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The evolution of an aerial application system for the control of Desert Locusts

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The regulation of Desert Locust numbers in a section of its total distribution area is possible only if certain basic conditions can be met. These are:

(i) Information on the numbers of locusts involved – quantitative survey.

(ii) The availability of a regulator, say an insecticide, cheap enough to be applied on the scale determined by the survey.

(iii) The availability of a method which enables the regulator to be applied on the necessary scale and in the time available.

(iv) The capability of operating on the required spatial and temporal scale notwithstanding political boundaries.

These conditions could be met for Desert Locust control in eastern Africa only by the evolution of an aerial application system designed specifically for the problem as it existed in this region.

The paper describes the evolution of the system.

1. Introduction

Locust control is a notable example of successful pest management, this defined as the overall regulation of the number of insects comprising a pest population.

In the case of the Desert Locust the interdependence of the world population of this species throughout its range of distribution was formally recognized in 1956 by a panel of experts, established under the chairmanship of the late Sir Boris Uvarov, to advise the Director-General of FAO on long term policy of Desert Locust control (FAO 1956). The Panel concluded 'that there was evidence of swarms produced in one end of the distribution region having, within a couple of generations, a decisive influence on events at the other'.

That is to say the population, for the purpose of control or regulation, was the entire world one, occurring over 30000000 square kilometres, or one fifth of the total land surface of the world. The tasks of Desert Locust control, therefore, were ones of scale: requiring the development of both methods of survey which would locate and provide information (in the time available) on the numbers of insects to be dealt with, and of methods by which a regulator could be applied on a scale which this information determined.

The object of this paper is to describe the evolution of an aerial system for Desert Locust control in eastern Africa, and to derive from this experience some general principles of insect pest management which can help in reducing current reliance on standard practices of spraying crops as almost the sole means of preventing damage from insect pests.

2. Quantitative survey

(a) *The scale of Desert Locust populations in eastern Africa*

Eastern Africa is invaded by swarms which have bred in Arabia, and to a smaller extent the Sudan. In eastern Africa locusts have annually four opportunities for breeding (table 1), and control teams need a capability of searching for hopper bands distributed over up to 500 000 square kilometres during the 6–8 weeks available between oviposition by parent swarms and evacuation of the area by progeny.

Table 1. Opportunities for annual breeding of Desert Locusts in eastern Africa

rains	period	locality	area over which breeding has been recorded (km²)	swarm production
short	November–December	Ogaden S Somalia NW Kenya Tanzania	600 000	January
long	April–June	Ogaden S Somalia NW Kenya	500 000	June/July
monsoon	July–October	N and Central Ethiopia Sudan NW Kenya	700 000	September/October
winter/spring	December–May	Red Sea littorals Gulf of Aden	200 000	February/June

A striking characteristic of Desert Locust hopper infestations is their clumpy or contagious distribution, so that hopper bands represent discrete entities within a breeding zone, referred to in field reports as gross infested areas. Various surveys, both from the ground and from the air, in which the total net area actually covered by hopper bands was estimated, gave a coverage which varied for example from 0.25 % of the gross infested area in the 1961 short rains breeding in the Somali Republic to 3.5 % in heavy infestations in Kenya in 1954–55 season. Each square kilometre of gross infested area is capable of producing 100–1000 kg of locusts.

The numbers of individuals in swarms is better known through the work for example of Gunn *et al.* 1948, Sayer 1959, Rainey 1958*a*, Ramana Murty *et al.* 1964 and Waloff 1972. For the purpose of planning control operations, a reasonable estimate of the requirements was obtained by assuming 50 locusts per square metre of plan area: that is 50×10^6 locusts per square kilometre, weighing about 100 tonnes. Thus a square kilometre swarm could be produced by hopper bands distributed over 100–1000 square kilometres of gross infested area, according to whether the infestation rate was 2.5 or 0.25 %.

In protecting crops against locusts we are concerned essentially with flying swarms, and the numbers comprising and sizes of Desert Locusts swarms are better measured than any other parameter of locust populations. Thus Rainey (1958*a*) describes how 50 swarms with a total area of 1300 square kilometres invaded Kenya in January 1954. From estimates of density made by assessment of mortality following spraying, supplemented by photographic data, he calculated that the total invasion represented 5×10^{10} locusts weighing 100 000 tonnes.

For efficient disposition of resources for killing locusts invading as swarms, the time the swarms are available from a given airstrip is very important. In the Northern Region of the Somali Republic swarms may be present between May and October, showing a general displacement eastward, and often a to-and-fro movement with changing winds, so that swarms remain for long periods within the range of a few airbases. On the contrary the swarms that invade Kenya are travelling on steady winds and are displaced typically 50–100 kilometres each day, so that a succession of bases must be established in order to maintain contact with an invading population.

(b) Surveys for hopper infestations

The initial method of attempting this was by the employment of local scouts, though, because of the high cost, this method was almost entirely superseded in the 1950s by direct survey by locust officers in Land Rovers. Thus survey was largely confined to country suitable for wheeled vehicles, and trials with vegetation poisoning along vehicle tracks by Sayer (1959) in 1957 showed that locust officers travelling along such tracks discovered only a fraction (ranging from <0.01 to 0.1) even of the total bands which crossed the track.

This method of survey, moreover, was not only expensive in men, vehicles and maintenance in the field, but also failed to provide information on what fraction of the total infestation remained undiscovered. What was needed was a sampling plan which could provide a chosen degree of confidence that an area recorded as infested was in fact infested to an extent which justified detailed search or control measures. This discovery confidence had to be high, say, above 80%. On the other hand it was necessary to ensure that the probability that an area recorded as uninfested contained in fact a greater infestation than was tolerable, was small. This escape risk might be placed at, say 5% when breeding was in the vicinity of cropped areas and, say 20% if the areas were remote.

Such a sampling scheme could be calculated from the expected density of infestation, and a knowledge of the distribution of hopper band sizes and numbers over areas ranging from 60–5000 square kilometres (Joyce 1962) giving a population distribution which proved to be negative binomial, approximating to logarithmic. Implementation of such a sampling scheme demanded systematic search, conveniently as traverses over the area, independent of the constraints imposed by terrain, a requirement met only by aerial survey. In practice in eastern Africa it was found that hopper bands of all ages could be readily seen from the air some 30 min after sunrise, when they basked in sunshine in open places, and for the subsequent 2–3 h before they spread out in marching. For aerial survey it was found convenient to divide the area into Lots, each being 10 min squares (approximately 20×20 km). Since it is easy to spot from an aircraft flying at 50 m above the ground hopper bands up to 500 m on each side of the aircraft track, two traverses of each Lot provided a 10% sample.

The discovery in a single Lot (in infestations in the Somali peninsula) of a single hopper band, provided a 98% chance that the Lot was infested beyond a tolerable level, (selected in Somalia as one hopper band per square kilometre), and a 5% chance that a Lot rejected as uninfested was in fact infested beyond the tolerable level. The sampling scheme was tested with apparently satisfactory results in Somalia in December 1960, in an area previously considered by ground teams to be uninfested.

An aircraft travelling at 3 km min^{-1} could sample 10–12 such Lots per morning thus surveying 4000–5000 square kilometres per day, a rate of survey which matched the control requirements and which could be achieved by no other method. This compares with an average

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of 15 square kilometres per officer-vehicle per day achieved by ground surveys during the Desert Locust Survey campaigns between 1955–8; and providing less complete information.

(c) *Survey for locust swarms*

Aerial survey has also been found, in practice, to be the only way of obtaining necessary semi-quantitative information about the numbers and sizes of Desert Locust swarms. Under conditions of good visibility swarms can be seen for up to 100 kilometres away from an observer in a low flying aircraft; in eastern Africa, where visibility is generally good, the limiting factor on such occasions was height of flight (so that swarms could be seen against the sky). Whatever the behavioural mechanisms of swarm cohesion it became evident that the density of locust in swarms reflected the structure of the air in which they flew. Thus for example in the Northern Region of the Somali peninsula where winds during morning flight during July and August may exceed 30 knots, swarms become dispersed to a density of about 0.001 m^{-3}, but reform in the afternoon when convergence, possibly associated with upslope winds and a sea breeze front within the inter-tropical front between northwesterly and southwesterly winds brings the locusts together frequently at very high densities, estimated for instance as sometimes reaching 2 m^{-3}.

Surveys for swarms accordingly are most reliable when they are conducted in zones of low level wind convergence in which locusts from much larger surrounding areas are trapped and accumulate. Such a zone was found to develop daily between June and August in the Northern Region of the Somali Republic, and could drain breeding areas covering some 500000 square kilometres in the Somali peninsula and adjacent areas in Ethiopia and southern Arabia.

Table 2. Air reconnaissance of northwest Somali peninsula

(Median latitudes and longitudes of swarm sightings between June and August 1961.)

period	median latitude	median longitude
1 June–10 June	09° 15′	40° 49′
11 June–20 June	09° 13′	40° 45′
21 June–30 June	09° 19′	40° 53′
1 July–10 July	09° 37′	43° 14′
11 July–20 July	09° 56′	42° 55′
21 July–30 July	10° 15′	44° 14′
31 July–9 August	10° 02′	44° 23′
10 August–19 August	09° 47′	43° 26′

Thus, during 1960 and 1961, most of the swarm population present in eastern Africa derived from breeding recorded in some 100000 square kilometres, was distributed as in table 2. Ninety-nine per cent of the locust sightings were within 12 km of the 09°42′ parallel during this period. This meant that most of the locusts whose breeding in October and November would generate swarms which could invade Kenya and Tanzania, could be found by searching an area of 200 km × 40 km = 8000 square kilometres and this could be done each day, if necessary, by a single aircraft off bases in Borama and Hargeisa.

3. Synchronized control

The availability of a suitable regulator and of a method which permits it to be applied to the entire population discovered by survey to require treatment, may be conveniently dealt with together under the title of synchronized control.

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In practice the regulator available for Desert Locust control is insecticide and this is available for application to hoppers and adults as stomach or contact poisons.

Killing locust hoppers by scattering ahead of them poisoned bran bait is clearly a method which lends itself to conditions under which 100% inspection of potential breeding areas is possible. The method is labour intensive and heavy in its demands on transport. The aerial survey system which matched the scale of infestations in Eastern Africa was best served by the techniques of barrier spraying, by which the hopper bands themselves, in the course of their marching, were made to pass through and feed on vegetation which had been poisoned by ultra-low-volume spraying from aircraft. This concept, developed largely by Sayer (1959), took advantage of the fact that hopper bands move, often downwind, eat their own weight of fresh food per day, half during marching hours, and that the insecticide, dieldrin, is completely cumulative. The contamination of the sprayed vegetation had to be such that each hopper would accumulate a toxic dose through feeding within one or more such barriers of poisoned vegetation. It was calculated that dieldrin application averaging 2.5 g ha^{-1} would produce 100% mortality amongst hoppers feeding for 8–10 days although it would be necessary to double this quantity if the vegetation exceeded say, 3 t ha^{-1} (Courshee 1965). The mean application rate could be achieved by drift spraying which resulted in less than $1/10^6$ of active ingredient on the vegetation, and intervals up to 5 km between successive barriers.

Lots found infested were sprayed from a height of 20–25 m with droplets having a volume median diameter of about 80 μm, the aircraft flying at right angles to the prevailing wind. These fine droplets were chosen because, having a largely horizontal component to their trajectory, they were collected selectively by the vertical surfaces of the scant desert vegetation rather than sedimenting onto the bare ground. Each lot was treated with 450 l of 20% dieldrin applied as 4 barriers in a single sortie, thus providing a rate of control commensurate with the rate of search: that is to say up to 5 infested Lots or 2000 square kilometres per day per aircraft. Under a system requiring 100% search and destruction using poisoned bran bait over 100 vehicles and officers had been required to achieve the same work output.

The destruction of locust swarms is rarely possible by means other than aerial spraying. The techniques initiated by Gunn (1948) were developed and employed by Rainey & Sayer (1953), Rainey (1958*b*), MacCuaig (1962*a*, *b*), and MacCuaig & Yeates (1972) and showed that a flying locust collects approximately twice as much spray as a settled locust experiencing a wind equal to the flying speed of a locust. Moreover, the toxic effect of a given quantity of spray was 20–80% greater to a flying than to a settled locust. Thus the flying locust can be regarded as at least three times as vulnerable to a given density of spray droplets when account is taken of the substantially lower airspeed to which the settled locust is normally exposed.

On the other hand, the most important single factor limiting the efficiency of spraying against flying locusts is the volume density of the swarm, and this is greatest during the last hour of the afternoon when convectional turbulence is reduced, and, during the morning, before the swarm streams away. Thus spraying against swarms may be limited to 2–3 h per day, during which time it is necessary to deliver the maximum possible number of toxic doses. Clearly, diazinon, with a toxicity coefficient of 32×10^6 was then the insecticide of choice. Using this chemical, Rainey (1958*a*) had achieved kills of about 750000 per litre.

From efficiencies found from field counts of dead locusts, an invasion, for instance, of 400 square kilometres of swarm (20×10^9 locusts) would require for complete destruction at least 80×10^{10} median lethal doses. This could be obtained in about 1250 l of Diazinon 85 or

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12500 l 15% γBHC. In a single sortie a Beaver aircraft could deliver 15×10^9 toxic doses in the form of diazinon and 15×10^8 in the form of γBHC. If strategy dictated the need for 95% chance of preventing swarms of this total size from invading crop areas, and the swarms were expected to traverse 50 kilometres per day and so to be available from a single base not more than 4 days, two Beaver aircraft, each flying four sorties per day, would provide the necessary strike power if diazinon were employed. If 15% γBHC alone were available, operations would have to be planned so that the swarms could be attacked from a succession of bases, unless 20 aircraft could be made available from a single base.

4. Freedom of movement to match biological dictates

(*a*) *The origin of DLCOEA*

During the 1950s the responsibility for protecting the crops of Kenya, Tanzania and Uganda from Desert Locusts was vested in the East African High Commission, the instrument of whose policy was the Desert Locust Survey. The policy for Desert Locust control had been determined as a result of the deliberations of a Commission of Enquiry under the chairmanship of Sir Francis Mudie, K.C.S.I., K.C.I.E., O.B.E., whose report was issued in December 1955. The report defined three closely interlinked objectives.

(i) To provide defence in depth for east Africa, both geographically and by attacking the parents and grandparents of the generation which endangered east African crops.

(ii) To fulfil the international obligations to control locusts in those areas in which Her Majesty's Government held overriding responsibility.

(iii) To provide assistance to Ethiopia and Somalia in a major breeding area of great international significance.

To achieve these objectives D.L.S. conducted control operations against locust swarms in the Northern Region of the Somali Republic during June to August, against hoppers in the Ogaden and adjacent parts of Kenya between October and May, and provided assistance in the form of cash, vehicles and insecticides to national teams operating in Ethiopia and Somalia (then under Italian trusteeship administration). Its budget for these operations varied from nearly £900000 in 1955–6 to £450000 in 1958–9 and had earlier reached £1½ millions. The organization employed 60 senior staff, all expatriates, and operated four light aircraft and 300 motor vehicles.

(*b*) *The policy of DLCOEA*

The convention which established the Desert Locust Control Organization for eastern Africa in 1962 defined the objectives and functions of the new organization as

'(*a*) to promote the most effective control of the Desert Locust in the region (Ethiopia, Kenya, Somalia, Tanzania, Uganda and (then) French Somaliland)

(*b*) to offer its services in the coordination and re-inforcement of national action against Desert Locusts in the region'.

In this formulation of objectives there had been a compromise between two mutually conflicting concepts, namely:

(*a*) The responsibility for Desert Locust control being vested in the National Teams with a Regional Commission coordinating national effort and supplementing this where necessary both by movement of national teams across frontiers and by material and financial assistance from a regional pool.

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(*b*) The responsibility for Desert Locust control being vested in a regional body financed by contracting Governments and permitted to operate freely within the region without regard to national frontiers.

While the first concept would have had the advantage of permitting the regional body to be set up as an FAO Commission, staffed by an FAO Secretariat, the second concept permitted the formation of an active operating body with a specific responsibility and judged by its performance in providing crop protection in the region. Such a body, charged with operational responsibility could not, by the current interpretation of the FAO constitution, be an FAO body, though it is able to operate under the umbrella of FAO with mutual commitments defined by treaty.

Among the signatories to the Convention establishing DLCOEA, Kenya, Tanzania and Uganda were the donors financing operations outside their frontiers.

Since their goal was to prevent locust invasion of their territory, their joint national team (the former DLS) was transferred *in toto* to DLCOEA. On the other hand, Ethiopia and Somalia, as the recipients of financial assistance had an interest in ensuring the maximum support to their national teams, who had relied, under the former policy, on East African High Commission provision of their vehicles, insecticide and a substantial cash contribution. To Somalia in particular locust control was regarded as of greater importance to the former British East Africa than to their own largely pastoral economy.

As an FAO Commission the role of DLCOEA would have been to reinforce the efforts of the national teams of Ethiopia and Somalia in accordance with national assessment of its needs as advised by the FAO Secretariat. As an operational body DLCOEA would utilize its resources in what the Director considered was the best way of executing the organization's responsibilities.

(*c*) *Financial constraints*

In contrast with the financial provision made for DLS, the Convention limited the participating governments contribution to DLCOEA to an annual budget not to exceed £280000, i.e. about 60% of the smallest budget enjoyed by the earlier organization, and one inadequate to operate the assets of staff and resources which the new organization had inherited.

Moreover, the responsibilities of the new organization were not limited to the protection of crops of the former British East Africa, but included protecting the far more vulnerable crops of Ethiopia and Somalia. To achieve the greatest economy and efficiency, the organization's policy had to be based on: (i) maximum annual utilization of resources through mobility between one breeding area and another, (ii) acquisition of reliable quantitative data on the scale and location of the populations to be attacked, (iii) accurate striking power commensurate with the needs.

These needs could be met only by a major change from reliance on ground control to the use of aircraft as the main control weapon, and the DLCOEA Air Unit, then consisting of three Beaver and one Cessna 185 aircraft, became central to the organization's locust control strategy.

This policy decision, supported by the financial constraints, made it necessary to terminate the services of the expatriate locust officers on whose efforts the control operations of the past has largely relied, and to change the role of the control bases at Hargeisa, Mogadishu, Diredawa, Asmara and Nairobi from the organization of large-scale ground based, to the servicing of aerial, operations. Thus many locally recruited drivers, mechanics and labourers became redundant.

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Since D.L.S. had been the largest employer of labour in four of its five bases, this policy was understandably unpopular, particularly in Somalia where difficulties of alternative employment were greatest. Much pressure was therefore exerted in the DLCOEA Council to achieve a return to the former policy of support of ground operations by diverting DLCOEA resources to augment the effort of national teams, a policy which FAO found easy to support. It is fortunate that financial constraints of the new organization added weight to the technical arguments for the new policy which was strongly supported by the main contributors, the Governments of Kenya and Tanzania, with Her Majesty's Government adopting a benevolent, generous, but somewhat neutral attitude.

(*d*) *Movement across frontiers*

It was possible to hold in reserve at all main bases vehicles, insecticides, aircraft refuelling and reloading equipment, camp equipment for temporary bases and other essential requirements. Each main base was linked by radio through the DLCOEA headquarters, which in Asmara, received special daily weather charts by facsimile from Nairobi and cloud cover data from the Nimbus Satellite via the United States Air Force Asmara Base. Operations could be mounted from any base in the time it took for the air unit to fly from its base in Nairobi (or from operations elsewhere), to the new scene of activity, providing that there was freedom of movement across the frontiers.

Despite a state of virtual war which existed between Somalia and Ethiopia, on the one hand, and Somalia and Kenya on the other, it is a remarkable tribute to the importance which was attached to the Desert Locust control that free movement of aircraft and personnel across frontiers was so rarely interrupted, although one pilot, forced-landing, was shot and killed. During one period of hostilities between Ethiopia and Somalia the organization's main base at Hargeisa in Somalia, within 60 km from the border, was indeed largely destroyed by an air bombardment, though fortunately without loss of life. Damage was professionally estimated, by loss assessors from London, at £100000 and the organization's council at its next meeting, established a special fund for the restoration of the base. This fund was fully subscribed, within the same financial year, from donations received from the governments of Ethiopia, Kenya, Tanzania and Uganda: further striking evidence of the importance attached by member governments to the activity of DLCOEA and to the freedom of movement of its aircraft and personnel.

The main bases were executive in function, servicing a campaign in accordance with an overall operational plan formulated and controlled by DLCOEA headquarters. This organization of work provided maximum flexibility so that virtually the entire striking power of the organization could be brought to bear in any critical area with the minimum notice.

With the collapse of the Desert Locust plague in 1962, the value of the new structure of locust control in eastern Africa had to wait until 1968 before being fully tested, as indicated by Ato Adefris and Dr Rainey.

5. Desert locust control as an aspect of pest management

The basic requirements for successful regulation of insect pests, which Desert Locust control was developed to meet, are: (i) *synoptic survey*, by which the distribution of the significant pest population, and its changes with time, can be determined and followed; and (ii) *near synchronized control*, by which a regulator is applied on the spatial and temporal scale demanded by the survey.

The chemical control of most crop pests usually relies on treating the crop to make it an environment lethal to the pest species. If the pest population is confined to the field sprayed, not only is the crop protected, but also the pest is controlled. If a fraction of the population lies outside the field sprayed, then the pest can make good the numbers lost. As Knipling (1972) has pointed out, many insect populations may be more effectively controlled when it is possible regularly to kill 90 % of their numbers in 100 % of the area occupied by the population than by killing 100 % of the population over 99 % of that area.

The first requirement for insect pest management is knowledge of the dimensions of the population to which it is necessary to apply a regulator in order to affect the numbers comprising that population. These dimensions are a function of the flight activity of the species.

For the purposes of this meeting we are considering only those migrant pests 'that require control before they enter the areas at risk'. To a farmer the area at risk is his own field into which pests from his neighbours' fields immigrate and from which his pests emigrate to his neighbours' fields. How may pests are non-migrant, in the sense that they breed on the same plant or in the same field as that in which they were born? The number of life strategies of insect pests is legion and some, it is true, after colonizing a crop lose their wings and pullulate locally. But as Southwood (1971) points out, 'most arable crops are derived from ruderals, plants that are colonizers of bare ground . . . These are temporary habitats and thus pests of arable crops, have, from their evolutionary history, high inherent levels of migratory activity.'

This flux of individuals within populations is recognized in crop protection by the success of persistent pesticides, but the unwanted side effects with which such chemicals appear to be inevitably associated makes the application of non persistent chemicals to the entire population as near synchronously as possible, increasingly necessary. Such an approach to pest management moreover makes the treatment of crop surfaces no longer the sole route of pesticide delivery, but provides the opportunity of exploring the possibility of new and more direct routes. Crop spraying as a means of killing insects is essentially inefficient and can never reach the efficiencies which are regularly achieved in locust control, especially the spraying of flying swarms. But the application of the principles of synoptic survey and near synchronous control carries with it the same implications which had to be faced in the organization of Desert Locust control. The first is the organization of survey and control on a scale determined by the flight activity of the pest and not constrained by artificial boundaries imposed by fields, farms or politics.

The second is the development of a coherent system for applying the regulator which matches the scale of the problem and which integrates the chemical, the application equipment and application technique. The system must be designed so that the greatest fraction of the chemical emitted is collected by a biological target precisely defined in relation to the route required by the chosen regulator.

The application of the principles developed for locust control to other pests carries with it far reaching implications, some of which are political. If we are to control insect pests efficiently, it is probable that we need to create specialist organizations which as Headley (1972) says will be designed to fight insect pests much as crime is fought in cities (but perhaps more efficiently).

It may be added that such a system designed for the protection of cotton against pest attack in the Sudan Gezira has been used during the past 4 years. Areas of up to 50000 ha employing this system have yielded 40 % more cotton than those areas subject to conventional aerial crop spraying practice (Joyce 1975).

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