, when the then Overseas Development Administration’s (ODA) Renewable Natural Resources Research Strategy (RNRRS) initiated an Integrated Pest Management Strategy Area (IPMSA) which included migrant pests in its brief, until 1999. Highlights of the IPMSA have been summarised by Hillocks and Eden-Green (1998). The IPMSA was replaced in 1995 by the Crop Protection Programme (CPP) of the
Department for International Development (DFID). The DFID Strategy for Research on Renewable Natural Resources aims to generate new knowledge in natural and social sciences and to promote the uptake and application of this knowledge to sustain livelihoods of poor people through better management of renewable natural resources. In addition to initiatives under the Research Strategy, DFID also has a Strategy for Aid to Locust Activities, which seeks to maintain a capacity to enable the UK to contribute towards national, regional and international efforts for the cost-effective and environmentally sound control of locusts. It functions through existing institutional structures and funding mechanisms, in order to enhance food security in low-income developing countries.

The DFID emphasis on a research- and knowledge-based strategy follows similar initiatives by the World Bank (1998), which uses the word knowledge to encompass both technical know-how and attributes, be they the quality of a worker or the credit-worthiness of a company (Anonymous, 1998). Such attributes allow the generation of knowledge, which coupled with sustainable capacity building and recognition of intellectual property rights (Butler, 1998), can be used to harness scientific knowledge towards achieving social and economic goals, in other words development, within increasingly knowledge-based economies (Anonymous, 1999). The trends are clear and information technology, the internet and radically improved global communication networks are already helping to bridge the knowledge gaps between rich and poor countries (Butler, 1999).

Until the advent of the internet, information about pest outbreaks could take too long to reach Europe-based migrant pest forecasters and by the time their predictions reached the pest-infested countries it was often too late for the forecasts to be put to good use. Now, however, satellite-derived information on rainfall can be sent regularly from the UK to Tanzania by email, and used at once in a model for forecasting likely armyworm outbreaks with almost no delay (Holt et al., 2000 or see page 151). If control measures can be taken, then an immediate benefit will be won for the rural poor whose livelihoods will have been improved by the application of knowledge. Such examples will constitute steps towards the goal of poverty elimination.

A consensus is needed on what are the most appropriate steps to be taken on the road to reducing the impact of crop losses, caused by migratory pests, which contribute to rural poverty within southern Africa. The extent of potential damage is illustrated by the depredations of the most infamous migratory pest, the Desert Locust, Schistocerca gregaria, which caused US$ 160,000,000 worth of damage at 1990 prices during the 1950–59 period (FAO, 1998). Annual losses in Africa due to Red-billed Quelea birds, Quelea quelea, have been estimated as US$ 45,000,000 (Elliott, 1989). The damage by migratory pests is often sporadic, localised and may be of little significance to some national economies, but to those small-scale farmers whose crops are completely destroyed their effects are catastrophic and can cause famine. Because of the general and widespread occurrence of migratory pests, the uptake pathways of research on them are, by necessity, through national and international crop protection authorities rather than through identified groups of farmer stakeholders. The international dimension of some of the pests predicates co-operation between countries and some altruism, in the spirit of African unity, as successful control in one country may make all the difference to the harvests of its neighbours.

MIGRATORY PESTS IN SOUTHERN AFRICA

It is problems related to the biology and control of locusts and grasshoppers, noctuid moths, quelea birds and the environmental effects of the control methods, which are of most concern. The main migratory pests in southern Africa are the Brown Locust,

Other candidates for migrant pest status include some aphid species, which are vectors of economically important virus diseases of crops. The sudden appearance of symptoms of such diseases, and the lack of known alternative host plants for the virus complexes, has led to speculation that the aphid vectors may migrate long distances carrying the viruses with them, as they are known to do in temperate regions. Migration is thought to occur with Barley Yellow Dwarf Virus and several vector species in Kenya (Wanjama, 1990) and with Groundnut Rosette Disease in Malawi, spread by *Aphis craccivora* (Adams, 1967; Davies, 1972), a known migrant in Australia (Gutierrez et al., 1971). Support for the possibility of long distance dispersal of aphids in Africa comes from the trapping of aphids in air-borne nets at heights up to 150 m over Côte d’Ivoire (R. C. Rainey, M. J. Haggis and R. A. Cheke, unpubl.). Also, 491 *A. craccivora* have been caught at dusk 15 m above groundnut, cotton, sorghum and fallow fields in the southern Gezira, Sudan, at aerial densities of 0.24/m³; the highest insect density ever recorded in more than 100 h of aircraft trapping in tropical Africa (Rainey, 1983, 1989). This and other catches were made of *A. craccivora* as high as 1200 m above the ground, and in suction traps (J. Bowden in Rainey, 1983) when the Inter-Tropical Front (ITF) was passing. Other pest aphids caught in aeroplane-borne traps in the same area included *A. gossypii* and *Rhopalosiphum maidis* (Rainey and Haggis, 1980).

Many plant-disease vectors other than aphids are known to be migrants outside Africa, and it is possible that some of these and related insects may be migratory, albeit for short distances only, within Africa too. Examples include: (a) whiteflies, which spread African Cassava Mosaic Disease and several other important viruses such as Cotton Leaf Curl, Okra Leaf Curl and Tomato Leaf Curl, since movements by *Bemisia tabaci* are of importance in American cropping systems (Allen et al., 1994, Byrne et al., 1994); (b) Homoptera such as leafhoppers, since some are long-distance migrants in Asia (Kisimoto, 1976) and there is evidence that *Cicaudulina* spp., the vector of Maize Streak Disease in Africa (also the subject of CPP projects, Cooter et al., 1999), may travel as far as 118 km (Rose, 1973; Thresh, 1983), but there are regional differences with Ugandan populations being more sedentary than those in Zimbabwe (Downham and Cooter, 1998); (c) thrips, which transmit Tomato Spotted Wilt Virus amongst others, the migrations of which have been discussed by Johnson (1969) and Thresh (1983); (d) beetles, which transmit Cowpea Chlorotic Mottle (Thresh, 1983); and (e) mealybug vectors of Cocoa Swollen Shoot Disease (Thresh, 1983).

**DFID-FUNDED RESEARCH ON MIGRANT PESTS**

During the 1989–99 period there have been few DFID-funded research projects on locusts and grasshoppers in southern Africa, but there have been projects there on African Armyworm moths, Migratory Locusts and quelea birds. These, and other projects on migratory pests elsewhere, have included work on basic biology, on population dynamics, on environmental aspects related to forecasting tools, and on control methods, including their environmental impacts. There have also been studies of the economics of migratory pest control strategies. The following sections summarise some of these studies.
The critical difference between a locust and a grasshopper is the former’s ability to change its phase from a solitary insect to a gregarious one with associated changes in morphology, physiology and behaviour (Uvarov, 1966, 1977). Thus, a goal of locust control would be to develop a means to prevent the gregarisation process. In order to achieve this it is necessary to understand the process itself, in order to try and manipulate it. The way that Desert Locusts become gregarised and revert to the solitarious phase has been investigated by laboratory experiments, which have demonstrated the time course of the changes and the stimuli promoting them (Roessingh et al., 1993; Roessingh and Simpson, 1994; Simpson et al., 1999). The importance of the insects’ recent history, including the phase status of the parents, in determining readiness to shift phases has been emphasised. It is also now known that a chemical in the foam part of an egg-pod has gregarising properties (Tickell, 1996, McCaffery et al., 1998). Eggs, which would normally be expected to hatch as gregarious nymphs, emerged as solitarious insects when deprived of the foam plug. When the foam from gregarious females was applied to eggs expected to hatch as solitaries, these emerged gregariform. It has also been demonstrated that a semiochemical which attracts gravid females to common egg-laying sites is deposited in the egg froth (Saini et al., 1995) and topical treatment of Desert Locusts and Migratory Locusts with azadirachtin-enriched neem oil has a solitarising effect (Schmutterer and Freres, 1990; Langewald and Schmutterer, 1995).

The role of such phase changes in Desert Locust population dynamics was investigated in an IMPSA modelling project. It was known that the intrinsic rate of increase ($r$) of populations of the gregarious phase of the Desert Locust is potentially much higher than the solitarious phase with faster development rates of the gregarious insects compensating for their lower fecundities (Cheke, 1978). Indeed estimates of $r$ were so high that theory predicted that the dynamics might be chaotic (Cheke and Holt, 1993, 1996). If so, this would mean that forecasting and predictions would only be possible over short periods, if at all, with important implications for the feasibility of forecasting. Analyses of time series of the numbers of territories infested have been unable to resolve this issue, with chaotic dynamics remaining a possibility and, indeed, some models including chaos gave good agreement with empirical trends. Further analyses using only the West African data confirmed a relationship with rainfall but the pattern was heteroscedastic, such that high rainfall did not always yield locusts. Interestingly, this pattern emerged from a model with chaotic parameters but did not from the same model with $r$ in the stable domain. Analyses of the time-series data revealed evidence for a 2-year lag in the dynamics (Cheke and Holt, 1993), a possibility also supported by theory (N.-C. Stenseth, R. A. Cheke and X.-S. Zhang, unpubl.). Further research on the dynamics of phase changes, and how shifts from one phase to another can be modelled to give realistic output, supports assumptions that locust dynamics are complex and that this complexity can be addressed with models incorporating phase shifts (Holt and Cheke, 1996a). However, quite simple rule-based models can also have predictive value (Holt and Cheke, 1996b). It would be instructive to apply similar analytical methods to data on Red, Brown or Migratory Locusts in southern Africa.

The importance of phase changes in the generation and termination of plagues has been investigated further in a project, co-ordinated by Jane Rosenberg and Richard Healey, on identification of the factors which lead to changes in Desert Locust populations at the beginning and end of recession periods. DFID has also supported research on the application of GIS and remote sensing techniques for the development and transfer of technology for Desert Locust management on the Red Sea coast of Eritrea, involving a computer-based system known as the Reconnaissance and Management System for the Environment
of *Schistocerca* (RAMSES). This, coupled with the FAO *Schistocerca* Warning Management System (SWARMS) (Cressman, 1997), should lead to improved forecasting abilities (Rosenberg, 2000; see page 165) and could be developed and adapted for other migrant pests including those infesting southern Africa.

DFID has also supported research into the use of radar for detecting and tracking migrant pests which has been tested successfully in the field with locusts, grasshoppers, armyworm, American Bollworm and other pests including aphids (Reynolds and Riley, 1997; Riley et al., 1995). Indeed, it is now practicable to have an early warning of the occurrence of locusts using a vertical-looking radar (Riley and Reynolds, 1997) which could act as an adjunct to traditional scouting methods and the monitoring of vegetation by satellite.

The optimal locust control strategy is prevention of gregarisation and swarming, through timely control of the hoppers. In the past, this was possible using the organochlorine insecticide dieldrin, but this was rightly withdrawn because of its potential adverse impact on human health, non-target organisms, and its accumulation in the environment. An alternative to full coverage insecticide spraying is the barrier technique in which insecticide is sprayed on to strips of vegetation, separated by wide spaces which are not sprayed. Marching hoppers encounter the sprayed barriers as they move around searching for food, and acquire a lethal dose of the insecticide. DFID-funded field trials in Madagascar showed that barriers treated with diflubenzuron, which is one of the first generation of insect growth regulators (IGRs) successfully controlled migratory locust hoppers (Cooper et al., 1995). Optimum barrier width and spacing is not known, nor is the potential usefulness of some of the more recent products for use in barriers, such as newer IGRs and fipronil, a phenyl pyrazole insecticide which is relatively new to locust control. A current CPF project is addressing barrier performance by developing a mathematical model, which incorporates the movement and feeding behaviour of four different species of locusts (J. Holt and J. F. Cooper, unpubl.). However, further work is needed to increase the efficiency and effectiveness of the technique and in particular to validate the model under field conditions. This work will be in collaboration with locust control departments which will be end-users of the technology.

A research programme on the environmental effects of control against the Migratory Locust *Locusta migratoria capito* occurring in Madagascar, where large-scale aerial spraying operations are continuing, is underway. The United States Agency for International Development (USAID) is currently supporting and helping to build national capacity in environmental monitoring, impact assessments and quality control of the spraying operations through the Office National pour l’Environnement (ONE). Staff from NRI are providing technical assistance in environmental monitoring, environmental impact assessment and quality control of locust spraying, and training in the principles of locust control, quality control of spray equipment, calibration, control techniques, navigation, weather conditions and droplet distribution. A more efficient monitoring system is now needed in Madagascar to provide quality control of locust spraying operations and thus an improved information management, analysis and archiving system.

Research on environmental monitoring has also included development of methods of pesticide residue analysis appropriate to less-developed countries, which can be used to assess effects of migrant pest control (Cox, 1993, 1994; NRI, 1993). Another DFID-sponsored project has been maintaining a database known as ENVIRON, which compiles information on the toxicity of pesticides, which can be freely accessed on request. Simple, inexpensive and portable equipment for environmental monitoring has also been developed
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(Grant, 1998) and the environmental effects of Desert Locust control operations have been reviewed by Ritchie and Dobson (1995).

DFID has supported biological approaches to the control of locusts and grasshoppers by contributing to the LUBILOSA project (Paraso et al., 1997; Thomas, 2000 or see page 173) and other research on use of fungal pathogens (Caudwell and Gatehouse, 1994).

A project on the effects of drought stress on food plants of locusts and how the insects respond concluded that the palatability to locusts of Schouwia purpurea increases with drought stress, possibly through the combined increase in sugar and proline content of the leaves.

Studies of the population dynamics and the egg-diapause of the Senegalese Grasshopper Oedaleus senegalensis have confirmed that outbreaks tend to occur after droughts (Colvin, 1997). Such studies are of interest to entomologists in southern Africa, given the parallels between the ecology of this species and that of the Brown Locust.

The economics of Desert Locust control policies have been evaluated in a recent workshop (Joffe in FAO, 1998), with an approach which could also be applied to southern African migratory pests.

**Armyworm Moths**

Models of populations of gregarious phase African Armyworm showed that, like Desert Locusts, they also have higher intrinsic rates of increase than the solitarious phase, with synchronisation of development and faster development rates of the gregarious phase being contributing factors (Cheke, 1995). Thus, a means of preventing gregarisation could also be a goal applicable to this pest. As is the case with all other migratory pests, rainfall is an important determinant of armyworm activity. A project based in Tanzania combines rainfall estimates, based on remote sensing data on Cold Cloud Duration (CCD), with data from a network of pheromone traps into a model to predict outbreaks (Holt et al., 2000 or see page 151). Data used in the derivation of the models were collected during earlier DFID-supported work which included the compilation of armyworm occurrences in a database (WORMBASE, Day et al., 1996), work on movements in relation to weather patterns (Tucker, 1993, 1994), and estimates of probabilities of movements to different destinations based on outbreaks in known source areas (Cheke and Tucker, 1995). A parallel project has been developing and testing the use of nuclear polyhedrosis viruses (NPV) as an alternative to pesticides for the control of armyworm (Cherry et al., 1997, D. Grzywacz and M. A. Parnell, unpubl.).

The control of armyworm, be it by pesticides or NPVs, has been based on the idea of strategic control, whereby initial outbreaks are deemed worthy of control whether they are on a crop or not, in order to prevent further outbreaks developing perhaps far distant from the controlled point. The economics of this strategic control approach were investigated and it was concluded that for some outbreak areas, but not all, strategic control would be cost-effective in terms of the values of crops saved in relation to armyworm control costs (Cheke and Tucker, 1995).

**American Bollworm Moths**

The IPMSA funded several projects on insecticide resistance in American Bollworm. The studies showed how best to detect and manage pyrethroid-resistance (Armes et al., 1994) and how it varied with the season and availability of non-crop food plants (Madden et al.,
Both the presence of non-cultivated hosts and diapause provided opportunities for conserving insecticide susceptibility. A simple bio-assay technique was developed enabling local staff to monitor the resistance (De Souza et al., 1995). Research on microbial methods of control of this pest was also conducted with evaluations of the efficacy of formulations of Bacillus thuringiensis and NPVs (Cherry et al., 1996, 2000). Other work included predictions of oviposition in relation to rainfall (Madden et al., 1993).

Quelea Birds

There had been little support from DFID for research on Red-billed Quelea birds (Quelea quelea) following the intensive research programme in the 1970s (Ward, 1971; Jones, 1989a,b,c,d) until the continuing importance of these pests led to renewed interest in 1995. A project on the southern African subspecies Q. q. lathamii, investigated its taxonomy (Jones et al., 1998, 2000b), genetic variability and movements in relation to environmental variables (Jones et al., 2000a or see page 139). Field work has been undertaken in Botswana, Namibia, South Africa and Zimbabwe to collect samples of DNA from different populations to help elucidate migration patterns. A database on quelea occurrences has also been compiled, which will be used in combination with rainfall and vegetation data to devise a predictive model of the birds’ likely movements under different circumstances.

Quelea control is still dependent on the use of explosives or the organo-phosphate avicide fenthion (Queltox). Both control methods have effects on the wider environment in general but on non-target organisms in particular. Thus there is a need for new control techniques, but until their development it is imperative to minimise the effects of fenthion and to this end the DFID project has been examining the possibility of bio-remediation of fenthion-contaminated soil using the fungus Phanerochaete chrysosporium to breakdown residues. By-products of the breakdown process have been identified, the speed of degradation measured and key variables influencing it identified, suggesting that it is worthwhile to proceed with field trials (Zacchi et al., 2000 or see page 191). The possibility of exploiting the bio-remediation of sites contaminated in control activities with other chemicals against other migrant pests would be worth examining too.

RESEARCH PRIORITIES AND POSSIBILITIES FOR THE FUTURE

There are several general themes applicable to most of the migrant pests discussed.

1. Novel environment-friendly control methods are required for all the pests discussed. Progress has been made with biological agents for use against locusts, grasshoppers, armyworm and American bollworm, but the methods all need refinements and further tests before they can become the control means of universal and widespread choice. There is an urgent need for a new means of controlling quelea birds to replace fenthion and explosives.

2. The consolidation, expansion and refining of existing knowledge-based computer applications such as the RAMSES system for Desert Locust in Eritrea, WORMBASE and forecasting models for African armyworm in eastern Africa and the quelea database for Q. q. lathamii in southern Africa. The development of parallel systems for the same pest species elsewhere and for additional pests such as Brown Locusts, within the southern African context, would also be worthwhile.

3. Knowledge of soil moisture levels is important for assessing the likelihood of orthopteran outbreaks. Research should be conducted to assess possibilities for estimating soil
moisture levels 5 cm or more below ground, which is feasible using satellite imagery based on radar (D. Archer, pers. comm.), to help predict hatching times by diapausing migrant pests such as Brown Locusts in southern Africa (and Senegalese Grasshoppers in West Africa) and the suitability of breeding grounds for others such as the Desert Locust.

4. Further work on the search for solitarising chemicals or other behaviour-modifying agents, which could be developed as sprays against hopper bands or swarms of locusts.

5. Standardisation and agreement on protocols for assessing the environmental effects of pesticides.

6. The development of bio-remediation techniques, which could be used as a follow-up to control methods, to reduce environmental contamination by pesticides.

7. Investigations of the migrations of vectors of plant diseases such as *A. craccivora*, whiteflies and thrips, and their possible epidemiological implications.

Research priorities not mentioned above specific to particular pests or groups of pests include for locusts: time-series analyses of long-term data on Red, Brown and Migratory Locusts and consolidation of progress with barrier methods of hopper control with IGRs. For quelea: investigations of Integrated Pest Management approaches, involving judicious use of planting times, resistant crops, fast-growing varieties and training of farmers regarding the need for rapid reporting of bird arrivals and nest-building.

It is also important to decide on the best ways to maintain national capacities and international organisations dedicated to migrant pest control, and how to co-ordinate responses from diverse sources efficiently. Without well-equipped and well-trained control teams, most forecasts are of little value.

ACKNOWLEDGEMENTS

This document is an output from the Crop Protection Programme of the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. I am grateful to A. G. Cook for comments on an earlier draft and to the following for discussions and information: D. Archer, J. F. Cooper, C. F. Dewhurst, P. J. Jones, J. I. Magor, L. J. Rosenberg, E. van der Walt.

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