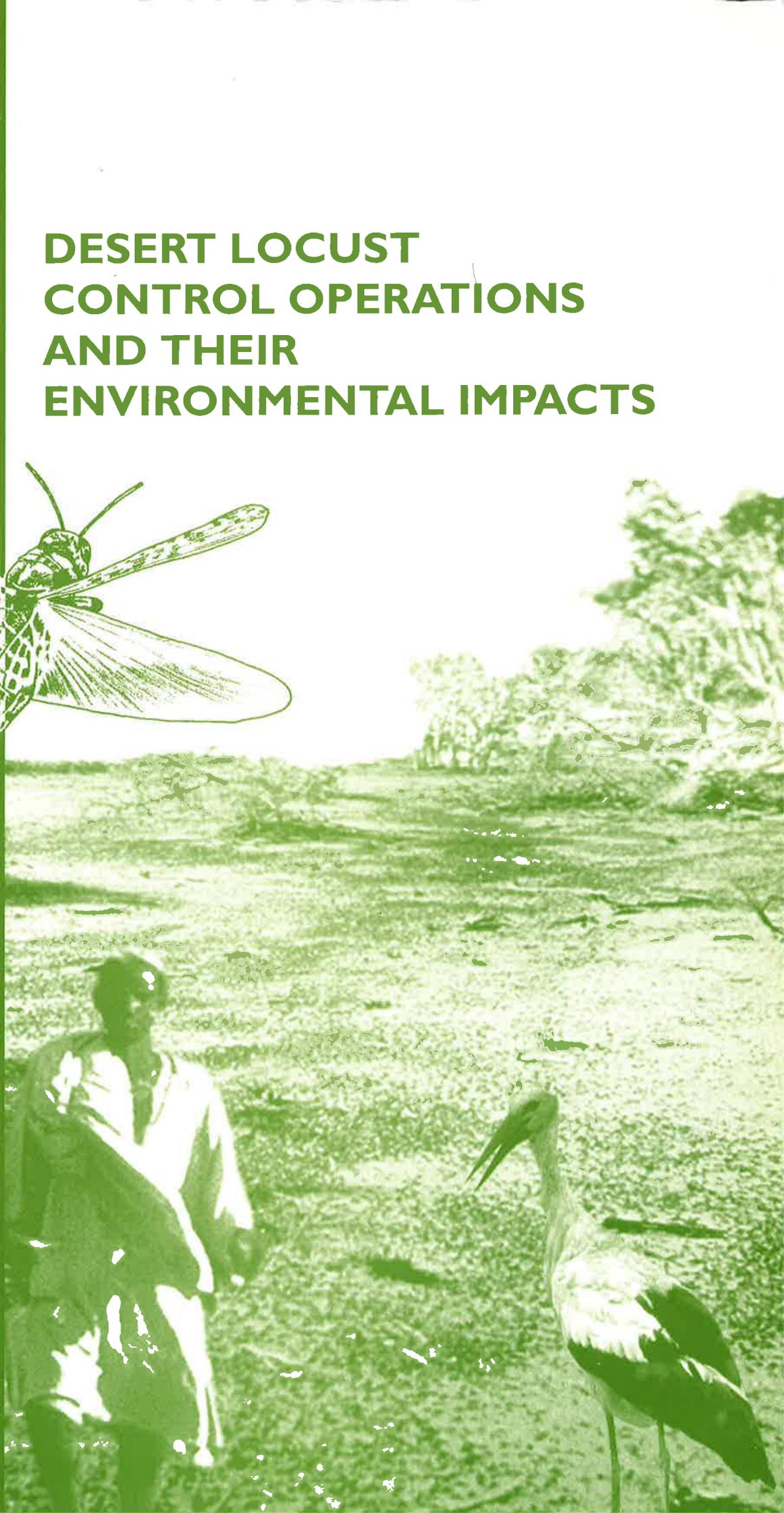


DESERT LOCUST CONTROL OPERATIONS AND THEIR ENVIRONMENTAL IMPACTS



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J M Ritchie and H Dobson

Bulletin 67



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ABBREVIATIONS

APHIS	Animal and Plant Health Inspection Service (USDA)
CGLR	Consultative Group for Locust Research
DGIS	Directorate General for International Cooperation (Netherlands)
FAO	Food and Agriculture Organization of the United Nations
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit GmbH
ICIPE	International Centre for Insect Physiology and Ecology
IGR(s)	insect growth regulator(s)
IUCN	International Union for Conservation of Nature and Natural Resources
NRI	Natural Resources Institute
ODA	Overseas Development Administration
ULV	ultra-low-volume
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
USDA	United States Department of Agriculture

Summaries

SUMMARY

This bulletin reviews methods currently available or under development for the control of the desert locust within the geographical and ecological context of the pest. The environmental impacts of these control methods are described and a range of mitigative actions are reviewed, including the development of new technologies with reduced impact. The relevance and application of the concepts of integrated pest management to locust control are discussed. Existing procedures for assessment of environmental impacts arising from donor-funded locust control activities are reviewed and a proposal presented for regulating donor provision of pesticide assistance.

The desert locust (*Schistocerca gregaria*) is an internationally important pest of agriculture in much of Africa north of the Equator, Arabia and western Asia. During recession periods it is scattered as solitary insects over large tracts of desert and semi-desert, migrating widely between suitable habitats that have received seasonal rainfall which permits breeding. After higher than normal rainfall, populations become denser and undergo behavioural modifications leading to formation of swarms of adults and mobile bands of flightless hoppers. If suitable conditions occur sequentially along the migration circuit for up to two years, population levels may rise dramatically leading to the invasion of previously uninfested areas by large swarms containing billions of individuals. At this stage, if not before, crops in countries remote from the original population build-up may be threatened, leading potentially to serious losses of food production and cash crops valued in tens of millions of dollars per annum.

Until the 1980s the technique of choice for control of the desert locust involved the spraying of barriers of persistent organochlorine insecticides (usually dieldrin) across areas infested by hopper bands. The insects were often killed weeks after spraying, by contact with such barriers. This technique was effective and economical but was discontinued due to the side-effects of dieldrin on human and animal health and a tendency, not found in non-organochlorine pesticides, to be accumulated in the bodies of animals and become concentrated through food chains.

In the absence of dieldrin, other less persistent pesticides are sprayed or dusted directly on to swarms and hopper bands or distributed as baits. Such control activities are difficult and expensive to mount and are often ineffective in reducing locust numbers. The relative merits of different chemical control technologies are reviewed and practical problems facing control operations are discussed. The current preferred application technique is ultra-low-volume (ULV) application of oil-based formulations and available ULV spray strategies are outlined. ULV application has the advantage of small quantities of material for transport which require no mixing, and independence from water supplies. It is economical and efficient but requires good technique for effectiveness.

Chemical control of locusts has caused environmental concern because of the very large quantities of pesticide used, the lack of evidence that this has been effective and the potential negative impact on humans contaminated by spray as well as on domesticated animals, bees, wildlife, birds, aquatic fauna (fish and invertebrates) and soil micro-organisms and invertebrates. Despite numerous reports, often circumstantial, of deaths among domestic animals, wildlife and birds resulting from spraying, there is little evidence that any widespread or long-term significant impact has affected any habitat or species as a result of current locust spraying activities. A possible exception to this may be the European stork (*Ciconia ciconia*) a migrant species which is in decline and is known to feed on locusts.

Most adverse side-effects of spraying can be avoided by adherence to application guidelines issued by FAO and careful choice of insecticides. Regular training courses for spray operators and other locust control personnel in survey, pesticide safety, ULV application, storage and handling of pesticides and campaign management are essential and control personnel need to have access to necessary transport, ULV spray gear, spares and ancillary equipment if they are to achieve effective control while minimizing pesticide use.

Potential alternatives to conventional control include the insect growth regulators (IGRs) which interfere with moulting. Sprayed as a barrier these may be persistent enough to replace dieldrin as an economical control method for hopper bands, with minimal impact on the environment. Field trials against desert locust are urgently needed if these compounds are to be brought into use within three years. Among the biological control methods proposed for locust control are mycopesticides consisting of oil-based formulations of fungal spores. These are unlikely to be available for use

within five years. Other proposed techniques, including semiochemicals, are conceptually unclear and unlikely to offer useful products within 10 years.

The use of programmatic environmental assessment for locust control is reviewed. In conjunction with technical assistance inputs including training, country-based environmental assessment and development of national locust control policy statements offer a means for donors to ensure that pesticide donations are effectively and safely used. Research needs for the monitoring and assessment of environmental effects of locust control are outlined.

RESUME

Ce bulletin examine les méthodes existant actuellement ou étant mises au point pour lutter contre le criquet pèlerin dans le contexte géographique et écologique de ce ravageur. L'impact de ces méthodes de lutte sur l'environnement est décrit et une gamme d'actions visant à les atténuer est étudiée et inclut la mise au point de nouvelles technologies avec un impact réduit. La pertinence et l'application des concepts allant de la gestion intégrée des ravageurs à la lutte contre les criquets pèlerins sont débattues. Les procédures existantes permettant d'évaluer les impacts sur l'environnement des activités de lutte contre les criquets pèlerins financées par des bailleurs de fonds sont examinées et une proposition visant à réguler la fourniture de pesticides par les bailleurs de fonds est présentée.

Le criquet pèlerin (*Schistocerca gregaria*) est un ravageur d'importance internationale pour l'agriculture dans une grande partie de l'Afrique au nord de l'équateur, de l'Arabie et de l'Asie occidentale. Au cours des périodes de récession, il est disséminé sous forme d'insectes solitaires dans de grandes portions du désert et des régions semi-désertiques, migrant largement entre les habitats appropriés qui ont reçu des précipitations saisonnières permettant sa reproduction. Après des précipitations plus fortes que la normale, les populations deviennent plus denses et leur comportement subit des modifications, entraînant la formation d'essaims d'adultes et de bandes mobiles de criquets sans ailes. Si, par la suite, les conditions sont favorables le long du circuit de migration pendant une période pouvant durer jusqu'à deux ans, le niveau des populations peut s'accroître de façon spectaculaire et conduire à l'invasion d'endroits jusque-là non infestés par de grands essaims contenant des milliards d'individus. A ce stade, si ce n'est pas le cas avant, les cultures dans des pays qui se trouvent loin de l'accumulation de la population d'origine peuvent être menacées, ce qui peut résulter en de graves pertes au niveau de la production alimentaire et des cultures de rente, évaluées à des dizaines de millions de dollars par an.

Jusque dans les années 80, la technique préférée en matière de lutte contre le criquet pèlerin consistait en la pulvérisation de barrières d'insecticides persistants organochlorés (habituellement de la dieldrine) à travers les régions infestées par les bandes de criquets pèlerins. Les insectes étaient souvent tués des semaines après la pulvérisation par contact avec ces barrières. Cette technique était efficace et économique mais a pris fin à cause des effets secondaires de la dieldrine sur la santé des Hommes et des animaux et d'une tendance de la dieldrine à s'accumuler dans le corps des animaux et à devenir concentrée dans la chaîne alimentaire, que l'on ne trouve pas dans les pesticides non-organochlorés.

En l'absence de dieldrine, d'autres pesticides moins persistants sont pulvérisés ou saupoudrés directement sur les essaims et les bandes de criquets ou répartis sous forme d'appâts. Des activités de lutte de ce type sont difficiles et onéreuses à mettre sur pied et s'avèrent souvent inefficaces à réduire le nombre de criquets pèlerins. Les avantages relatifs des différentes technologies de lutte chimique sont examinés et les problèmes pratiques auxquels doivent faire face les opérations de lutte sont débattus. La technique d'application préférée actuellement est l'application en ultra-pulvérisation (ULV) de formulations à base de pétrole et les stratégies d'ultra-pulvérisation existantes sont ébauchées. L'application en ultra-pulvérisation a l'avantage de nécessiter des petites quantités de matériel à transporter ne requérant pas de mélange et de ne pas dépendre des approvisionnements en eau. C'est une méthode économique mais elle requière une bonne technique pour être efficace.

La lutte chimique contre les criquets pèlerins a suscité des inquiétudes pour l'environnement à cause des très grandes quantités de pesticide utilisées, du manque de preuves quant à leur efficacité et de l'impact négatif potentiel sur les Hommes contaminés par la pulvérisation ainsi que sur les animaux domestiques, les abeilles, la faune sauvage, les oiseaux, la faune aquatique (poissons et invertébrés), les micro-organismes du sol et les invertébrés. Malgré de nombreux rapports, souvent circonstanciels, sur la mort d'animaux domestiques, d'animaux sauvages et d'oiseaux à la suite de la pulvérisation, il existe peu de preuves qu'un impact significatif étendu ou à long terme ait affecté un habitat ou une espèce particulière à la suite des activités actuelles de pulvérisation contre les criquets pèlerins. Une exception possible est peut-être celle de la cigogne européenne (*Ciconia ciconia*), une espèce migratrice qui est en déclin et qui se nourrit, on le sait, de criquets pèlerins.

La plupart des effets secondaires néfastes peuvent être évités en suivant les directives d'application de la FAO et en choisissant soigneusement les insecticides. Des stages de formation réguliers, pour les personnes opérant les pulvérisateurs et le personnel de lutte contre les criquets pèlerins, portant sur les méthodes d'enquête, la sécurité des pesticides, l'application en ultra-pulvérisation, l'entreposage et la manipulation des pesticides ainsi que la gestion d'une campagne,

sont essentiels et le personnel de lutte doit avoir accès au transport nécessaire, à l'équipement d'ultra-pulvérisation, aux pièces de rechange et à l'équipement accessoire pour parvenir à une lutte efficace tout en minimisant l'utilisation de pesticides.

L'alternative possible à la lutte conventionnelle inclut les régulateurs de croissance des insectes (IGRs) qui entravent la mue. Pulvérisés sous forme de barrière, il est possible qu'ils soient suffisamment persistants pour remplacer la dieldrine comme méthode de lutte économique contre les bandes de criquets, avec un impact minime sur l'environnement. Des essais sur le terrain contre les criquets pèlerins sont requis de façon urgente si ces composés doivent pouvoir être utilisés d'ici trois ans. Parmi les méthodes de lutte biologique proposées pour lutter contre le criquet pèlerin se trouvent les mycopesticides consistant en des formulations de spores fongiques à base de pétrole. Il est peu probable qu'ils soient mis en vente d'ici cinq ans. D'autres techniques proposées, incluant des produits semio-chimiques, ne sont pas claires du point de vue conceptuel et il est peu probable qu'elles fournissent des produits utiles d'ici 10 ans.

L'utilisation d'une évaluation de l'environnement pour un programme de lutte contre les criquets pèlerins est étudiée. Combinés à une assistance technique, des intrants incluant une formation, une évaluation de l'environnement par pays et la mise au point de déclarations de politique nationale en matière de lutte contre les criquets pèlerins sont un moyen pour les bailleurs de fonds d'assurer que les dons de pesticides sont utilisés de façon efficace et sûre. Les besoins en matière de recherche pour la surveillance et l'évaluation des effets de la lutte contre les criquets pèlerins sur l'environnement sont esquissés.

Desert Locust Control Operations and their Environmental Impacts

INTRODUCTION

Concern over the environmental effects of locust control has grown over recent years. This concern arose initially from the reliance of locust control on the use of persistent organochlorine insecticides (including dieldrin and BHC). This family of chemicals share two features: they break down slowly in the environment and they can be accumulated in the tissues of animals and concentrated in predators at the top of food chains (including humans). Dieldrin was withdrawn from use in the USA in 1974 by the Environmental Protection Agency (EPA) on the basis of its potentially damaging effects on human health and the environment. In 1975 USAID, which had continued to sponsor overseas use of pesticides banned or restricted for use in the USA, was sued by environmental organizations for failing to prepare an environmental impact statement on these uses as required by the 1969 US National Environmental Policy Act (OTA, 1990). In response USAID prepared an environmental impact statement in 1977 and subsequently played a major role in the world-wide banning of dieldrin.

More recently commentators have expressed concern at the sheer scale of interventions with pesticides against locust and grasshoppers during the 1986–89 upsurge which involved the application of 14 million kg of pesticide dust and 16 million l of liquid formulations (Greenpeace International and The Pesticide Trust, 1993). A major programmatic environmental assessment on locust and grasshopper control in Africa and Asia has been conducted for USAID (TAMS Consultants, 1989) and a review of environmental concerns was issued by USAID (1991).

In 1988 a group of international donors formed the Consultative Group for Locust Research and an advisory body, the Scientific Advisory Committee, was set up by the United Nations Development Programme (UNDP) and FAO (Joffe, 1995). This organization set out to sponsor a range of novel approaches to locust control in the short and medium term, aimed at progressively replacing existing broad spectrum pesticides with more efficient and safer methods. FAO organized an international workshop in Marrakech, Morocco in May 1993 to review progress on control methods and a seminar was convened in Wageningen in December 1993 to examine the overall strategy of locust control using current methods (van Huis, 1994b).

This bulletin describes briefly the geographical and ecological context of desert locust control operations, the major components and activities of those operations which may give rise to significant environmental impacts, and the nature of those impacts. It goes on to describe possible mitigation measures, including the development of new technologies with less serious environmental impacts, and the monitoring necessary for detection and evaluation of impacts.

HABITAT OF THE DESERT LOCUST

The total area of invasion by desert locust swarms covers 29 million km² in Africa and south-western Asia. Within this huge area the locust engages in migratory movements consisting of several interconnected seasonal circuits over successive generations on an intercontinental scale, extending for distances of up to 3000 km in one season (Uvarov, 1977). The nature and timing of these migrations has been summarized by Pedgley (1981).

In the true desert zone, with rainfall less than 50 mm per annum, locust breeding is infrequent and tends to be associated with drainage from highlands though swarms migrate regularly across desert in transit between seasonal breeding areas in western Asia, the Arabian peninsula, the horn of Africa and West Africa. Locust swarms regularly breed in areas receiving annual rainfall of between 80 mm and 400 mm (Magor, 1962) which constitutes the Sahelo-Saharan transitional zone and much of the true Sahel to the south of it, consisting largely of a fairly uniform cover of annual grasses with scattered trees. Here, breeding commonly occurs in depressions with clay/silt soils supporting lush annual herbaceous vegetation after rain. Further south, the Sahelian zone gives way with increasing rainfall above 500 mm to Sudan savannah consisting typically of continuous tall grass with trees and shrubs (Uvarov, 1977). This zone is less suitable for breeding owing to its more humid micro-environment during the summer rains. However human activity in the form of intense grazing and settled cultivation of millet and sorghum may produce a habitat for locusts more akin to the true Sahel zone (Popov, 1965).

COMPONENTS OF CURRENT LOCUST CONTROL OPERATIONS

Locust control operations typically consist of a range of chemical control techniques applied on the basis of availability of chemicals, equipment and personnel at remote locations and over a relatively short time span, financed by governments or donors. The window of opportunity for successful control may be as short as a few weeks from first report of infestation because swarms may invade from neighbouring countries or may develop in remote or inaccessible areas. The location and scale of the operation may change abruptly during the campaign and operations frequently cross national boundaries.

Strategies for control of the desert locust reflect the fact that upsurges generally begin among populations of solitary-behaving locusts in remote semi-desert localities. When subjected to appropriate cues such as physical contact with other locusts, pheromones and visual stimuli, solitary locusts change phase to become gregarious. This is apparent in their coloration, e.g., bright yellow adults; in their physiology, e.g., longer wings for better flying; and in their behaviour, e.g., crowding together rather than dispersing. Cohesive groups of gregarious adults flying together are known as swarms and groups of gregarious nymphs hopping along together are known as hopper bands. As a result of unusually heavy rainfall in this recession area, successful breeding occurs. An upsurge progresses by a series of such above-average rains in areas to which the locust migrates in successive generations. Initial swarm formation occurs as a result of wind convergence concentrating locusts in areas of green vegetation and their subsequent selection of suitable parts of such areas for laying and other activities leading to gregarization of the next generation of hoppers. Many experts believe that it is only after swarm formation has occurred, that the locusts constitute a practical and economic target for current control techniques (Steedman, 1990). At present, this issue is the subject of debate and three major approaches to control strategy have been proposed, as summarized below (see Joffe (1995) for more detailed discussion of these).

(a) *Upsurge prevention* (preventive control, also known as strategic control (USAID, 1991)). This is the currently preferred approach which involves monitoring possible breeding areas using satellite imagery, meteorological information, ground surveys by trained staff and information gleaned from local people. Intervention is based on the density of locusts and their degree of gregarization, detected by survey teams. Originally preventive control was largely based on the use of persistent chemicals, normally dieldrin, sprayed in widely spaced parallel bands, which gave economical control of locust hopper bands (van Huis, 1994a). Since the banning of dieldrin it was being questioned whether preventive control was viable.

(b) *Upsurge elimination*. This involves a more serious level of control intervention in cases where the early stages of the upsurge have gone undetected or have proceeded too fast for adequate early action.

(c) *Plague suppression*. This occurs at a stage when an upsurge has already become widespread and involves an increasing component of crop protection activities by farmers and others as gregarious locusts threaten cultivated areas.

These three approaches form a continuous sequence.

Mechanical/traditional methods

Various traditional methods exist for killing or repelling locusts. These include digging trenches in the path of hopper bands to trap and kill them, burning, beating and smoking the bands and swarms. They are generally practised by farmers for crop protection purposes and may be effective against low-level infestations. If infestations are heavier, large bands or swarms may enter from any direction at any time and mechanical methods cannot keep pace with the ingress. These methods are very labour-intensive and are not generally thought to be effective against serious infestations (TAMS Consultants, 1989). The effect on the overall locust population, and thus the potential as a preventive or curative strategy will be small since individual farmers only ever encounter a small proportion of the locust bands and swarms. Swarms and bands usually form in areas of natural vegetation in sparsely inhabited semi-desert zones far from cultivation. Concerted action by farmers on a larger scale using traditional means alone might be difficult to mobilize, given expectations of intervention by government control teams (TAMS Consultants, 1989).

In considering the use of traditional (or any other) control techniques, it is important not to assume that those which are effective against one species of locust or grasshopper pest can necessarily be applied to others. For example, destruction of egg masses of the variegated grasshopper was shown to be effective (Page, 1978) because this pest lays dense egg beds near to cultivations. Where desert locust eggs are laid in dense egg fields close to centres of human population, this method can be applied since the pods are delicate and ploughing causes damage and exposure to desiccation and predation by natural enemies as well as burying many hatchlings and preventing them from reaching the soil surface. This method was successfully applied against an egg field in Tunisia in 1988 (Showler, 1993). However, in the majority of cases the desert locust lays its eggs in remote areas where they are not detectable until they have hatched. There does not seem to be much scope for improving traditional crop protection methods against the desert locust and in any case, it is clearly preferable to control locusts before they reach cultivated areas. However, locusts often do reach farmers' fields and in the absence of any other technology, farmers have no choice but to try to safeguard some of their crops by traditional methods.

Conventional insecticides

These are generally neurotoxic, with modes of action by contact and/or stomach. The active ingredients can be divided into four main groups.

(a) *Organochlorines*: this group contains well-known examples such as BHC, DDT, dieldrin and endrin. They are characterized by broad-spectrum action and persistence in the environment (several weeks for dieldrin under desert conditions). Dieldrin is no longer recommended for use for reasons of human health (WHO category 1b, highly hazardous) and because of its impact on the environment where it accumulates in food chains, reaching high levels in predators such as raptors. No organochlorine pesticides are now approved for locust control by FAO (Symmons, 1993).

(b) *Organophosphates*: this group contains the two most widely used locust insecticides, fenitrothion and malathion. They are moderately fast-acting (2–8 h), relatively non-persistent, but non-selective compounds. Malathion has the advantage of very low mammalian toxicity (WHO class III, slightly hazardous).

(c) *Synthetic pyrethroids*: examples are deltamethrin and lambda-cyhalothrin. They are fast-acting ('knock-down' within minutes) with varying levels of persistence and a broad spectrum. Recovery from knock-down has been reported where less than the recommended dose has been used or where meteorological conditions for application were not appropriate. They are of fairly low mammalian toxicity – most are in the slightly hazardous WHO category, although some, e.g., deltamethrin, are in the moderately hazardous group.

(d) *Carbamates*: e.g., bendiocarb. These are similar in characteristics and action to organophosphates.

Some locust insecticide formulations contain two of the above types of insecticides to exploit the useful characteristics of both. An example is fenitrothion and esfenvalerate which combines the knock-down effect of the pyrethroid with the slow, but sure, efficacy of the organophosphate.

FAO publishes a list of pesticides for which there is a recommended dose for control of desert locusts (see Appendix 1). This is often interpreted as a list of recommended pesticides, and the problem arises then with the implication that pesticides not on the list are not recommended. FAO is at pains to point out that there are many other pesticides which are effective against desert locusts, but these are the only ones for which it is confident to recommend a dose, based either on well-executed and documented field trials or on long field experience. The list is reviewed annually by the FAO Pesticide Trial Referee Group which sits to examine new laboratory and field data demonstrating efficacy and effective dose.

In theory, certain situations suit some of these pesticides better than others. For example, it has been suggested that pyrethroids are not suitable for spraying flying swarms (FAO Control Guideline, appendix 6) since the locusts may be 'knocked down' by contact with the first small dose, and thus fall out of the swarm before acquiring a lethal dose, resulting in the locusts recovering later. This has not been verified in the field. Conversely it has been suggested that pyrethroids and other fast-acting compounds are particularly good for hopper band control since the hoppers are rapidly disorientated, resulting in them staying in the sprayed area and picking up additional insecticide from the vegetation.

In practice, however, control will be carried out with whichever pesticide is available at the time. From the procurement stage, donors provide the pesticide of their choice, which may be influenced by national commercial policy (OTA, 1990). Even if pesticides are bought by the locust-affected country, at the time of purchasing the responsible body is unlikely to know whether the target is going to be bands, settled swarms or flying swarms, so decisions are more likely to be

made on cost and availability. Even if a choice of pesticides is available in the country, the pre-placing of inputs which is essential during the early stages of a campaign may not accurately match the needs of the particular targets which have to be controlled later. Choice of the 'wrong' pesticide is not seen as a factor contributing to incomplete control; more serious difficulties exist with application equipment, application technique, meteorological conditions under which spraying is carried out and the logistics of finding and getting to a significant proportion of any medium to large infestation.

Pesticide formulations, application techniques and equipment

(a) Baits consist of a carrier such as wheat bran impregnated with an insecticide such as bendiocarb. Locust hoppers eat the bait and are killed. Baits are applied at between 5 and 15 kg/ha, usually distributed by hand from the back of a vehicle or while walking through the bands. They can also be scattered from suitably adapted aircraft.

(b) Dusts comprise a fine carrier, such as chalk, mixed with insecticide, then applied by hand or from vehicles to kill hopper bands. The formulations are applied at 2–10 kg/ha with very simple application equipment by farmers with hessian dusting bags which they shake or beat with a stick as they walk through the bands. Alternatively they can be applied by knapsack or vehicle-mounted motorized dusters.

(c) Emulsifiable concentrate (EC) formulations of liquid insecticides are concentrated insecticide solutions containing emulsifiers which are mixed with large volumes of water and applied at a rate of 200–700 l/ha in relatively large drops which fall rapidly to the ground (Symmons, 1994). They are applied by conventional field crop pesticide application equipment, i.e., either lever-operated knapsack sprayer, vehicle-mounted airblast sprayer or aircraft-mounted boom and nozzle equipment (placement spraying).

(d) ULV spraying (drift spraying or incremental spraying; Symmons, 1994) involves applying around 1 l/ha or less of a concentrated oil-based insecticide. A narrow droplet size spectrum is required so that most of the volume of the spray is contained in droplets within a fairly small optimal size range between 50 and 100 μ m diameter (there are 1000 μ m in a millimetre). Rotary atomizers achieve this more effectively than conventional nozzles. They can be either hand-held, vehicle-mounted or aircraft-mounted.

Advantages and disadvantages of different chemical control technologies

The very large quantities of bait formulations required for locust control present logistical problems of manufacture, transport, storage and application in comparison with some other methods. Shelf life is usually no more than a few weeks because of degradation of the carrier.

With dusts again there are logistical problems of supply and application which make use over large areas impractical, and there are reports of low efficacy on later stage nymphs due to their thicker cuticles. There are also reports of a shelf life of no more two years for propoxur and bendiocarb (Munir, personal communication). There is a trade-off in that dusts can be more safely applied by untrained operators with minimal protective clothing (dust mask) than can some other formulations such as oil-based ULV products because dusts generally have lower dermal toxicity than these formulations.

The disadvantages of using EC formulations are that large quantities of water must be found – often difficult in desert locust habitat – and that the distance

between spray passes (track spacing) must be quite narrow, e.g., 10 m for an aircraft, to ensure that there is a reasonably even coverage of the target area.

The disadvantages of ULV spraying are the slightly increased hazard to untrained or ill-equipped operators handling concentrated formulations and the need for special spray equipment (including batteries for hand-held sprayers) and suitable wind conditions. The advantages of ULV spraying are that water, which may be hard to find, is not required and no mixing of formulations is required with its attendant risk of operator exposure. Supply logistics are attractive with small volumes applied per hectare and the work rate is very rapid since wide track spacings can be used (e.g., 100 m for an aircraft). However, care must be taken with application of ULV insecticides to ensure that the low volumes are deposited fairly uniformly over the target area. If too many large droplets are produced, a lot of pesticide will be wasted as fall-out on the ground and if too many small droplets are produced, there will be excessive drift out of the target area. This technique is the most efficient and now the most widely used method of controlling desert locusts and guidelines for its use have been issued by FAO (Symmons, 1993). For large areas it has been shown to have cost advantages.

Costs of control operations

Accurate costing of control operations is problematic since costs are split between donors, national plant protection departments, other parts of the national administration (e.g., army) and farmers. Control of locusts and grasshoppers together between 1986 and 1989 involved the treatment of 26 million ha with 16 million l of liquid pesticide (ULV and EC formulations) and more than 14 million kg of pesticide dust, at a cost of at least US\$ 315 million (van Huis, 1994a). The cost of crop protection efforts in one plague year has been estimated as equal to the cost of 15–20 years of preventive control (PRIFAS, 1989). It is doubtful however whether accurate cost figures exist which would justify such a statement. In Tunisia the cost of control operations has been estimated at between US\$ 15 and US\$ 30 per ha treated and the potential annual value of harvested produce saved has been estimated at US\$ 29 million for an expenditure of US\$ 8–17 million (Potter and Showler, 1991).

The meeting of the Directorate General for International Cooperation (DGIS) in Wageningen (van Huis, 1994b) carried out simulation exercises to attempt to evaluate relative costs of different current methods to treat an infestation equivalent to 1200 km² of settled swarm. Options included use of baits, dusts and ULV formulations, applied by farmers, plant protection staff using vehicles, or aircraft spraying. Farmer control using bait was the cheapest method but was deemed to achieve only 25% treatment of the area infested as a crop protection measure. This approach would not have controlled the locust population as a whole and in real life might well have had to cope with reinvasion of crops. When simulating control carried out by the plant protection department, spraying band-infested blocks was the most expensive population control method, used very large amounts of pesticide and would, if applied in reality, have major impact on the environment. ULV application against individual hopper bands using vehicles was found to be the cheapest option for population control. ULV aerial treatment of settled swarms was found to be better in simulations than ULV aerial control of flying swarms on grounds of cost, amount of pesticide used and safety of operators.

ULTRA-LOW-VOLUME SPRAY STRATEGIES

Given that ULV spraying is the most efficient and widely used type of application, there are several different types of ULV spray strategy. One or more may have to be used simultaneously depending on the terrain, locust developmental stage, and resources available.

(a) Band spraying involves finding individual hopper bands and treating them by ground or aerial means. This is pesticide-efficient, but the chances of finding any significant proportion of bands in a large infestation are low. Portable or vehicle-mounted sprayers are used – aircraft cannot be used efficiently for targets less than 0.25 km².

(b) Block band spraying involves demarcating a block of country which has a relatively high proportion of its surface area covered by bands, say 5%. The whole block is then sprayed by aircraft. This is less pesticide efficient and more environmentally damaging since much uninfested land is sprayed between the bands, but is rapid since location of individual bands is not required.

(c) Barrier spraying entails spraying widely spaced strips of vegetation in areas infested with hopper bands using a persistent insecticide (originally dieldrin). As the bands march (often several hundred metres per day), they eventually encounter one or more of these strips and build up a lethal dose by feeding on treated vegetation. The product used must be persistent enough on the vegetation to be still active by the time a band encounters it, and preferably persistent enough to control bands over a period of several weeks resulting from successive waves of hatching in the region. Barrier spraying of old stocks of dieldrin by air and ground equipment in the uninhabited areas near the India-Pakistan border during 1993 may be partly responsible for eliminating hopper bands following a late upsurge swarm invasion. It is doubtful whether the same effect could have been achieved by spraying individual hopper bands, simply because of the scale of the task. The technique avoids the necessity of precisely locating bands within an infested area and is now being revived using the persistent but more environmentally benign IGRs. This approach has recently been tested against the migratory locust in Madagascar (Schefer and Rakotonandrasana, 1993) with encouraging results in terms both of control success and environmental impact.

(d) Settled swarm spraying involves locating swarms at roost and spraying them by ground or aerial means. This usually has to take place in the relatively short window between dawn and departure of the swarm (requiring swarm location the previous night) but spraying is sometimes possible in the evening after settling, or even occasionally at night by ground-based means.

(e) Flying swarm spraying. This has been practised successfully in the past, but most desert locust spray aircraft are not specially equipped to prevent entry of locusts into the air intakes and do not have adequate screen washing to cope with the inevitable accidental encounters with the locusts. It is potentially the most rapid and pesticide-efficient spray strategy (Symmons, 1993) but most pilots will not attempt it because of the dangers.

In the absence of suitable barrier spray products, the speediest and most efficient option involves ground teams or aircraft spraying ULV formulations of a limited range of pesticides on to bands of locust hoppers and settled or flying swarms of adults. This must be carried out under the right conditions (i.e., a steady cross wind of more than 2 m/s at 2 m height with minimal thermal convection), using properly calibrated ULV spraying equipment (i.e., appropriate drop size, emission height, forward speed, track spacing and flow rate). The scale of the target will determine the most appropriate spray platform. Portable sprayers have a work rate of the order of 30 ha/day and are suitable for individual

hopper bands of any size. They also have the advantage that operators can dismount from vehicles and treat areas inaccessible to vehicles. Vehicle-mounted ULV sprayers have a work rate of around 250 ha/day and are suitable for individual hopper bands larger than 1 ha and sometimes settled swarms. Aircraft have a work rate of up to 8000 ha/day and are suitable for spraying hopper band infested areas larger than 10 ha and for swarms.

PROBLEMS WITH CURRENT CONTROL OPERATIONS

Locust control campaigns are rarely well monitored or documented. This makes any accurate analysis of constraints to effective and efficient locust control extremely difficult. Operations are usually carried out in a rush, often by overworked technical staff who are supervising recently and minimally trained labourers/operators and documenting the events is low on the priority list. Anecdotal information on the difficulties encountered is scattered amongst many individuals, for example, the many ground control teams which are mobilized in any large campaign. There is also often a vested interest in glossing over the difficulties, for example, contract pilots not wanting to admit they have applied the wrong dose, or Plant Protection Departments not admitting that the activity of the pesticide is low due to poor storage. Even donor-funded consultants can only ever see a small sample of the control operations, and they may not know what specifically to look for. Further detailed analysis of practices and problems must be carried out to identify appropriate equipment, techniques and training requirements of the locust-affected countries.

However, from the anecdotal evidence, certain common problems emerge.

(a) *Finding the locusts.* New technologies are making a valuable contribution to the forecasting of desert locust upsurges. Satellite imagery (greenness and cold cloud cover) is helping to identify regions where locust breeding is likely. Mathematical models have been developed to attempt to predict the development of locust populations. However, the importance of raw data from surveys cannot be overemphasized since cold cloud does not always mean rain and favourable conditions will not produce breeding without locusts. In practice these raw data are often lacking. From the air, hopper bands may or may not be visible, depending on their stage and the vegetation or soil they are on. It is very unlikely that any significant proportion of hopper bands in a large infestation will be individually treated, or even located. Swarms are easier to spot from further away but the problems of getting to them and treating them before they fly away are greater. Security difficulties or simple shortage of vehicles or fuel may prevent survey teams entering zones where conditions are favourable for locusts. Organizations may be unwilling to pass on information which might reflect unfavourably on them or may wish to conceal the absence of good quality information. Constraints are limited search capability, security restrictions in some areas, communication equipment shortages and organization.

(b) *Reaching locusts with spray teams.* Even if all of the hopper bands are found, getting to all of them with ground spray teams will be almost impossible. This leaves the option of block band spraying with aircraft, but if the overall percentage infestation is not high, this will be extremely wasteful of resources. Constraints are sufficient transport, sprayers, and accurate enough navigation compounded by short spray window (usually 08:00 to 11:00 and possibly 16:30 to 18:00).

(c) *Limitations on pesticide products.* Dieldrin is no longer available and IGRs are not yet field validated; consequently the logistical advantages of barrier spraying are denied to control teams at present, i.e., application of widely spaced

strips of persistent pesticide in the knowledge that they will kill any hopper bands (even those hatching after application) which encounter the strip over the following 4–6 weeks. All other pesticide options require a search and spray policy. A recurring problem with these pesticides is reduced activity as a result of long and/or inappropriate storage. In conclusion, constraints are as follows: no acceptable persistent product available for barrier spraying; the sporadic nature of the pest; and the lack of adequate pesticide storage facilities in many locust-affected countries resulting in degradation of pesticide active ingredient and formulations.

(d) *Limitations on spraying machinery.* The mainstay of most locust ground campaigns is still the exhaust nozzle sprayer. This is an inefficient applicator in that it produces a wide range of droplet sizes (large ones constitute a large proportion of the pesticide fall-out near to the sprayer and the small ones drift out of the target area) and flow rate varies with throttle opening and is not easily adjustable. This is not to say that it does not kill hopper bands – it just does so by vastly overdosing them. In some countries, canon-type airblast sprayers are being introduced. These are, or have been crudely modified from, sprayers designed for high volume or low volume application of emulsifiable concentrates. Piping and pumps are often not resistant to the aggressive solvents in ULV formulations and there is little advantage of the airblast, except perhaps occasionally to treat locusts in low trees, to compensate for the disadvantages of the complexity and maintenance requirements of the auxiliary motor. Droplet spectrum is poor and therefore wasteful. Purpose-built locust sprayers incorporating rotary atomizers are available, but they have a poor reputation for reliability, sometimes justifiably so, compared with the exhaust nozzle sprayer. Boom and nozzle sprayers are still used to apply ULV products from aircraft when there is no other choice. This will be a very inefficient use of pesticide and flying hours. Constraints are inefficient sprayers in use in many countries and the need for convincing field validation of sprayers with a better fundamental performance.

(e) *Applying the right dose.* The three parameters of track spacing, forward speed and flow rate must be managed correctly to apply the volume of formulation per hectare which will deliver the recommended dose of the active ingredient per hectare. Apart from aircraft with electronic flow metering and an experienced pilot this is rarely kept to for a mixture of deliberate, unavoidable or inadvertent reasons. Where calculations are not carried out, it is understandable that operators should err on the side of overdosing to be sure that the mortality is high. In fact the psychology demands that spray teams see significant effects, even with slow-acting products, before moving off to the next target. Unavoidable overdosing occurs with the exhaust nozzle sprayer where flow rate cannot be adjusted to a low enough level to match the appropriate track spacing and forward speed. Inadvertent over- or under-dosing occurs where the operators do not know how to manage the spray parameters and therefore apply according to what seems right at the time. Constraints are the level of training of spray teams and the low quality of some spray machinery.

(f) *Achieving a good deposition.* To apply the correct amount of pesticide per hectare does not mean that a good kill will be achieved; the pesticide may not reach its target (the insect or the vegetation on which it is perching or feeding). Some sprayers, such as the exhaust nozzle sprayer and the canon-type sprayers cannot produce a droplet spectrum which will give a reasonably uniform deposition over the target area. In practice these sprayers are often set up incorrectly so that the droplet spectrum is far worse even than their rather poor initial potential. Much of the pesticide falls out on the soil near to the sprayer and some is carried out of the target area as drift of small drops. An inappropriate

choice of emission height with aircraft applications will result in an apparently correct area dosage, but either very stripy deposition if flying too low or very little pesticide in the target area if flying too high. Spraying under inappropriate meteorological conditions such as inversion, strong convection and very low winds can result in patchy deposition or very little deposition at all. Constraints are type of equipment available, training in application technology, and timing.

(g) *Maintaining infrastructure and expertise.* Effective large-scale control operations require a communication and support structure to ensure that operational teams do not run out of essentials such as pesticides, fuel and spare parts. In many cases organizations lack trained and experienced staff to manage the large logistical problems, and lack the resources and communications network to maintain such a supply and service operation effectively. Constraints are lack of training and experience of logistics, lack of communication equipment, and lack of spare parts. Extended recession periods when locust swarms are absent exacerbate these problems.

SOURCES OF ENVIRONMENTAL IMPACT

Insecticide hazard characteristics

The insecticides currently used for locust control are mostly classified as 'moderately hazardous' to human health on the basis of their acute oral and dermal toxicity to rats, expressed in terms of the weight of technical compound (mg) per kilogram of body weight required to cause death to half the tested animals (LD50) (WHO, 1990). The relevant information is given in Appendix 2 for common locust control insecticides. Insect growth regulators and some synthetic pyrethroids are deemed "unlikely to present acute hazard in normal use", although other synthetic pyrethroids (e.g., cyhalothrin) are moderately hazardous. It should be noted that for some insecticides (e.g., phoxim) the acute dermal toxicity is higher than the oral toxicity. The toxicity will in practice vary according to the formulation which may involve dilution or admixture of a carrier or synergist which itself may be toxic. A basic classification of anti-locust insecticides in terms of their relative toxicity to non-target organisms is given in Appendix 3.

In addition to toxicity, several other intrinsic factors govern the hazard posed by a pesticide. The dosage received is a function of the concentration of active ingredient, and the rate (g/ha) and frequency of application. Persistence, the length of time the compound remains in the environment, will influence the degree of impact. If the pesticide is mobile (e.g., soluble in water) its effects may reach further. Attenuation due to dilution in air, soil or water will reduce the effects. Degradation rate may be influenced by the interaction of the compound with water, sunlight and micro-organisms. Bio-accumulation, the steady build-up of pesticide residues in living organisms through feeding on contaminated food, may lead to predators at the top of the food chain receiving large doses over time. This is a feature of the organochlorine pesticides which has led to their banning for locust control use.

Storage, handling and transport of insecticides

Designs for simple pesticide stores have been developed (e.g., by GTZ) (USAID, 1991) which include the necessity for an impermeable base (concrete), good ventilation and security, and avoidance of direct sunlight and high temperatures. Siting must be designed to minimize run-off and percolation into groundwater in the vicinity of wells and human habitation. Washing facilities for staff are essential. Spillage must be contained by raised door sills or bunding around the store. Sand or sawdust should be used to absorb spillage, followed by scrubbing with detergent and water.

The most serious spillage to date occurred when the Main Operational Base of the Desert Locust Control Organization for East Africa (DLCO-EA) at Hargeisa, Somalia, was bombed and looted during the civil war in 1988 (Lambert, 1993). In the process, more than 81 200 l of organochlorine and organophosphate insecticides were released into the environment, penetrating to a depth of at least 3 m into the stony soil at the site. Reptiles in the immediate vicinity of the spill accumulated heavy doses of pesticide. Local people excavated contaminated soil to use and to sell for pest control and three children who handled the soil were said to have become ill, one fatally. As a result of run-off after heavy rain the local seasonal river became contaminated and the population have been advised not to drink water from it. Samples from wells dug into the riverbed during the dry season did not, however, show any detectable contamination of groundwater. FAO has paid for the building of a retaining security wall around the spillage site.

Pesticide spraying

Environmental pollution may be caused or exacerbated by human error in the course of locust control activities. During spray operations overdosing may result from navigational errors, poor flow control, poor maintenance of equipment, or repeated applications. Occasionally pilots may deliberately discharge unwanted insecticide from aircraft causing a serious risk of contamination of people and livestock (Grant, 1989).

Disposal of unwanted pesticides and decommissioning of contaminated equipment

Substantial concentrations of out-of-date or banned pesticides exist in parts of the desert locust area. Some of these are no longer suitable or permitted for agricultural use. They form a part of the estimated minimum figure of 6500 t of obsolete pesticides stored in Africa and the Middle East of which the largest part consists of organochlorine compounds (E. Ambridge, personal communication). These pesticides were acquired, often with donor assistance, for control of a variety of pests including locusts. Their safe disposal should be a major concern to donor agencies involved in locust control. While old stocks of organochlorine insecticides are still available in affected countries, there is the danger that they will continue to be used for emergency locust control when stocks of less-damaging alternatives have been exhausted, as happened in Tunisia in 1988 when shortage of other compounds led to the application of BHC dust (Potter and Showler, 1991).

RECEPTORS OF ENVIRONMENTAL IMPACT

Impacts on survival and health of fauna and flora and ecosystem function

The environmental impacts of locust control affect the receiving environmental media (air, water, land) and the living organisms within those media (humans, fauna, flora). Temporary changes in air quality (via levels of specific atmospheric pollutants) are likely to occur locally during spraying operations, potentially affecting humans, domestic animals and wildlife in the path of aerial spraying operations. These effects cannot easily be separated from those of absorption through the skin and by mouth.

Changes in water quality (e.g., altered physical/chemical characteristics) will occur if water bodies are over-sprayed. Types of water bodies which may be affected include temporary water courses (*wadis*, *tugs*), springs, permanent streams and rivers, ephemeral and permanent swamps, lakes and marshes, rice

paddies, groundwater and wells. Apart from being a source of water for human consumption these water sources may support fish, crustacea and molluscs of importance in supporting humans and various bird species including migrant storks. Pesticides may be rapidly bio-accumulated, especially by molluscs. Chlorpyrifos and pyrethroids are especially toxic to fish and amphibia, and pyrethroids also affect aquatic invertebrates, especially crustacea (shrimps, prawns and lobsters). However, there is a tendency for pesticides to become adsorbed to sediment or suspended organic matter in water bodies leading to less serious impact on non-target fauna than would be expected from laboratory exposure to the same quantity of pesticide. Temporary pools in desert areas are critical habitats which may receive run-off from large areas and be contaminated by spraying operations, leading to biodiversity changes among insects and crustacea (Lahr and Diallo, 1993).

Soil microbial processes including the breakdown of organic matter and nitrogen fixation are not at risk from currently approved pesticides sprayed at recommended rates, but transient effects might be expected from over-spraying with diazinon, chlorpyrifos or propoxur (Grant, 1989). Soil microbial processes can be readily measured with inexpensive techniques and such measurements should be included in evaluation trials of pesticides (Grant, 1989). Effects could be expected to vary in relation to the organic matter content and moisture status of the soils. Aerial application of fenitrothion and chlorpyrifos at normal rates has been shown not to affect microbial decomposition processes in savannah soils (Grant, 1990).

Suitability of land for particular purposes such as grazing or human habitation will be severely affected by major accidents involving persistent insecticides, through high levels of chemical residues in soil. The use of organochlorine compounds is now largely banned but stocks of these chemicals are still held in some control centres and access to some areas used for long-term storage under poor conditions may need to be restricted.

Specific types of terrestrial environment are at particular risk of serious impact from locust spraying activities. Agricultural areas such as desert oases and fruit orchards may be delicately balanced ecologically, relying on pollinators which are seriously affected by spray operations (Potter and Showler, 1991). Some areas used for growing food or cash crops may be already receiving excessive insecticide inputs such that locust spraying may cause incremental impacts. In others there may be reliance on biological control by insect parasitoids to suppress populations of important introduced pests (e.g., the cassava mealybug) which would be adversely affected by locust spraying operations.

In Gambia after extensive aerial spraying against grasshoppers in 1988, crop protection entomologists attributed upsurges of cassava pests and blister beetles to the treatment (Gruys, 1991). Such reports are circumstantial. Studies of the impact of fenitrothion on predation of grasshopper egg pods in Senegal (Niassy *et al.*, 1993) found an unexpected increase in the level of egg pod destruction by predators in sprayed areas when compared with unsprayed control areas. This was thought to be due to higher mortality of natural enemies of the egg pod predators in the treated plots. However, mortality among honey bees can be caused by most locust pesticides, including malathion and pyrethroids (the latter also toxic to spiders), and has consistently been reported in relation to locust and grasshopper control in The Gambia and Morocco (Gruys, 1991) and in Tunisia where the authorities were sufficiently disturbed to ban future locust control operations in the vicinity of oases (Showler, 1993). In south-eastern Morocco deaths of honey bee colonies of the Saharan race, *Apis mellifera sahariensis*, were considered a significant impact because of the value of lost income to breeders and the already limited gene pool of this race (Gruys, 1991).

Various kinds of birds, mammals, reptiles and amphibians are at risk from locust-spraying activities. These will include jackals, rodents, aardwolf, foxes, small cats, mongooses and toads which may feed on contaminated living or dead locusts at night and lizards, storks, egrets, rollers and raptors feeding by day which may be exposed also to direct spray deposition. In the late 1950s spraying of a range of pesticides against locusts and mosquitoes in Turkey led directly to the deaths of 600–700 individuals of the northern bald ibis (*Geronticus eremita*), 70% of the last remaining Turkish colony, contributing to its eventual extinction in 1989 (Collar and Stuart, 1985). Feeding on corpses of locusts treated with fenitrothion and chlorpyrifos is likely to lead to deaths of insectivorous birds and reptiles and numerous reports have confirmed this. The FAO recommended rate of application for fenitrothion, 400–500 g/ha, applied aerially, is near the threshold where it can cause immediate deaths in birds (Steedman, 1990).

European storks (*Ciconia ciconia*) can consume large numbers of desert locusts and over 300 specimens have been found in the gut of a single bird (Smith and Popov, 1953). Some correlation has been established between cycles of desert (and other) locust plagues and recessions and corresponding fluctuations in European stork populations (Dallinga and Schoenmakers, 1987). Spraying against locusts and grasshoppers in the Sahel has been identified as a threat to this species through reduction of its food supply (Thiollay, 1985; Grimmet, 1987). Deaths of storks from fenitrothion poisoning have also been recorded (TAMS Consultants, 1989). In August 1993 hundreds of grasshopper buzzards, black kites and swallow-tailed kites were seen spread across a wide area of dry country in Kordofan, central Sudan, in the vicinity of locust infestations. There were unconfirmed reports of three raptor deaths resulting from the control operations (Dewhurst, 1993). These deaths were almost certainly caused by spraying of EC formulation of fenitrothion (C. Dewhurst, personal communication). By comparison, malathion has a relatively low toxicity to vertebrates.

Impacts on human health and survival

Operator exposure is common in locust control operations, through handling pesticide and through drift from operations. Constraints are non-availability of protective clothing or unwillingness to wear it under hot field conditions. Local residents and nomadic pastoralists may also be affected directly by spray drift and through loss of livestock or contamination of milk and meat due to stock being over-sprayed or feeding in treated areas or drinking from contaminated water sources. Despite these dangers there do not appear to have been any human fatalities attributed to the control operations during the last desert locust upsurge.

Both organophosphate and carbamate insecticides are nerve poisons and can depress levels of cholinesterase – the enzyme which breaks down neurotransmitter chemicals at nerve synapses. Exposure of workers may cause symptoms ranging from mild dizziness to convulsions and death in severe cases. Test kits are available for sampling blood acetylcholinesterase levels in control staff and should be applied at appropriate intervals to staff who are in regular contact with insecticides. However, use of these, though simple and safe, may require official government permission and the attendance of medical personnel. Staff are unlikely to co-operate if they fear dismissal in the event of a positive test and alternative work not involving exposure must be provided. Cholinesterase levels vary widely in healthy individuals and a baseline figure must be established for each person before exposure. In Morocco acetylcholinesterase tests were routinely used to monitor control staff during the 1986–89 campaign and 1016 staff were temporarily or permanently taken off spraying duties. This high figure may be associated with the use of dichlorvos, an organophosphate pesticide

(rated as highly hazardous by WHO) which is not recognized by FAO as suitable for locust control (Showler, 1994). The absorption of pyrethroids can be detected by analysis of urinary metabolites but in most cases, routine testing is unlikely to be necessary under normal working conditions since pyrethroids are rapidly broken down and excreted.

MITIGATION OF ENVIRONMENTAL IMPACTS OF CURRENT LOCUST CONTROL TECHNOLOGIES

Removal of obsolete pesticide stocks and improved procurement procedures

Technology exists to destroy unwanted pesticides using high temperature incineration (up to 1600 °C). However it would be necessary for major agencies to organize and underwrite the costs of this. Costs of re-packing, shipping to Europe and incineration of pesticides in the European Union are estimated at up to US\$ 5000 per ton (sic). However the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal* prohibits shipments from non-signatory countries from entering the European Union unless their governments have notified the relevant European Union department of their wish to conclude a shipment agreement under the convention. Few African/Caribbean/Pacific countries have made such a notification (E. Ambridge, personal communication).

Several donors, notably GTZ, have already assisted developing countries with disposal of unwanted dieldrin stocks, mostly by incineration in Europe, though GTZ has mounted a project to remove stocks of DNOC, an obsolete organochlorine pesticide originally intended for locust control, from the International Red Locust Control Organization – Central and Southern Africa (IRLCO – CSA) in Zambia to Tanzania where they are being incinerated in a cement kiln. The hazard associated with this technique needs to be assessed and any necessary remediation measures applied. There is clearly a danger of transferring a soil/water pollution hazard into an air-borne pollution hazard if the required operating temperatures are not maintained and if appropriate emission levels of breakdown products such as chlorine are exceeded. Pilot tests of the incineration of mixtures of organophosphate pesticides and dieldrin in a cement kiln in Pakistan were reported to meet Pakistani environmental protection standards for air pollutants and only narrowly failed to meet US Environmental Protection Agency standards (Showler, 1994). Electrostatic filtration of the flue gases may be possible to remove particulate combustion products and ‘scrubbing’ might remove some gaseous pollutants but both would increase costs.

FAO is in the process of establishing a project for the *Prevention and Disposal of Unwanted Pesticide Stocks in Africa and the Near East* to co-ordinate disposal activities in the region. This will set up a working group of interested donors, establish an inventory of obsolete stocks, and develop guidelines on tender for the procurement of pesticides. These guidelines will assist donors and recipients to avoid accumulating unnecessary stocks. During the 1986–89 plague an international ‘pesticide bank’ scheme was operated by the European Community and USAID (Showler, 1994). This type of scheme involves a multilateral agreement between locust-affected countries and a suitable central organization which ensures the ready availability of pesticide stocks held safely, pending verification of a specific need when required amounts can be swiftly despatched for immediate use. Schemes of this kind reduce the danger of accumulating pesticides in affected countries.

Used pesticide drums are extremely difficult to clean and attempts to wash them result in the production of contaminated washings needing disposal. They

are sometimes reused for carrying water for human consumption and therefore present an unacceptable risk. If not reusable for pesticides, they should be decontaminated by burning and cut up for other purposes or crushed and buried. Some suppliers are moving towards provision of an internal removable liner for drums which will reduce contamination problems (USAID, 1991).

Improved application of pesticides

Whichever the pesticide or habitat, overdosing represents an unnecessary environmental challenge. This was reported to be one of the most significant environmental factors in the 1994 desert locust campaign in Senegal (H. Van der Valk, personal communication) with operators not capable of calibrating equipment properly. There were several reasons for this: not knowing how to carry out the necessary calculations to determine sprayer speed, track spacing and flow rate; poor droplet spectrum from inappropriate equipment (canon-type sprayers); difficulty in carrying out flow rate checks and adjustments due to sprayer characteristics (it is difficult to collect and measure spray when mixed with an airblast) and lack of measuring cylinders; lack of confidence in the technique, leading to a desire to see an unnaturally rapid result. This highlights the need for sound advice and choices on spraying machinery and the overriding need for training of technicians and operators in application techniques. They must also be provided with all necessary field equipment (meteorological, spray sampling, mortality assessment) to allow them to carry out good, well-monitored application operations.

There is also significant scope for improvement to aerial spraying operations. They operate rapidly (30 times the work rate of a vehicle-sprayer, 200 times the work rate of a portable sprayer) and typically apply the largest share of the pesticide used to the greatest treated area in most control campaigns, so small mistakes can have serious efficiency and efficacy implications. Pilot training is required since many are more accustomed to high-volume field crop spraying and are unfamiliar with the special requirements of locust control. It is also necessary to implement a joint equipment inspection by trained plant protection staff to prevent inadvertent or deliberate wrong calibration settings which are common. New navigation technology for aircraft and ground teams has potential for improving locust control operations. Global positioning systems are now relatively cheap (US\$ 500–1000) and can give an accurate position fix anywhere in the world. This is an invaluable tool when combined with good radio communications for calling aircraft to locust spray targets. If the aircraft is also fitted with one, it can fly direct to the spray site without the usual navigation problems.

In addition, if the aerial spray equipment is linked to the track guidance of a global positioning system, there is potential for accurate navigation of spray tracks without the need for ground flagging parties. This would permit automatic avoidance of ecologically sensitive areas (equipment switches off over pre-programmed co-ordinates of temporary water bodies), and automatic logging of surface area sprayed, volume used, dose applied (to be downloaded later for the spray record). With aerial operations often being unsupervised, far from any critical observers, this may be an invaluable tool to improve accountability, pesticide efficiency, mitigation of environmental effects and efficacy. However the cost of fitting this equipment to an aircraft and testing it is currently relatively high (roughly US\$ 70 000 per system) (C. Dewhurst, personal communication).

Improved operator protection and training

It cannot be stressed too highly that regular training and rigorous application of standards in relation to maintenance, protective clothing, labelling and procedures for decanting and mixing pesticides must be followed if control staff are to remain safe. It is essential that disposable face masks and gloves, visors, loose

cotton overalls or 'pyjamas' and rubber boots are provided for operators and worn by them. Adequate facilities for washing themselves and their clothes must be provided. Decanting of pesticides should be carried out with siphons made of pesticide-resistant materials. Sprayers and siphons require provision of maintenance kits of perishable parts to avoid dangerous leakages in operation. FAO and other agencies organize regular courses on safe pesticide use for control staff. The emphasis in training programmes needs to move from certifying attendance to certifying competence of spray staff and their supervisors on the basis of objective performance testing. Principles of quality control need to be applied to this process.

Avoidance of protected and critical habitats and migrant birds

All countries within the desert locust area contain areas of land or water of special conservation value which may or may not be the subject of national protective legislation. For protected areas an inventory has been prepared (IUCN, 1992). Many of these critical habitats are wetland areas of particular importance for birds such as migrant waders (e.g., the Niger Delta in Mali) while others are savannahs supporting populations of large mammals of conservation value. Ideally all such areas should be avoided in locust-spraying operations, and buffer zones of 2.5 km should be established around them (TAMS Consultants, 1989).

An area of particular concern is the only remaining breeding ground of the northern bald ibis (*Geronticus eremita*) north and south of Agadir, Morocco, which now supports the last 74 remaining breeding pairs of this species in the wild since the species became extinct in Turkey in 1989. Part of the area is covered by the Souss-Massa National Park but the birds can forage more than 17 km from the nest (C. Bowden, personal communication) and are therefore at risk from any locust control operations in the National Park or the surrounding area. There is a need for country-specific environmental assessments to identify and locate all such areas of special value. Control managers will then be able to make informed decisions on the best control options for that site in conjunction with national conservation bodies.

Migrant birds from Europe traverse the Sahara to reach over-wintering areas in western, eastern and southern Africa. Migration routes are complex and nearly 170 individual maps were used to prepare a simplified scheme showing two major movements via Morocco and the Sahelian countries in West Africa and via the Red Sea coast and Ethiopia in East Africa (TAMS Consultants, 1989). Many of these birds are insect feeders, and some may be rare and endangered, e.g., European stork, *Ciconia ciconia*. Some birds migrate seasonally within Africa itself (e.g., black kite, *Milvus migrans*, and Abdim's stork, *Ciconia abdimi*) and some of these, together with some Palearctic migrants including the European stork, congregate opportunistically at the site of locust swarms.

At times of year when birds are known to migrate across the desert locust area, spray operations should employ techniques of the lowest possible avian toxicity since large birds will gorge themselves on large numbers of contaminated locusts. The use of malathion rather than fenitrothion would greatly reduce risk to birds. The need for research on effects of spraying on birds has been noted by the SAC (1993). This should include an assessment, from the literature, of the likely risks to migrant birds.

Avoidance of populated areas

In case of aerial application, a 2.5-km buffer zone should be left around population centres (TAMS Consultants, 1989). The population should be advised in advance of the spray operation so that wells can be covered and water

containers and food (e.g., drying grains) covered or removed indoors. Careful marking of spray areas is essential and global positioning indicators and radio links with ground teams should be used to assist precise positioning. Animals must be removed from the spraying area and nomadic pastoralists and other herders informed of the safe period for avoidance of the sprayed area. Use must be made of available local information networks (local radio, newspapers, village committees, etc.) to inform people to avoid contaminated areas and not to eat fruit, crops or locusts from the area. In Tunisia in 1988 warnings of imminent spray campaigns were given nationally by radio and locally by crop protection personnel (Showler, 1993). These were apparently disregarded by some beekeepers.

ALTERNATIVE CONTROL METHODS

Use of insect growth regulators (IGRs)

The benzoyl urea IGRs such as diflubenzuron, triflumuron and teflubenzuron act by inhibiting the synthesis of chitin (the hard material in their exoskeletons) so that the nymphs cannot successfully moult. They are showing promise for locust and grasshopper control (Schefer and Rakotonandrasana, 1993; Cooper *et al.*, 1995) but have not yet been tested in large-scale operational trials against the desert locust. IGRs are not just a new product, they offer the possibility of a new control strategy, or more accurately, a return to something like the old dieldrin strategy. They are very persistent on vegetation and thus have the potential to perform in a similar way to dieldrin as a barrier spray. The attraction of this technique is that it is not a search and destroy method requiring the laborious location of thousands of isolated targets, but works in effect by remote control, provided the sprayed barriers are somewhere in the infested area at some time during the development of the hopper bands. It may even be possible to spray a site of reported egg laying since the persistence of IGRs means they are still active weeks later when hoppers have emerged from the eggs and are marching as gregarious bands.

It is likely that certain parameters will have to be more accurately controlled than with dieldrin: the barrier spacing, barrier width and IGR dose on the vegetation because the products are not accumulated in the insect in the same way as dieldrin is, being rapidly excreted and deactivated. As such the design of any barrier technique would have to take into account the need to kill hoppers by passage through just one sprayed barrier, since the IGR may have been metabolized by the time the insects reach the next barrier. These variable parameters are currently being examined by modelling and by field trials, but early trial results in Madagascar against migratory locust bear out the great potential of these products.

The persistence of IGRs is not an undesirable characteristic when taken in the context of their other attributes: low vertebrate toxicity, the fact that they are adsorbed and deactivated rapidly on contact with soil, their low solubility in water such that groundwater contamination is unlikely, and their predominantly stomach action which confers a degree of specificity among invertebrates. Recent ecotoxicological results suggest that even if an IGR product has a small negative effect on some non-target organisms, the fact that only widely spaced strips of vegetation are sprayed means that there is a reservoir of these organisms in the unsprayed areas between the treated strips (C.Tingle, personal communication) from which reinvasion may occur.

No large-scale field trials of IGRs were mounted against desert locust during either of the last two upsurges (1986–89, 1993–94) despite the fact that their potential has been recognized for almost a decade. This may be partly due to the

understandable reluctance of affected countries to mount experimental control trials during an emergency against large hopper band infestations. Large-scale trials are required against hopper bands to determine efficacy, and if proven, to refine the important parameters for greatest efficiency. However, there are difficulties in achieving this. The mobility of bands means that they can move in and out of small plots, so 100 km² is a minimum plot size. The trials, by the nature of their target, would have to be carried out during an upsurge and carry the risk of swarm escapes if control is poor. Reliable conventional pesticide spraying capacity must be available to provide control if the IGR technique does not work satisfactorily. Trials would have to be mounted rapidly so that treatments are made before fledging and preferably at an early stage of hopper development to give time for backup conventional control if IGRs fail. Good communications will be required with a range of likely host countries and a contingency plan should be in place which can be activated quickly when egg laying or hatching occurs on a sufficient scale. Due to these constraints such emergency research would be more likely to succeed with donor assistance, participation by representatives from several countries and co-ordination by FAO.

Control by insects and other natural enemies

There are many natural enemies of *Schistocerca gregaria*, including vertebrate and invertebrate predators, insect parasitoids, parasitic nematodes and pathogens (Greathead, 1963, 1992). Vertebrate predators include the terrestrial enemies such as rodents and reptiles and birds such as hornbills, storks, egrets, raptors and rollers which are often seen feeding on hopper bands, sometimes until they have been completely eliminated. Invertebrate enemies include scorpions and solifugids and insects such as ground beetles. Some Hymenoptera such as the sphecid wasps use locusts and grasshoppers to provision their nests. Various parasitoids attack the eggs (Hymenoptera), hoppers and adult stages (Diptera). Some nematodes (e.g., Mermithidae) are parasites of Acrididae although they require moisture for maturation and oviposition, so are rare in desert locust habitats. Damage to eggs by predators may reach high levels locally but is patchy in space and time.

In general these predators and parasitoids play a small role in regulating locust populations because, despite some documented exceptions, they are unable to follow swarms to the next breeding area (Uvarov, 1977). It has been suggested that they may hasten the end of plagues but do not prevent upsurges (Greathead, 1992). Many insect natural enemies cannot be easily reared in the laboratory. The possibility of introducing exotic egg parasitoids would require careful studies of host selection since non-swarming acridid hosts might be eliminated in favour of locusts. Introduction of parasitoids should also only be carried out after taxonomic assessment of the related species already present to ensure that the species to be introduced is not already present. Failure to develop the means to discriminate indigenous and exotic parasitoids may lead to misleading perceptions of successful establishment or wastage of resources in reintroducing a species already present. In general control techniques should seek to conserve natural enemy populations.

Use of pathogens of locusts for control

The scope for microbial control of locusts has been reviewed by Prior and Streett (impress). They consider pathogens unsuitable as candidates for the once-only introduction of an exotic disease. Their preferred option is the formulation of spores of a suitable pathogen for application as a substitute for chemical pesticides, with the aim of massively augmenting naturally occurring low levels

of infection to kill as large a proportion of the target pest population as possible with the initial application. However, quite the opposite strategy, relying on establishment of introduced pathogens to maintain locust populations at a low level, has been proposed by Raina (1992). There are many reported pathogens of the Acrididae belonging to the protozoa, bacteria, fungi and viruses. Protozoa (e.g., *Nosema locustae*) have been used in rangeland grasshopper control in the USA (TAMS Consultants, 1989), but trials in the tropics have not shown promise. In general, protozoa cause a chronic disease taking several weeks to kill. *Malamoeba locustae*, another protozoan, occurs widely in nature but has not been developed for control purposes since it has little effect in field populations (Greathead, 1992). However, there are apparently efforts being made to develop this species as a control agent for desert locust at the International Centre for Insect Physiology and Ecology (ICIPE) (Raina, 1992).

Bacterial infections in locusts are generally caused by non-specific agents (e.g., *Aerobacter aerogenes*) which are potential human pathogens and have therefore been discounted as potential biocontrol agents. Strains of *Bacillus thuringiensis* which attack many insect pests, have not been found in locusts, which are resistant due to their low gut pH that prevents activation of the toxin crystal in the insect gut (Prior and Greathead, 1989).

Viruses affecting locusts include the entomopox viruses and the crystalline array virus. Entomopox viruses cause debilitating disease of grasshoppers but multiplication for control purposes is difficult because they can only be reared in living cells (Streett and McGuire, 1990). Fears of potential human infection were based on perceived similarities to human pox viruses (smallpox). It is now known that the viruses are not closely allied and human infection is not a risk. Nuclear polyhedrosis viruses are not known in locusts but there has been a report of oral transmission of *Spodoptera littoralis* nuclear polyhedrosis virus to desert locusts and migratory locusts in the laboratory, causing a disease known as 'dark cheeks'. Development of host-cell-dependent pathogens such as entomopox viruses and some fungi (e.g., *Entomophaga grylli*) as control agents requires development of cell culture systems to multiply the pathogen prior to formulation and release. This issue is being addressed by the United States Department of Agriculture/ (USDA/APHIS) (Cunningham, 1992). Genetic engineering of entomopox viruses is also being studied with a view to speeding up kill.

Fungi are among the most frequently reported pathogens of locusts and include *Entomophaga* spp., *Beauveria* spp. and *Metarhizium* spp. – the last of which is the subject of a multidonor-funded research programme, based at the International Institute of Biological Control (IIBC) in UK and International Institute of Tropical Agriculture (IITA) and Département de Formation en Protection des Végétaux (DFPV) in West Africa, entitled *Biological Control of Locusts and Grasshoppers*. Research currently centres on development of mycopesticides using spores of the fungi *Metarhizium flavoviride* (Prior *et al.*, 1992). It is already clear that spores of this species can be formulated in oil as a ULV spray for use in place of insecticides. As yet there has still not been a definitive test of any fungal pathogen formulation against field populations of the desert locust. Current optimism is based on encouraging results with locusts in field cages in Niger and small plot trials against grasshoppers in Benin (Bateman, 1993), as well as small-scale field tests against other locust species in Madagascar, South Africa and Australia. A similar project is being funded by USAID and carried out jointly by Montana State University and Mycotech.

Most of the potential bio-pesticides being developed at present will experience all the current problems of conventional insecticide spraying – finding the locusts, communicating their whereabouts, supply logistics for inputs, reaching them and spraying them properly at the right time – and have additional

difficulties to cope with such as slow action of mycopesticides and the need to reach the hoppers at an early nymphal stage with protozoan parasites such as *Nosema locustae*. As such, they can only be as good as, or worse than, conventional insecticides in controlling locusts. However, if they are effective, environmental benefits may justify their choice.

Environmental impact assessment of mycopesticides has hardly begun. Factors governing specificity in fungal pathogens are complex and there are difficulties in extrapolating from laboratory tests to the field. *Beauveria* strains isolated from grasshoppers may affect leafcutter bees (used as a laboratory model for honey bees) (Goettel and Johnson, 1992). Impacts should be assessed by continuous monitoring during and after field application following preliminary laboratory and field testing.

Cultural control

Given the mobility of desert locust and the narrow window of available rainfall for cropping available to subsistence farmers in semi-arid regions of Africa and western Asia, there is small scope for early planting and the use of early-maturing varieties. This strategy may work with pests which develop in the farmers' fields and cause damage to the crop mainly late in the growing season, just before harvest, e.g., the millet head miner (*Heliocheilus albipunctella*) (Jago, 1993). However, since the desert locust may arrive suddenly as adult swarms this approach cannot be used with precision. Early harvesting of grain crops before the grain has dried has been used against the Sunn pest in the Middle East and might occasionally assist farmers faced with desert locust swarms after heading of grain crops.

Modification of the environment as a control strategy has been proposed for other locust species but has not been attempted against desert locust. Many locust and grasshopper problems have been made worse by human activity creating a mosaic of open bare soil for basking and oviposition interspersed with patches of crops and weedy fallows providing food and shelter. Reversing these conditions by modifying cropping or grazing systems may help to reduce the problem in some cases. However, in drawing attention to this ecological pattern, Roffey (1972) noted that the desert locust was almost the sole exception to the rule since it normally lives in arid natural environments which are not easily accessible for modification. Any proposal to modify the vegetation of these delicate desert environments could have serious implications for their mammal and bird fauna and indigenous flora, already under threat from hunting and degradation of habitat, and would need to be carefully screened for potential long-term environmental impact.

Use of biorationals

Biorationals include semiochemicals of plant or insect origin (or synthetic analogues) which exercise behavioural or physiological effects on the target insect. Several classes of compound have been regarded as showing promise as potential control agents. Since 1987, a wave of research has begun, encouraged by new funding from the Consultative Group for Locust Research (CGLR), aimed at the assessment of a wide range of semiochemicals and other novel approaches, of which the more significant are described below.

Research on the sequestering of pyrrolizidine alkaloids from the plant *Chromolaena odorata* by the variegated grasshopper, *Zonocerus variegatus*, which uses the poisonous chemicals for defence, has led to the development of a bait for this species using the chemical as an attractant (Krall and Nasseh, 1992). However, such an attractant has no potential for desert locust control because sequestering pyrrolizidine alkaloids is a specialized attribute of *Zonocerus* (Whitman, 1990).

Antifeedants have been extracted from various plants including the neem tree (*Azadirachta indica*) and *Melia volkensii*. Neem oil causes developmental abnormalities and reduced amounts of juvenile hormone in locusts, leading to some degree of phase change in hoppers from solitarious to gregarious (Langewald and Schmutterer, 1992). In adults it also reduces flight performance, probably by interfering with the locusts' ability to mobilize body fat reserves (Wilps *et al.*, 1992). Efficacy of neem extracts for field control of locusts and effects on non-target organisms are poorly known. In cage trials with neem extract in Niger, Nasseh *et al.* (1992) found strong antifeedant effect but no direct mortality in locusts at an application rate of 10 l/ha. However severe phytotoxic effects were seen in *Schouwia thebaica*, a cruciferous annual plant that is a major food source of the desert locust. A significant mortality was also recorded in cage trials with the tenebrionid beetle, *Pimelia angulata tschadensis*, a common constituent of the non-target insect fauna in the Sahara (Peveling and Weyrich, 1992).

Juvenile hormone analogues disrupt the development of the insect in some way which prevents it reaching adulthood or sexual maturity successfully. More than 2000 insect juvenile hormone analogues are known and some are under examination as potential control agents (Krall and Nasseh, 1992). None has so far shown promise in field trials and the effects of these compounds on non-target organisms are unknown.

Pheromones are being investigated for their potential in modifying behaviour and development of locusts with the aim of disrupting the process of gregarization (Raina, 1992). Work is continuing in Germany and at ICIPE in Kenya on identifying pheromones for sexual maturation, gregarization, solitarization and oviposition. To date three pheromone 'complexes' consisting of blends of several chemical compounds have been detected (El Bashir, 1994). One system, found in mature gregarized adult males, promotes adult aggregation in adults but inhibits nymphal aggregation. It also accelerates adult maturation. A second system in gregarious nymphs promotes aggregation of nymphs but not adults, and also delays adult maturation. An oviposition pheromone has been demonstrated in the froth of egg pods laid by gregarized females. Two of its component compounds have been identified. Finally a sex pheromone attractive to males has been demonstrated in solitary, but not gregarious, females.

If any of these chemicals proves to exercise a dominant role in any important physiological or behavioural process they may be usable in control. Unfortunately, however, locusts deploy a range of sensory devices (including good vision) and respond to a wide range of environmental stimuli (e.g., soil moisture for oviposition). Since most locust pheromones are probably perceived over short distances, blanket spraying or use of pheromone lures may be less likely to cause them confusion than is the case for many other pests such as Lepidoptera which rely heavily on chemical communication over great distances. Aggregation and maturation pheromones would be extremely difficult to apply to a large dispersed locust population that has not yet gregarized. Once the identity and biological activity of the various chemicals involved has been worked out and the compounds synthesized it will be possible to conduct behavioural field trials.

INTEGRATED PEST MANAGEMENT AND THE DESERT LOCUST

Many recent documents describing and analysing the desert locust problem refer to integrated pest management (IPM) as a desirable goal (e.g., TAMS Consultants, 1989; OTA, 1990; USAID, 1991). Closer inspection of the literature, however,

reveals that the goal has not been attained and current control practices do not constitute an IPM approach. To appreciate the difficulties of applying this concept to the desert locust it is necessary to understand what IPM is. IPM has been defined (Dent, 1991) as "a pest management system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest population levels below those causing injury".

IPM was essentially a response to the excessive use of pesticides to control crop pests from the 1940s onwards which led in the 1960s to pesticide resistance, emergence of secondary pests due to loss of natural enemies, and growing problems of pesticide residues. IPM represents a move away from pest eradication as a goal to the management of pest populations at levels below an economic threshold. IPM perceives the pest as a component of an assemblage of other organisms affecting a crop or cropping system including pests (weeds, birds, mammals, pathogens, insects) and their natural enemies as well as other beneficial organisms such as pollinators. It follows that IPM involves the development of a coherent overall strategy for pest management with a minimum of harmful side effects.

To apply a system of IPM it is essential to define the problem in terms of the actual yield losses caused by the pest and the socio-economic context of the farming system(s) where they occur which will affect not only the perceived seriousness of the pest but the viability of particular management options (Dent, 1991). In the context of the desert locust, this raises a problem in that the time and effort required to assess these factors is considerable and the likelihood that locust outbreaks, if left unchecked, will have a major impact on production creates very real political pressure for immediate control action. Very basic action thresholds exist in the sense that solitary locusts are not targeted whereas gregarious locusts are controlled, but the concept of economic threshold is difficult to apply to such a mobile pest because the entire strategy of control depends on preventing or eliminating upsurges in remote desert areas before they become plagues which will seriously impinge on areas of high agricultural productivity. Only if a plague is allowed to happen will significant damage occur, probably in a country remote from that in which the initial population build-up took place. Nonetheless the necessary socio-economic analysis is in progress (Joffe, 1995).

A second requirement for IPM is an understanding of the population dynamics of the pest. This information is broadly available for the desert locust but necessitates the maintenance of a complex infrastructure for gathering and analysing information from ground surveys, weather, satellite images and case history data and a programme of research. The swarming migrant characteristics of the desert locust take the problem out of the orbit of any single farming system. Dent (1991) points out the need for a co-ordinated management of research in developing IPM systems. In the case of the desert locust it has been proposed that this role should be taken by the UNDP/FAO Scientific Advisory Committee to the CGLR (Gruys, 1991).

IPM stresses the need for modelling of pest population dynamics and its interaction with control activities (Dent, 1991). Modelling population development of the desert locust under the influence of different control options was proposed by Gruys (1991). The DGIS Wageningen seminar (van Huis, 1994b) attempted to carry out simulations of this nature, with parameters based on the informed opinions of experts present, with interesting but inconclusive results. Such simulations will not be able to predict where future upsurges could be expected because of the complexity of locust biology, the imprecision of long-range weather forecasting and the political inaccessibility of some areas to

ground survey teams (Gruys, 1991). However such methods will enable comparisons of theoretical population responses to different control options. This should indicate, for example, whether control efforts should be limited to areas of locust concentration (south of the Atlas mountains in Algeria and Morocco, the Red Sea coast and the Tihama of Saudi Arabia) as has been suggested by some experts (van Huis, 1994a).

The range of available control methods is a crucial limiting factor on IPM programmes. For many pest species there are known natural enemy complexes which exercise significant levels of control and there may be effective strategies involving cultural techniques, host plant resistance or the use of synthetic pheromone analogues in mating disruption or 'lure and kill'. However, as already noted, the range of non-chemical techniques available for the desert locust is currently very limited and manipulation of the natural enemy complex does not appear to be feasible.

The newer control techniques currently under development, which have been described above, may eventually permit a more varied and appropriate response to locust problems in different situations that will more closely approximate to true IPM. Appropriate formulation of biopesticides may in the future result in greater persistence leading to much greater efficiency and the possibility of barrier spraying against hoppers. In some cases mixtures of slow-acting and 'knock-down' approaches may be combined. For example the spores of *M. flavoviride* are known to be stable in formulations of teflubenzuron and the mixture shows synergistic activity (Prior and Streett, 1994). However neem oil is toxic to conidia of *M. flavoviride* (Stathers *et al.*, 1993) so this mixture is not viable. Novel approaches to formulation of existing compounds is an area relatively unexplored. Micro-encapsulation of oil-based formulations may extend field persistence of conventional pesticides and could reduce mammalian and aquatic toxicity (Jepson, 1993). Field testing of mycopesticides is beginning and will intensify, probably leading to the availability of effective products within 5–10 years. Usable semiochemical control techniques applicable to the desert locust seem to be further off. It seems unlikely that current research could yield exploitable technology within much less than 10 years.

With adequate co-ordination and political will IGR insecticide formulations could be tested and registered for use in barrier spraying within three years. It is likely therefore that the major method for the management of desert locust for the next three years at least will probably remain chemical control with organophosphate, carbamate and pyrethroid insecticides. Until alternatives become available, it remains a goal of IPM to minimize insecticide use and to ensure that necessary applications are made as effectively as possible (TAMS Consultants, 1989). A plea has been made for a 2–3-year research programme aimed at development of a menu of 'recognized control systems' based on standardization and simplification of approaches which it is argued will permit more economical control with less wastage (Haskell, 1993). There is certainly scope for improvement to the implementation of current control technologies which will result in immediate economic, environmental and human safety benefits in addition to more reliable locust control efficacy.

ENVIRONMENTAL ASSESSMENT REQUIREMENTS FOR DONOR FUNDING OF DESERT LOCUST CONTROL

Most if not all donors now operate standardized procedures for evaluating environmental impacts likely to arise from proposed development projects, as part of their approval sequence for loans or grants. Typically these procedures

adopt a checklist approach with projects being screened into categories for further evaluation. For example the World Bank uses five categories (IBRD, 1991a).

- A Projects/components which may have diverse and significant environmental impacts – normally require an environmental assessment.
- B Projects/components which may have specific environmental impacts – more limited environmental analysis appropriate.
- C Projects/components which normally do not result in significant environmental impact – environmental analysis normally unnecessary.
- D Environmental projects – not requiring a separate environmental assessment, as environment would be a major part of project preparation.
- E Emergency recovery projects – because of the need for rapid processing and the fact that these relate to existing facilities, a full environmental assessment is not required.

Locust and grasshopper control would normally fall into category B. The World Bank's *Guidelines for the Agriculture and Rural Development Sector* stress an IPM approach and highlight the aim of managing rather than eradicating pests (IBRD, 1991b). The Guidelines advocate the establishment of an economic threshold level (ETL) by yield loss assessment and costing crop protection measures. An action threshold level of population size is then set at which control action should be taken to prevent damage reaching the economic threshold level. However, as already noted, there are difficulties in applying this approach strictly to the management of the desert locust.

In contrast to the project-level environmental assessment, procedures may be applied at the regional or sectoral scale. This approach may save time and effort in preparation of several project-specific environmental assessments in the same region or sector which have common issues and for which common baseline data can be assembled, and may sometimes eliminate the need for project-specific environmental assessments entirely (IBRD, 1991a). A variant of the sectoral environmental assessment is the programmatic environmental assessment which can be used to assess the impact of a sector-wide programme such as locust control. Consultants prepared a programmatic environmental assessment for locust control in Africa for USAID (TAMS Consultants, 1989). This programmatic environmental assessment described the impact of current control measures and evaluated alternatives and mitigating measures and provided 32 programmatic recommendations to ensure that environmental concerns would be fully met in future USAID control programmes. Recommendations included "preparing an inventory of environmentally sensitive areas; prohibiting spraying in human settlements and environmentally fragile areas; selecting pesticides with the least impact on non-target species; monitoring selected organisms, and soil and water for pesticide residues; supplementing control techniques with a strong technical assistance component; assisting countries in disposal of obsolete pesticides; testing biological control in the field; and providing training and equipment" (IBRD, 1991a).

These recommendations remain as valid now as they were five years ago. Some of the required actions are proceeding but there is still a pressing need to prepare national inventories and maps detailing the location and nature of environmentally sensitive areas. The expense in most cases will be small since the affected countries will already be reviewing such areas in fulfilment of their responsibilities under the terms of the Biodiversity Convention. Some of the required information is already on file within organizations such as the IUCN World Conservation Monitoring Centre, Cambridge. Some of it has already been

published (e.g., IUCN, 1992). In relation to locust control some data relevant to individual countries have already been assembled for environmental assessment purposes (e.g., Mali – USAID, 1991; Sudan – Pinto, 1988; Madagascar – USAID, 1992).

USAID's *Environmental Procedures for Foreign Assistance* include a section dealing with pesticide procedures which stipulates that an environmental examination must be undertaken to evaluate the environmental risks associated with provision of pesticide before procurement can proceed. This regulation has provision for suspension of evaluation requirements in the event of an emergency requiring immediate importation of pesticides. Such a suspension operated during the locust emergency of 1986–89. This environmental examination is incorporated in the programmatic environmental assessment and elements of it may be carried out at the national level where supplementary environmental assessments have been prepared for locust control covering individual countries including Burkina Faso, Cameroon, Chad, Madagascar, Mali, Mauritania, Niger and Senegal. These documents review USAID regulatory structures and existing relevant national legislation and provide a short national environmental profile and other baseline data relevant to the locust problem. In the case of the Madagascar supplementary environmental assessment (USAID, 1992) it goes on to define thresholds for interventions and a broad strategic approach to the problem and set standards for pesticide safety. Critical habitats are described and pesticide use prohibited in them. Subsequently an amendment to the supplementary environmental assessment was issued (Belayneh, 1993) covering the use of the IGR, diflubenzuron (Dimilin), for locust and grasshopper control in Madagascar. The amendment proposal documents the environmental risks and benefits of using Dimilin and refers back to the programmatic environmental assessment and the supplementary environmental assessment which set the proposal in its regional and sectoral context.

Gruys (1991) proposed that a sound national control policy should be a basic condition for future funding of control operations. With the USAID system as a model, he advocated the preparation of national control policy statements detailing such matters as control strategy, pesticide management plans, training programmes, and environmental impact mitigation measures. He proposed that regional organizations and FAO should help affected countries to prepare such statements. Another model for evolving appropriate procedures for impact reduction in locust control is provided by the USDA's programmatic environmental impact statement on its Co-operative Rangeland Grasshopper Management Program which was drawn up under the terms of the US National Environmental Policy Act (USDA/APHIS, 1986). This environmental impact statement lays down detailed operating procedures for control teams, including the buffer zones to be left around endangered raptor nesting areas, water bodies, and inhabited places. Site-specific environmental assessments are mandatory for threatened species and sensitive areas.

IMPROVED DECISION-MAKING TOOLS FOR ENVIRONMENTAL IMPACT ASSESSMENT

The European Plant Protection Organization (EPPO) has produced a set of decision-making schemes for the environmental risk assessment of plant protection products. These include data on the behaviour of specific pesticides in the (temperate) European environment and their effects on non-target fauna. The advantages of this approach have been summarized by Oomen (1993) who argued for its extension to locust control in Africa. However, based on experience from the LOCUSTOX project in Senegal, it has been argued that the risk posed by an insecticide may depend more on the ecology and population

dynamics of the non-target organism species than on the direct toxicity of the compound (Van Der Valk, 1993). These two viewpoints are in reality the two sides of the same coin. What is needed are decision-making tools and checklists for impact assessment of locust control operations based on accumulated knowledge of the ecotoxicological hazard posed by each product, known exposure risks and a greatly increased knowledge of the function and diversity of semi-arid ecosystems in locust-affected areas of Africa and the Middle East. These elements of hazard information for individual chemicals and site-specific environmental assessment need to be combined with detailed operating procedures and incorporated into national control policies.

MONITORING OF ENVIRONMENTAL EFFECTS OF LOCUST SPRAYING

At present almost any spraying campaign against locusts constitutes an experiment in which non-target effects are an important element. Frequently pesticide treatments are applied inadequately such that little active ingredient reaches the target (e.g., Ghaout *et al.*, 1993). The routine use of oil-sensitive papers or glass slides to monitor deposition of droplets in control operations would provide valuable information for assessing drift and efficacy and the degree of exposure of non-target organisms. However, the samplers must adequately mimic the natural target if meaningful results are to be obtained. For example, horizontal collectors will not measure the dose the vegetation is receiving.

During the 1986–89 upsurge of the desert locust, few monitoring or ecotoxicological monitoring studies were undertaken (Gruys, 1991). This made evaluation of circumstantial reports of deaths of non-target organisms impossible. Several experimental studies of the effects of locust and grasshopper spraying have been carried out in Mali by American and Norwegian teams (Dynamac International, 1988; Fiskvatn, 1993; Johannessen, 1991; Krokene, 1993; Otteson and Somme, 1990; Otteson *et al.*, 1989). FAO commissioned an environmental assessment of aerial spraying with fenitrothion against locusts in Sudan (Pinto *et al.*, 1988), and in 1989, with funding from DGIS, Netherlands, conducted a pilot study of the environmental effects of locust and grasshopper control (Everts, 1990), which developed into an ecotoxicological research programme in Senegal (the LOCUSTOX project) to determine the level of residues from locust control operations and to assess their effects on non-target fauna.

Gruys (1991), commenting on the earlier studies, noted that the inputs of funding and effort required to conduct meaningful field studies on environmental impact are very substantial and the results often disappointing. He instanced lack of knowledge of the ecosystems involved, difficulties in identifying indicator species and adequate sample sizes for statistical analysis as problems and noted that studies were generally short term, measuring acute effects and unable to address long-term effects on the ecosystem function. The LOCUSTOX project will address this issue and has already produced a number of reports (Danfa and Van Der Valk, 1993; Gadji, 1993; Lahr and Diallo, 1993; Niassy *et al.*, 1993; Van Der Valk and Kamara, 1993). Protocols for monitoring of control operations have been discussed by Grant (1989).

The techniques used are likely to vary in different cases but there is a need to develop appropriate low-cost technology and ensure that Plant Protection Departments and regional bodies involved in locust control have access to suitably trained and equipped personnel. The LOCUSTOX project also has an important role in training personnel from locust-affected countries and developing appropriate techniques. The pilot study (Everts, 1990) suggested that ecotoxicological surveys should include birds' reproductive performance, and movement and survival of immatures (since spraying removes insect food in

addition to direct toxic effects); small fish species (such as *Porogobius schlegelii*, a goby which was entirely wiped out in an artificial pond sprayed at standard rates with chlorpyrifos); macrocrustaceans in temporary pools, foraging termites, and various Hymenoptera and Coleoptera including tenebrionid beetles which are an important component of desert insect fauna and are often predators of grasshopper and locust eggs.

A major problem of impact assessment studies in the context of real control operations is the short period available for baseline data collection. This makes inferences based on before/after comparisons questionable because of unknown seasonal effects. At the same time environmental heterogeneity makes simultaneous sprayed/unsprayed comparisons equally difficult. Increasing effort is being put into the development of monitoring techniques for environmental impact of control operations by the FAO LOCUSTOX project and other groups. There is a need for more baseline studies of the functioning of semi-arid ecosystems in which locust upsurges occur (Van der Valk, 1993). Senegal does not contain characteristic desert locust recession habitat though it is very important because of the close proximity of sensitive natural habitats to cropping areas. There is a need to extend monitoring studies to areas such as the Red Sea coast and the central Sahara. A cautionary note has been sounded by Gruys (1991) who argued that in view of the high cost of monitoring studies, their numbers should be restricted and their programmes carefully co-ordinated.

Since the late 1980s a spate of reports and papers have sought to describe the effects of the traditional locust control insecticides and the newer insect growth regulators on non-target fauna. Much of the recent work has appeared in 'grey' literature including project reports and theses. It would be a cost-effective exercise to commission an ecotoxicologist to review and summarize this information and provide a critical assessment of the sampling and statistical methods being used, the value of indicator species being proposed and to identify specific gaps in current knowledge which need to be filled. Such a review has been proposed as a research priority by the UNDP/FAO SAC (1993). There is also a need for the development of guidelines, similar in approach to the *Desert Locust Guidelines*, covering the techniques and equipment needed for ecological monitoring of pesticide application against locusts.

CONCLUSIONS AND RECOMMENDATIONS

IPM

1. The overall strategy of desert locust control requires the control of gregarized populations (as swarms or bands) as early as possible during the onset of an upsurge. The long-term aim of locust control is to adopt an IPM approach, utilizing a broad range of control methods and minimizing adverse impacts on the human population and the natural environment. Even though for the time being effective control methods are limited in practice to deployment of conventional chemical pesticides, there is an economic and environmental incentive to choose appropriate compounds and to use them as sparingly and efficiently as possible. Organochlorine insecticides carry unacceptable risks to operators, humans and wildlife in sprayed areas. They are no longer supplied by donors and should never be used for locust spraying. The choice of pesticide active ingredient from the FAO list of compounds for which there is an effective dose (Appendix 1) is not a major factor in the efficacy of control operations. Use of a range of products is desirable to prevent monopoly pricing of one favoured product by suppliers during locust upsurges. However some pesticides have more or less serious effects on specific classes of non-target wildlife such as birds, fish, bees and crustacea (Appendix 3) and they should be used in such a way as to minimize these effects.

Recommendation: The current range of active ingredient options on the FAO list should be maintained and broadened, on the basis of pesticide trials, to include dosage recommendations for other effective products with acceptable environmental impacts.

2. It is possible to apply some of the basic principles of IPM to desert locust control including modelling population dynamics and its response to different control options, refining thresholds for intervention, and improving forecasting and survey to monitor the movements and dynamics of locust populations. Development of mycopesticides constitutes the most promising potential biological control technique for the desert locust, but is not likely to become available for 5–10 years. It is unclear from recent literature whether research on protozoal infections and viruses is likely to lead to effective control agents.

Recommendation: Development of improved monitoring and forecasting, including modelling and simulation tools should be continued as a basis for devising control strategies and assessing their efficacy and costs. Continuing research into new application technology, novel control products and biological control agents is also necessary.

Ultra-low-volume pesticide application and control equipment

3. Application of ULV formulations of chemical pesticides is currently the most rapid, cost-effective and environmentally acceptable method of treating large infestations of hopper bands and adult swarms. ULV rotary atomizers can be used for applying IGRs and will also be suitable for applying oil formulations of mycopesticides when these become available. Baits, dusts and emulsifiable formulations suffer unacceptable constraints of time and expense in handling high volumes of material. However, these more labour-intensive methods may be appropriate on some occasions. For example, dusts may be used to increase operator safety in cases where there is no prospect of providing training in safe and effective ULV application.

Recommendation: ULV spraying should be used for desert locust control unless the benefits of choosing other methods outweigh the loss of cost-efficiency and speed.

4. Control staff often have little practical understanding of ULV application technique. Spraying in inappropriate weather conditions (low wind/strong convection), incorrect use or neglect of the equipment may often lead to over- or under-dosing with consequent wastage, lack of efficacy and negative environmental impact. Protective clothing, spares and minor technical equipment all have to be paid for with foreign exchange and are frequently not made available to spray teams.

Recommendation: Control personnel need regular in-service refresher training. Training requirements need to be assessed and appropriate courses devised for ground spraying teams (pesticide safety and ULV application techniques, routine maintenance) and their supervisors (supervisory and inspection skills), spray pilots and engineers (application). Courses must be designed to test attainment of theoretical and practical learning objectives and certify competence, not merely attendance. Requirements for vehicle spares, spraying equipment, radios, equipment for spray sampling and meteorological measurements, protective clothing, insecticide siphons, spare parts and cholinesterase kits must be established.

5. The scale of the target will determine the most appropriate type of ULV equipment for use in specific situations, whether hand-held, vehicle-mounted, or aircraft-mounted. It is essential that equipment supplied and used for ULV

application against desert locust should be not only effective but efficient in use of pesticide and time, safe for operators and the environment, and reliable. Preferably ULV equipment should be of the rotary-atomizer type which is designed to produce spray droplets consistently of the correct size range. Inefficient exhaust nozzle sprayers, boom-and-nozzle, and airblast equipment designed for high-volume application should not be supplied for locust control. Use of such equipment should be phased out and where it is unavoidable the machinery must be regularly inspected and maintained to a high standard.

Recommendation: Technical appraisal and field validation of rotary-atomizer ULV sprayers for aerial and ground-based application must be carried out to assess, and if necessary, improve reliability of potential sprayers for provision as part of donor assistance to desert locust control programmes. Unsuitable or defective exhaust nozzle, airblast and boom-and-nozzle spray equipment must be phased out if correct dose rates for efficacy with economy and environmental safety are to be achieved.

Pesticide procurement, storage and disposal

6. Large quantities of unusable organochlorine and organophosphate pesticides are still held by many locust-affected countries despite action by donors and FAO to destroy or remove some of them. The intermittent nature of locust upsurges leads to pesticides supplied under emergency conditions being stored for long periods (2–5 years) after the end of an upsurge pending reinvasion. Shelf-life of organophosphate insecticides is severely curtailed by storage at high temperatures and drums may be damaged by rough handling and storage in damp conditions.

Recommendation: The excessive stockpiles of redundant and degraded pesticides held in locust-affected countries must be eliminated and storage standards improved by

- supporting and extending FAO's Prevention and Disposal of Unwanted Pesticide Stocks Project
- assisting completion of inventories of obsolete and viable stocks
- preparing realistic guidelines for environmentally safe disposal of obsolete pesticide stocks and used pesticide drums
- assessing needs for and constructing upgraded storage facilities and providing training in pesticide store management.

In the event of renewed desert locust activity, rapid access to appropriate pesticides for affected countries will be best assured by the creation of a central 'pesticide bank' able to distribute supplies rapidly on behalf of donors in response to verified needs.

Trials of insect growth regulators

7. Barrier spraying with persistent chemicals such as dieldrin ceased to be acceptable when the organochlorine insecticides were found to cause significant environmental impact through bio-accumulation in food chains and high toxicity to vertebrates. As a result, current chemical control of desert locust hopper bands involves searching for and treating individual hopper bands or treating larger blocks known to contain several bands by aerial spraying. The former approach is labour-intensive and time-consuming and can only locate a small minority of the bands present in an area while the latter technique involves the application of pesticide over very large areas, with potential for adverse effects on non-target organisms. Large-scale trials of IGRs against desert locust hopper bands are essential to confirm the effectiveness of these compounds as a

potential replacement for dieldrin and to provide a more economical alternative to current chemical control.

Recommendation: There is a pressing need to speed up field validation and registration of selected IGR pesticides for use as a barrier spray against the desert locust. This will require co-ordination by FAO with donors and with locust-affected countries to mount collaborative trials of IGRs at short notice against hopper infestations which would otherwise be controlled by current methods.

Traditional control

8. Traditional methods of crop protection against locust swarms can never prevent or eradicate an upsurge because of the high proportion of locusts in sparsely inhabited uncultivated areas. They may be of occasional local value against isolated hopper bands but they are not amenable to improvement by research.

Recommendation: No further studies should be undertaken of traditional locust control methods against desert locust as they are unlikely to lead to significant improvements in crop protection or population control.

Management and reporting of control campaigns

9. Desert locust control campaigns require efficient deployment and utilization of material and human resources, which are often lacking due to shortage of trained and experienced staff capable of planning and resourcing complex field operations and coping with unexpected events during the course of the campaign.

Recommendation: Training should be provided to senior locust campaign staff in the logistics of campaign management.

10. Feedback from control campaigns is usually limited and inaccurate. Campaign reports rarely contain the detail necessary to lead to future improvements in control practices. Compiling this information is difficult because of the scattered nature of operations and the fact that priorities are perceived to lie elsewhere during emergency control activities. There is also little incentive for field personnel or pilots to report problems which may reflect badly on the reporter. However, without this feedback, it is difficult to tailor training to real needs, to assess the cost-effectiveness of control operations or to improve the technology.

Recommendation: Monitoring and reporting of operations should be given a higher priority and experienced personnel should be assigned to this specific task. It is in the interests of locust-control organizations and donors to provide these people. Control staff and pilots should also be required to complete detailed control records during the operations. New technology being introduced to aircraft (global positioning system linked to spray systems) can provide a greater level of transparency and accountability to aerial operations. Trials of this equipment are required to assess its value for desert locust control.

Environmental protection

11. Procedures for provision of pesticides operated by USAID constitute a valuable model for other donors to follow in relation to locust control. FAO is ideally placed to co-ordinate the preparation of a programmatic environmental assessment for desert locust control for agreement by affected countries and donors. This could form the basis for the preparation of individual country-level

environmental assessments containing a control policy statement (updated regularly) which should accurately describe the operational capability of the national control organization and stipulate safety standards and operating procedures for control using listed products for which ecotoxicological hazard statements are given.

Donors need to assure themselves that pesticides they provide are appropriate for the locust control method proposed and that they will be stored and utilized correctly. One means of achieving this is to require a control policy statement as a condition of pesticide provision. The other is to assist and monitor compliance with the agreed policy by the provision of appropriate technical assistance and training. In the absence of such an agreed and monitored policy, donor provision of pesticides alone is likely to be wasteful and environmentally damaging. It is important that agreed policies are in place before the next upsurge begins, since emergency conditions produce a political momentum which may override close scrutiny of control proposals.

Recommendation: National control policy statements for locust-affected countries should be prepared as a condition of donor assistance, setting out national strategic objectives for locust control, and detailing operational procedures and environmental mitigation measures. The latter should include country-specific environmental assessments, including inventories and maps of sensitive and protected ecosystems and hazard information for chemicals to be used. Donors need to be prepared to supply technical assistance in preparing and monitoring policy statements.

Environmental monitoring

12. There is even less feedback on the environmental effects of locust control campaigns than on control efficacy and resource utilization. Closer examination of the impacts of operations will yield information to help decision-making on choice of control methods. The FAO LOCUSTOX project in Senegal is playing a valuable role in elucidating environmental impacts of insecticidal locust spraying and developing appropriate techniques for monitoring, but this area is not representative of typical desert locust recession habitats in which spraying may take place to prevent locusts moving into cropping areas.

Recommendation: Research on environmental effects of locust spraying should be extended into more typical desert locust recession habitats such as the Red Sea coast or the Sahara, if possible in conjunction with actual control operations. A review of the literature on non-target effects of locust and grasshopper spraying by conventional and IGR insecticides should be carried out to collate, summarize and assess information on the effects of control, and on the value of the sampling and statistical methods used and the value of indicator species proposed. This study should be a prelude to the development of guidelines, similar in approach to the FAO's *Desert Locust Guidelines*, detailing the techniques and equipment needed for ecological monitoring of pesticide application against locusts.

Hazard to birds

13. Insectivorous birds are an important and visible constituent of the vertebrate fauna of desert locust habitats. Locust swarms attract large numbers of rollers, bee-eaters, storks and raptors, among other birds which are potentially at risk from large-scale spraying of pesticides against locusts. The impact may be especially serious for migrant species such as the European stork (*Ciconia ciconia*) and Abdim's stork (*Ciconia abdimi*) which exist in relatively low numbers.

Recommendation: A literature review is needed on the potential hazard to migrant insectivorous birds posed by insecticidal control of locusts,

especially in relation to the routes and timing of migrations in west and east Africa and research is needed into the effects of locust control operations on reproductive performance of non-migrant birds and the movement and survival of immature birds.

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Appendices

APPENDIX 1. ULV PESTICIDES FOR DESERT LOCUST CONTROL

This Appendix contains volume application rates and area dosages for ULV pesticide formulations in common use for desert locust control.

Chemical name	Type	Recommended dose	Manufacturer	Brand name	ULV formulation	Rate
bendiocarb	carbamate	100 g a.i./ha	CAMCO	Ficam	ULV 20% (200 g/l)	0.51/ha
chlorpyrifos	organo-phosphate	225-240 g a.i./ha	Dow Chemicals	Dursban, Lorsban	240 ULV (240 g/l)	1.0 l/ha
					450 ULV (450 g/l)	0.5 l/ha
deltamethrin	synthetic pyrethroid	15.0 g a.i./ha	Roussel UCLAF	Decis	ULV 12.5 (12.5 g/l)	1.2 l/ha
					ULV 25 (25 g/l)	0.6 l/ha
diazinon	organo-phosphate	450-500 g a.i./ha*	Ciba Geigy	Basudin, Diazinon	90 SCO (980 g/l)	0.5 l/ha (swarms only)
			Nippon Kayaku	Dianon, Diazinon	90% (w/vol.) 900 g/l	0.5 l/ha (swarms only)
fenitrothion	organo-phosphate	400-500 g a.i./ha	Sumitomo	Sumithion	L-50 (500 g/l)	1.0 l/ha
					L-100 (1000 g/l)	0.5 l/ha
					96% (w/w) technical	0.4 l/ha
					L-20 (200 g/l)	2.5 l/ha
fenitrothion + esfenvalerate	organo-phosphate + synthetic pyrethroid	245 + 5 g a.i./ha	Sumitomo	Sumicombi	L-25 (250 g/l)	1.0 l/ha
					L-50 (500 g/l)	0.5 l/ha
lambda-cyhalothrin	synthetic pyrethroid	20 g a.i./ha	ICI	Karate	0.8 ULV (8 g/l)	2.5 l/ha
					4.0 ULV (40 g/l)	0.5 l/ha (hoppers)
malathion	organo-phosphate	900 g a.i./ha	American Cyanamid	Malathion	96% (w/vol.) (960 g/l)	0.9-1.0 l/ha
			Cheminova	Fyfanon	96% (w/w) (1180 g/l)	0.75 l/ha
					ULV technical	
			Cheminova	Fyfanon	ULV/EC (925 g/l)	1.01 l/ha
					ULV/EC (1000 g/l)	0.9 l/ha
phoxim + propoxur	organo-phosphate + carbamate	258 + 42 g a.i./ha	Bayer	Volaton-Unden	UL 300 (300 g/l)	1.0 l/ha

Source: SYMMONS, P.H. (1993) *The Desert Locust Guidelines. IV. Control. Appendix 1*. Rome: Food and Agriculture Organization of the United Nations.

Note:

* Rate may sometimes be too low for reliable effective control (FAO Pesticide Referee Group, 1992).

APPENDIX 2. ACUTE TOXICITY AND HAZARD RATING OF SOME INSECTICIDES USED FOR LOCUST CONTROL

Insecticide name	Class of compound	Hazard	Acute oral toxicity to rats (mg/kg)
Diflubenzuron	Benzoyl Urea IGR	Unlikely	+4640
Esfenvalerate	Pyrethroid	Moderate	c450
Deltamethrin	Pyrethroid	Moderate	c135
Lambda-cyhalothrin	Pyrethroid	Moderate	c144
Malathion	Organophosphate	Slight	2100
Phoxim	Organophosphate	Moderate (dermal)	1975
Fenitrothion	Organophosphate	Moderate	503
Diazinon	Organophosphate	Moderate	300
Chlorpyrifos	Organophosphate	Moderate	135
Propoxur	Carbamate	Moderate	95
Bendiocarb	Carbamate	Moderate	55

Source: WORLD HEALTH ORGANIZATION (1990)

APPENDIX 3. RELATIVE TOXICITY* OF SELECTED ANTI-LOCUST INSECTICIDES TO NON-TARGET ORGANISMS

Chemical name	Chemical family†	Persistence	Bio-accumulation	Birds	Mammals	Fish	Aquatic invertebrates
Bendiocarb	C	M	M	M	M	M	M
Carbaryl	C	L	L-M	L	L	L	L
Chlorpyrifos	OP	M-H	M-H	-	M	L-M	H
Cypermethrin	PY	M-H	H‡	-	L	H	H
Diazinon	OP	M	M	M-H	L	M	H
Dieldrin	OC	H	H	H	H	H	M
Fenitrothion	OP	L	M	H	L	L-M	H
Lambda-cyhalothrin	PY	M	H‡	L	H	H	H
Lindane	OC	M-H	H	M-H	M	M	M
Malathion	OP	L	L	M	L-M	L	L

Source: SHOWLER, A.T. (1994) Infestation de criquets en Afrique du Nord: protection de l'environnement et de sécurité humaine. In: *Détérioration de l'Environnement de l'Afrique du Nord*. BENCHARIFA, A. and SWEARINGEN, W.D. (eds). Rabat, Morocco: Université Mohammed V Press.

Notes

- *L low
- M medium
- H high
- no data
- +C carbamate
- OP organophosphate
- OC organochlorine
- PY pyrethroid
- ‡ Based on log P.

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Chemical control of locusts has caused environmental concern because of the quantities of pesticides used and the potential resulting negative impact of control on humans, domestic animals, wildlife and other organisms.

Desert Locust Control Operations and their Environmental Impacts reviews and assesses the methods currently available or under development for the control of the desert locust, an internationally important pest of agriculture in much of Africa, Arabia and western Asia. The main types of environmental impact arising from locust control operations are outlined and specific recommendations are made for mitigating or avoiding them, including the development of country-based environmental impact statements and national locust control policy statements as a precondition for donor assistance in locust control.

The bulletin provides a succinct introduction to the environmental issues involved in combatting one of the world's most serious pests. It will be of equal value to decision-makers involved in the management of migrant pests whether they are desk officers in donor organizations, EIA professionals, or pest management specialists in locust-affected countries.