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The Desert Locust: An International Challenge [and Discussion]

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The Desert Locust: an international challenge

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A new plague of the Desert Locust *Schistocerca gregaria* started in 1986; it developed quickly in 1987 in the Sahelian countries and reached northwest Africa at the end of 1987. It expanded in 1988 in north Africa, the Sahel, the Sudan, the Near East, southwest Asia, and in October 1988, swarms crossed the Atlantic to the Caribbean. The plague declined dramatically in the past quarter of 1988, and by March 1989 the plague was over. A study of the latest known upsurges provides more support to the theory that a build-up of locusts arises from initially low-density populations rather than from the persistence of undetected swarming populations. The decline of the recent plague was probably attributable to the cumulative effect of control operations combined with natural environmental factors. Prevention of new plagues of the Desert Locust will be much more difficult as the restriction on the use of dieldrin poses major technical, logistic and financial problems.

1. Introduction

There has been a series of important events involving locusts since the 1977 Royal Society Discussion Meeting on migrant pests (Gunn & Rainey 1979). A short-lived plague of the Desert Locust *Schistocerca gregaria* (Fôrsk.) occurred in 1976–79, which has already been summarized (Roffey 1979, 1982). Other smaller upsurges occurred in Niger in 1980 (Castel 1982) and Indo-Pakistan in 1983 (Food and Agriculture Organization (FAO), Desert Locust Situation Summary and Forecast nos. 59–62). These were successfully checked by control operations. In 1986 there was a further upsurge in Desert Locust populations, which led to the plague which is the main subject of this article.

The period 1985–1987 also witnessed upsurges of all four of the other main locust species in Africa. The African Migratory Locust *Locusta migratoria* (R. & F.) gregarized in several parts of Africa: Sudan, Eastern and southern Africa, Madagascar and most recently in Chad during 1989. The Brown Locust *Locustana pardalina* (Wlk.) erupted in the Karoo region of the Republic of South Africa and invaded Botswana. The Red Locust *Nomadacris septemfasciata* (Serv.), after years of deep recession, bred successfully in several outbreak areas from which several swarms escaped. Tree Locusts *Anacridium melanorhodon* (Thnbg.) became significant pests in Sudan and Chad. In southwest Asia the Moroccan Locust *Dociostaurus maroccanus* (Thnbg.) continued to infest the border areas of Iran and Iraq and a new plague has developed since 1987 in the northern provinces of Afghanistan. Simultaneously, very important upsurges of the Senegalese grasshopper, *Oedaleus senegalensis* (Krauss), and other species of grasshoppers occurred in the Sahel. The American continent also experienced important events. The Brazilian Locust, identified by Carbonell (1988) as *Rhammatocerus schistocercoides* (Rehn), which had never been

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recorded as a gregarious species in the past, started to swarm in 1985 in Mato Grosso State in Brazil. It has since invaded several other States, infesting an area of some 35 million ha†. The central American Locust, *Schistocerca piceifrons* (Wlk.) has again swarmed in the region since 1985 and emergency control operations had to be organized in Costa Rica in 1986–87, in the Gulf of Fonseca (Nicaragua, Honduras, El Salvador) in 1988–89 and a number of small fully gregarized swarms developed in the Yucatan Peninsula in Mexico.

2. Desert Locust recessions and plagues: an introductory synopsis

The following is a brief summary of the salient features of Desert Locust recessions and plagues to provide a background to our interpretation of events during the 1986–89 plague. Fuller accounts are given by Pedgley (1981); Roffey *et al.* (1970); Steedman (1988); Waloff (1966).

The similarities and differences between the timing and distribution of breeding of Desert Locust populations during recessions and plagues are clearly revealed by a comparison of the monthly degree-square frequency maps for the major 25-year (1939–1963) plague period (prepared by the Anti-Locust Research Centre, unpublished) and those for the 20-year recession period 1964–1984 (less 1968) (FAO, unpublished). The main similarity is, naturally, that breeding follows the onset of seasonal rainfall, but because of the reduced mobility of non-swarming adults, there are large areas where gregarious breeding occurs but not low density breeding e.g. in northwest Africa, the countries to the north of the Arabian peninsula, north-central India, southern Somalia and East Africa. In the Central Region even the spring breeding grounds in the interior of Arabia, the monsoon breeding grounds in the interior of Sudan and the short-rains breeding grounds in the Somali peninsula remain almost completely clear of adults and of breeding except during major upsurges, when they soon become involved.

High-frequency breeding areas, where locusts are more numerous and occur more often than elsewhere, also exist within the recession area. Thus, in the Central Region, Desert Locust populations most frequently occur during recessions in the coastal areas around the Red Sea and Gulf of Aden, where there are overlapping rainfall regimes and where breeding beginning in one season often continues into the next, and sometimes lasts for many months. The coastal areas thus constitute a major reservoir within which locust populations survive and breed, producing two to three generations annually. Breeding occurs principally from July to March, but occasionally it may last until April or even June, with the production of an extra generation. Other high-frequency recession breeding areas are found in the Western Region, where they are associated with the major geomorphological relief and drainage features in the southern and western Sahara, while in the Eastern Region they correspond to the drier and warmer, low-lying part of the spring and the central part of the summer breeding grounds. To a large extent, these differences can be ascribed to the biological and behavioural differences between plague and recession populations.

There are marked differences in the flight behaviour of swarms characteristic of plagues, which migrate by day, and the mainly non-swarming recession populations which fly principally at night (Roffey & Popov 1968). The intensive gregariousness of individuals in swarms frequently results in swarms overflying habitats that are suitable for non-swarming populations, while the latter are prevented from reaching areas attained by swarms because of

† 1 hectare = 10^4 m^2.

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low night temperatures. As a result, the area which can be reached by swarms, the invasion area, is almost double that of the recession area. The latter corresponds to the great Sindo-Saharan desert where most of the locust habitats receive less than 100 mm of rain annually.

The Desert Locust is not wholly resistant to drought at any stage of its development and has no built-in mechanism, such as an egg diapause, to protect it from extreme dessication. When females lay, water must be available in the soil, in sufficient quantities to ensure both the development of the eggs and the growth of vegetation to sustain the resulting hoppers and adults. The Desert Locust survives in its arid environment by moving from one area where rain has fallen to another, which may be several thousand kilometres distant.

It follows that the chances of survival and the resulting numbers of locusts are highest where sequences of sufficient rainfall are most frequent and reliable, where direct rain is enhanced by run-off and flooding, and especially where certain combinations of soils and vegetation create particularly suitable habitats. Occasionally, when such sequences of successful breeding span several successive generations, population build-up of an order of magnitude may occur at each generation. The resultant insects can aggregate and gregarize in particular habitats leading to hopper band and swarm formation. In addition, wind fields and mesoscale convergence provide transportation and at times the concentration of locusts. Thus Uvarov's concept of outbreaks of *L. migratoria* arising through a process of phase changes in particular outbreak areas (Uvarov 1921) also holds true for the Desert Locust, but in a more dynamic context, involving complexes of temporary breeding habitats linked by successive displacements.

The present strategy of plague prevention which evolved during the 1960s consists essentially of conducting surveys in seasonal breeding areas and controlling any gregarious or significant gregarizing populations. A second school of thought favours delaying control operations until most of the populations are in bands and swarms. Although the first is the recommended strategy, in practice the second is often implemented (Bennett 1976). Its weakness is that a major population build-up may occur in areas inaccessible to control; a phenomenon successively observed in Eritrea, Chad, Mauritania and Western Sahara during the 1986–89 plague upsurge.

3. The Desert Locust plague 1986–89

The upsurge of the Desert Locust in 1985–86 in Africa and Arabia rapidly attained plague proportions at the end of 1987 when locusts invaded northwest Africa from the Sahel countries. In 1988 all the Sahelian belt from Mauritania to Ethiopia, northwest Africa, the Arabian Peninsula and the western part of southwest Asia were affected (see figures 1 and 2; Skaf 1990.)

The period from the summer of 1985 to the summer of 1988 was marked by repeated successful breeding and gregarization by the Desert Locust in the central and western regions of its invasion area. The plague developed because suitably timed rains fell in areas which were reached rapidly by increasingly gregarious populations which, in 1987–88, allowed almost continuous breeding in west and northwest Africa. Because of the inaccessibility of certain areas (successively Eritrea in 1986, Chad in 1987, northern Mauritania and Western Sahara in late 1987 and early 1988), and the restrictions on the use of persistent pesticides, the locust situation was not brought under control in spite of very large scale operations. However, control continued through 1988, but it was not until the last quarter of 1988 and the first quarter of 1989 that a combination of adverse weather and control led to a dramatic decline of the plague.

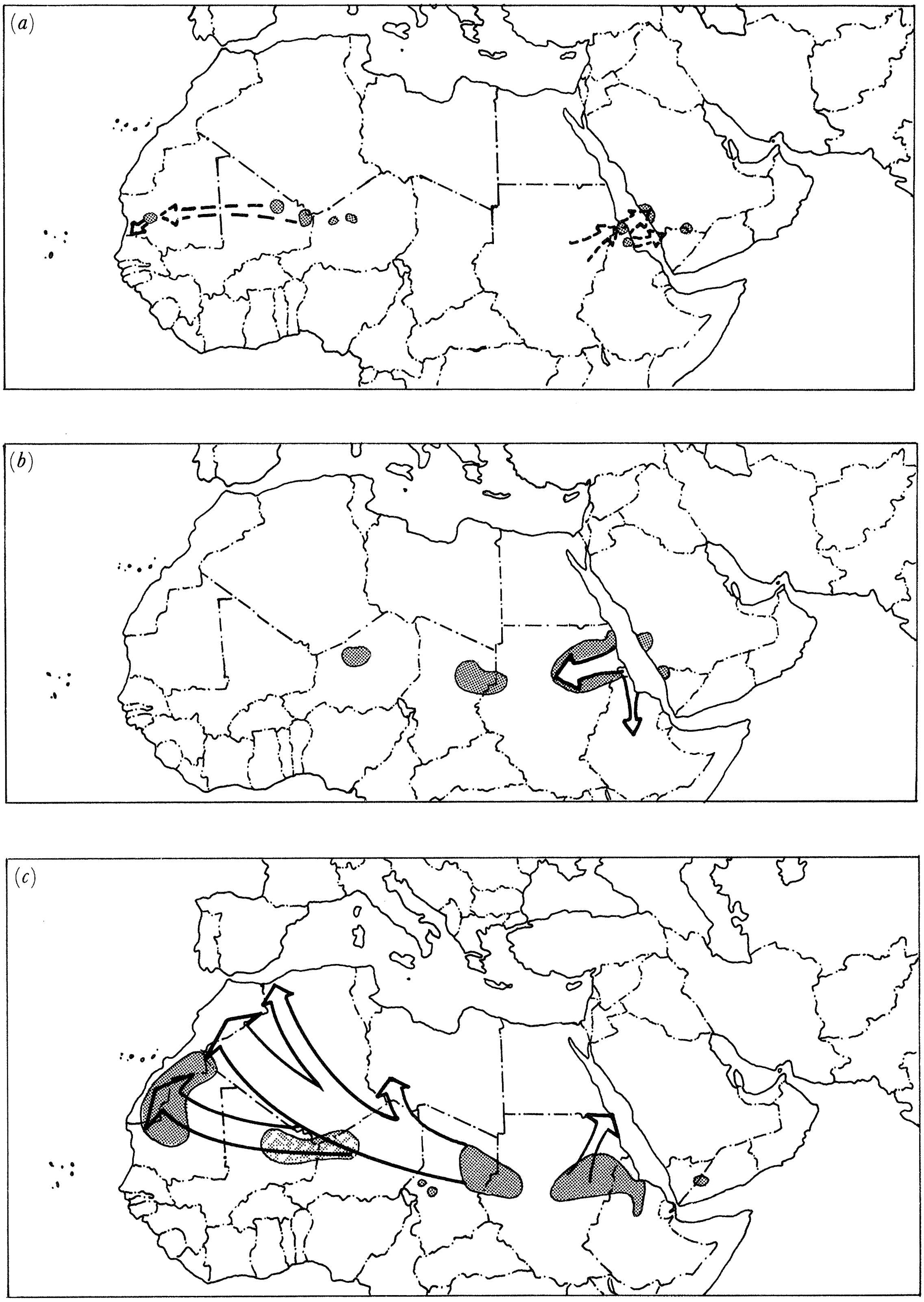

FIGURE 1. (*a*) 1985 campaign. (*b*) 1986–87 Winter-Spring breeding. (*c*) 1987 Summer breeding. (breeding; ⟹, migration; ⇢, possible migration.)

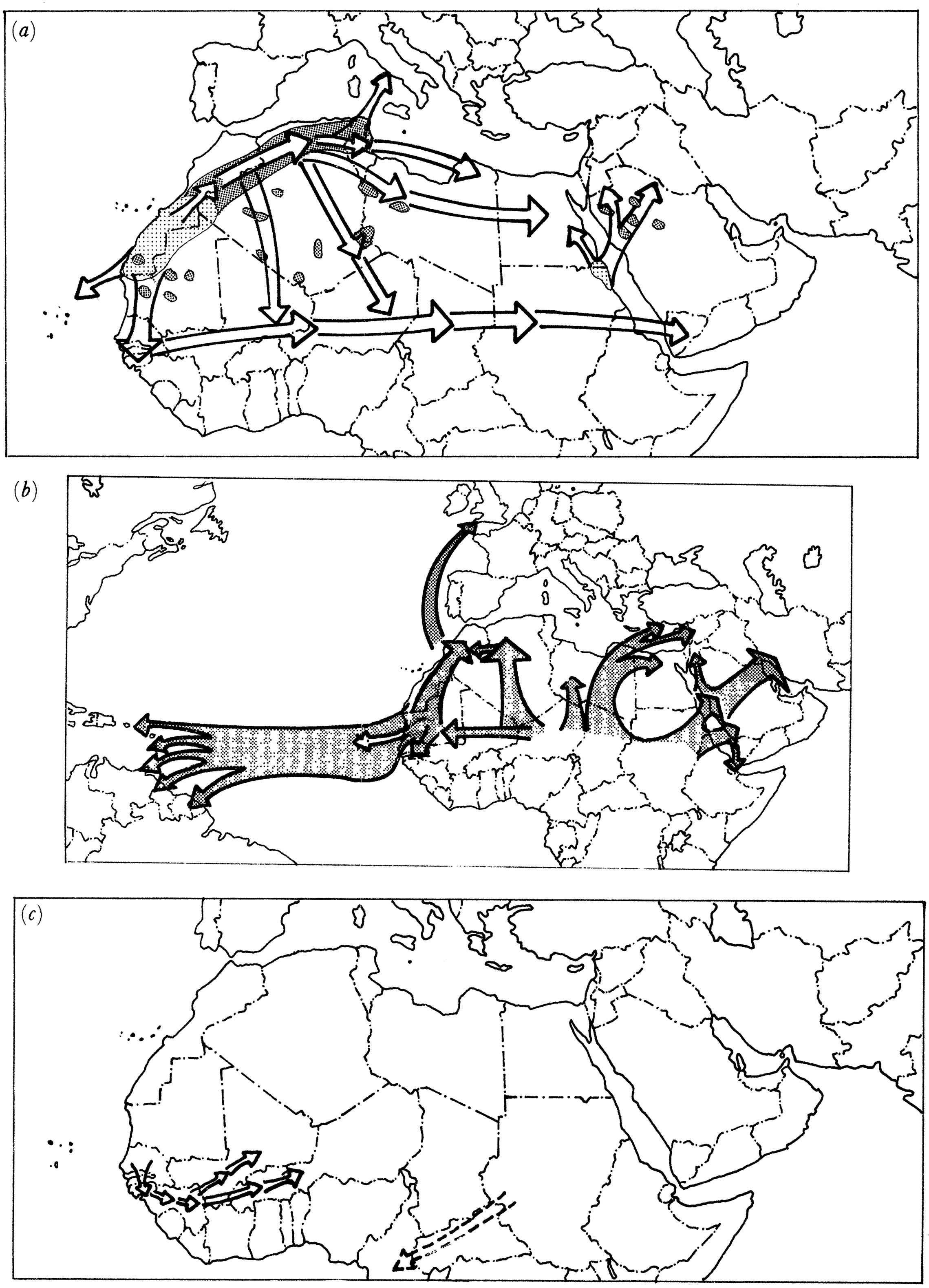

FIGURE 2. (*a*) Winter-Spring breeding 1987–88. (*b*) Movements of swarms of the first summer generation (June–September 1988). (*c*) Movements of swarms of the second summer generation (October 1988–May 1989). (◌, breeding Jan.–Mar.; ●, breeding Apr.–Jul.; ⇒, migrations; ⇢, possible migrations.)

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First, very large numbers of adults were drowned in the Atlantic, serious control operations in countries as far apart as Mauritania, Sénégal, Sudan and Saudi Arabia were increasingly effective and, finally, failure of winter rains in the Red Sea Basin prevented anticipated winter breeding. Furthermore there was no winter-spring breeding in 1989 in northwest Africa as there had been in 1988. A few swarms, however, followed the southern circuit in Guinea and re-invaded Mali and Niger in May, but later dispersed. In July residual populations existed in most Sahelian countries but, in spite of good summer rains, they failed to breed on any substantial scale.

This plague of the Desert Locust, which followed a large-scale upsurge of grasshoppers in Africa, aroused the interest of all countries concerned and that of the international community, particularly because of the speed of its expansion and the number of countries affected. Never in previous plagues were so many resources, from both the countries concerned and the international community, involved in the control campaigns. From September 1986 to May 1988, 7.6 million ha were treated and from June 1988 and to June 1989, 9.2 million ha. Three million litres of liquid pesticides and 1200 tonnes of bait and dusts were used up to May 1988 and 8 million litres of liquid pesticides and 1500 tonnes of bait and dusts from June 1988 to the end of the plague: a total of 11000000 litres of liquid pesticides and 2700 tonnes of dusts and bait. Total donor assistance provided for the locust and grasshopper control was approximately U.S.$49 million in 1986, U.S.$50 million in 1987, U.S.$115 million in 1988 and U.S.$60 million in 1989, totalling U.S.$274 million, of which about U.S.$200 million was used for Desert Locust control.

The use of baits and dust during the campaign was very limited. Helicopters and fixed-wing aircraft were used to spray against hoppers and adults but little air-to-air spraying of swarms was done. The pesticides used were mainly fenitrothion and malathion and smaller quantities of diazinon, DDVP, deltamethrin, cypermethrin, dursban and carbaryl.

In the execution of the campaign, FAO was the overall coordinating agency. Its work was facilitated by the creation of the Emergency Centre for Locust Operations (ECLO). This role was recognized in 1988 by a resolution adopted by the United Nations General Assembly.

4. Issues arising from the 1986–89 plague of the Desert Locust

(*a*) *Swarm Movements*

Have there been any radical changes in the movement of swarms and the evolution of the plague which have not been recorded during previous plagues? Some phenomena occurred in the behaviour of the insect which were at first considered as unique or without precedent. In 1966, before the 1967–68 plague, and in 1976 before the 1977–78 plague, locust populations were extremely low and this was also true in 1984–85 when they were possibly at their lowest levels for 50 years. Indeed, during the 24-month period from November 1983 to November 1985 there were no reports of gregarious populations anywhere, although the occurrence of pink coloured adults in southeast Mauritania in April 1985 was evidence that some gregarious breeding had recently taken place. Within two years gregarious populations were widespread between Mauritania and Sudan, and numerous swarms had crossed the Sahara to invade Morocco and northern Algeria. In spring 1988, the southward movement of swarms produced during winter-spring breeding in northwest Africa began very early: southern Mauritania, Sénégal and the Cape Verde islands were reached in late March; later, swarms moved eastwards through Mali and Niger reaching Chad and Sudan in late May and Ethiopia and the Yemen Arab Republic in July; such a major and prolonged easterly movement is without recorded precedent. Even more spectacular was the movement of locusts in October 1988 out over the Atlantic Ocean, leading to repeated invasions of the Cape Verde Islands and a large scale invasion of the eastern Caribbean and northern coastal areas of South America on a front of some 1500 km. Again, such a crossing of the Atlantic Ocean was without historical precedent. There were also unprecedented migrations, although on a smaller scale, to Italy (March, May), Greece (May), Turkey, Syria and Lebanon from the west (December). Other migrations were not exceptional and have been recorded previously (Donnelly 1947; Rainey 1963; Waloff 1966; Pedgley 1981).

(*b*) *Plague commencement*

The start of the plague can only be attributed, like the short-lived 1978 plague (Roffey 1979, 1982) to the progressive and rapid build-up and gregarization of initially solitary-living populations as a result of successive and successful breeding. Indeed the transformation from 1984 to 1986–88 provides better evidence for such processes in the generation of plagues than did earlier upsurges. It does not lend support to an alternative hypothesis to explain the generation of plagues which requires the continuity of major populations and invokes a prolonged loss of contact with swarms to account for gaps in their recorded occurrences (Rainey & Betts 1979). The controversy is far from being academic; it has operational, practical and strategic implications. The acceptance of the 'prolonged loss of contact' hypothesis presupposes the establishment of a costly fleet of aircraft equipped with sophisticated equipment and operating, probably with little return, all the year. Also, it will discourage the preventative control strategy which we are trying to strengthen and/or introduce in all the countries concerned.

(*c*) *Control tactics*

Where and how could the developments of the 1986–89 Desert Locust plague have been most effectively dealt with? There are three possible explanations for the developments that occurred:

(i) A lack of preparation for large-scale control operations which resulted in inadequate control of the early infestations in Mauritania (late 1985) and the Central Region in late 1985, and early 1986.

(ii) The decreasing use of chlorinated hydrocarbons (including dieldrin) and their restriction when most locusts in the invasion area were concentrated in relatively small areas: August 1987 in northeastern Chad and northwest Sudan; November 1987 to March 1988 in northern Mauritania and Western Sahara.

(iii) The lack of security which limited surveys and control operations in Ethiopia in 1986, Chad in 1987 and Western Sahara in 1988.

These events have already been described (Skaf 1988). In spite of predictions and warnings, opportunities to check the plague in Chad and then in Mauritania by the use of dieldrin in barrier spraying were missed.

(*d*) *Methods of pesticide application*

Only limited quantities of baits and dusts were used during the campaigns. Most operations were conducted with liquid pesticides including both ultra low volume (ULV) and emulsifiable concentrate (EC) formulations.

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However, until the spring of 1988 several countries were still using a high volume application technique at the rate of 25 l of diluted formulations per hectare! Their conversion to ULV spraying required modification and training, which were executed at remarkable speed. Also, in spite of the very large-scale aerial control operations covering millions of hectares, several countries and donors ignored the experience with ULV aerial application gained in previous plagues, and applied direct spraying with narrow swaths even with large aircraft. It was only after the end of the plague that a joint US-FAO technical consultation meeting, held on 6 and 7 November 1989, agreed key principles of ULV aerial application for Desert Locust control (US-FAO 1989).

As no successful government aerial unit exists in Africa, most aerial operations were undertaken by private companies using different techniques. The dissolution of l'Organisation Internationale Contre le Criquet Migrateur Africain (OICMA), the disappearance of l'Organisation Commune de Lutte Antiacridienne et de Lutte Antiaviare (OCLALAV) as an operational regional organization, the decline of the operational power of the Desert Locust Control Organization for Eastern Africa (DLCO-EA), and the scarcity of suitable aircraft and trained pilots able to undertake air-to-air spraying have exacerbated the situation.

(*e*) *The use of dieldrin*

The use of dieldrin was very limited at the start of the plague and, later, strict limitations on its use were imposed. This gave rise to controversies and high-level discussions at many meetings during the campaigns. Technicians were almost unanimously in favour of its use under special circumstances to stop the plague, backed by Gunn's arguments (Gunn 1979), which remain valid. As a result of the technicians' insistence, a special meeting was organized in October 1988 in Rome on the use and hazards of dieldrin in Desert Locust control (FAO 1988*c*). Widely divergent opinions were expressed on the future use of dieldrin in Desert Locust control, ranging from a complete ban and the destruction of stocks to recommending its use against hopper infestations in remote areas, under technical guidance. It was suggested that 'dieldrin is a pesticide of the past', not on account of its hazards, but 'as it is no longer produced'. It was noted that the use of alternative pesticides for Desert Locust control would result in substantially higher control costs and opportunities for a rapid reduction of the current plague would be missed. Only existing stocks needed to be considered so it was agreed that: FAO would make a detailed inventory of existing stocks; a study would be undertaken of the area where Desert Locusts would have to be controlled and these areas would be classified according to the potential environmental risk that application of dieldrin might entail; on the basis of this information, a use or destruction plan for all or part of the dieldrin stocks would be prepared.

(*f*) *The size of the* 1986–89 *plague*

Although unprecedentedly large-scale control operations were undertaken during 1987 and 1988, there is little evidence to support the view, often expressed during the campaign, that the plague was the most serious ever recorded. In fact not only was no systematic plotting of infestations done, except in Morocco, Algeria and at OCLALAV in 1988, but there were repeated occasions when estimates of the area claimed to be infested were inflated. No quantitative assessment was done of the real number, size and density of swarms and/or of adult populations at the lower densities. The only quantitative studies on hopper infestations were by an FAO/OCLALAV/CIDA team in early September 1988 followed by an FAO/multi donor evaluation study in late September 1988, both in southeastern Mauritania (FAO 1988*a*); and by G. B. Popov (unpublished results) in Mali and Niger in July–August 1988 in the Sahelian belt.

In July 1988 there were 40000 ha of swarms in Mauritania, 30000 ha in northwestern Mali and 50000 ha in Niger. By September, a gross area of 2750000 ha within southeastern Mauritania contained infestations. In general, the area actually infested was 5% (137500 ha). Hopper bands in Mauritania varied in size between 0.1–400 ha with averages of 8 ha in the centre and 15–140 ha in the south and southeast, respectively. The average number of hopper bands varied between 0.5 km^{-2} in some blocks, with mainly small bands, and 0.1 per km^2 in other blocks with mainly larger bands. The total hopper population was potentially able to produce 5×10^{11} adults, i.e. 1 million ha of new swarms in October. Something like this actually happened; for in addition to the many millions which flew out over the Atlantic, numerous large swarms invaded Morocco, where the 3000000 ha treated represented repeated applications to prevent invasions of crops, while others went southwards into Sénégal, Gambia and Guinea Bissau. Similarly, in Niger, escapes from the 60000 ha area originally infested gave rise later to 600000 ha of adult infestations, which required control. In Sudan over one million hectares were also treated.

(*g*) *The decline of the Desert Locust plague in* 1988–89; *control operations or natural causes?*

In spite of problems posed by the assessment of the effects of control measures on the development of the overall Desert Locust situation, as against the effect of natural causes, it is clear that throughout 1988 control operations were conducted in the affected countries on unprecedented scales. Of particular impact were those campaigns waged against swarms in Morocco from October to December 1988, when most known swarms in northwest Africa were located, against hopper infestations in Sénégal and Gambia and elsewhere in West Africa, and in Saudi Arabia against the invading swarms in late 1988 and early 1989.

In addition to efficient control operations, natural factors cannot be ignored. Of particular impact was the loss of swarms over the Atlantic and the failure of breeding in the Central Region and northwest Africa in the winter of 1988–89.

The reasons for the failure of the 'southern circuit' swarms to lead to substantial breeding in the Sahelian countries in the summer of 1989 are not known. The apparent loss of fecundity by the locusts could, perhaps, be ascribed to the effects of cumulative sublethal doses of pesticides or the cumulative effect on the environment of continuous control operations undertaken since the start of the plague.

Other likely contributing factors include: mortality factors throughout the period (attacks by man, birds and other predators, disease, adverse climatic conditions); fragmentation of swarms (as was observed in southern Mali and Burkina Faso); the possible loss of a reproductive ability postulated for 'southern circuit' swarms (Pedgley 1981).

5. Control strategy and alternatives

The intensity of the 1986–89 Desert Locust plague, the amount of external assistance involved (in excess of U.S.$200 million) and the interest that it aroused have confirmed the necessity of improving control strategies and considering new alternative approaches to the prevention of new plagues. For its part FAO organized a series of expert meetings in 1988–89, dealing with various aspects of the problem (FAO 1988b, 1989).

As stressed by Bennett (1976), a great deal of improvement is needed in the organization of campaigns once an upsurge has started, to concentrate control operations when and where large locust populations are concentrated for protracted periods of time (strategic areas). Such concentrations have frequently occurred in Morocco and northern Somalia; other potential target areas such as the lakes region of Mali have been identified in the Sahel. Radar and aircraft properly equipped with doppler radar could be useful in the strategic areas at appropriate times, but we have to recognize the limits of radar's use and its feasibility because of the frequent distribution of locusts in remote and inaccessible areas and the short period when adult control can be undertaken. On the other hand, we support the use of radar to detect night flying adults at the early stage of plague periods.

Consideration of previous upsurges suggests that a critical situation may arise very rapidly, leading to a locust population in the range of 10^9 or 10^{10} individuals within an area of 20000 km^2, comprised of a large number of small bands (covering 1–5% of a band zone, defined as an area containing bands separated from another band zone by at least a few kilometres). They may be very difficult to locate. They are also very costly to control, for the simple reason that band zones will have to be covered when using non-persistent pesticides and all insecticides applied to the gaps between bands will be wasted.

Although the merit of treating the insects themselves rather than the band zone containing them appears obvious, we find in practice that most attacks on locusts can only be directed at a treatment of the band zones for achieving the work in the time available; a band zone may remain extant for about six weeks, but a swarm may pass in a day. Given the difficulties of finding more than a small proportion of the small bands, except in inhabited areas, and of controlling flying swarms by air-to-air spraying, it is difficult to envisage the prevention of the spread of plagues without:

(i) the rehabilitation of dieldrin for barrier spraying;

(ii) the organization of large-scale hopper band zone spraying, using 50 times the necessary quantity of non-persistent pesticides and unnecessarily polluting the environment;

(iii) the organization of systematic tracking and spraying of swarms in flight as was widely practiced in the 1950s, often efficiently (because airborne locusts collect a higher proportion of the spray than settled targets) and at acceptable cost, or against settled swarms as in 1988 at a very high cost.

6. The international challenge; possibilities of preventing and checking future plagues of the Desert Locust

It is to be hoped that the implementation of a preventive control strategy involving the strengthening and/or creation of national locust control units in all the countries concerned, during recession periods, and the establishment of adequate regional task forces able to intervene and check initial upsurges, will prevent important upsurges and new plagues in the future. The recent large-scale campaigns against grasshoppers and locusts undertaken since 1985 in Africa and the Near East, generously supported by the international community, have resulted in the better equipping of national units and a better understanding by governments of the need for preventive control. However, as the use of dieldrin is limited, an economical reduction of numbers by barrier spraying will not be possible. Consequently, for preventive control to be successful, more equipment, manpower and pesticides than were used during the 1962–1985 period will be needed, as non-persistent insecticides will require the finding and spraying of individual concentrations or bands of hoppers. For future planning the following factors must be borne in mind: the decreasing role of regional locust control organizations and their replacement by the national plant protection services; the economic difficulties of developing countries that cannot support the continuity required for preventive control; the depth of the involvement of international community assistance in controlling grasshoppers and locusts during the recent pest years, thereby creating a heavy reliance on foreign assistance and implying the necessity of commitment by donors to support preventive control costs over a long period; the persistence of political problems within the recession area of the Desert Locust; the time needed to promote new alternative pesticides and control strategies.

Therefore, to be realistic, we cannot deny the likelihood of new upsurges and even new plagues in the decades to come. The challenge consists in understanding the problems involved and envisaging approaches and solutions able to check situations in time before explosions occur.

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Discussion

G. B. Popov (*FAO*, *Rome*, *Italy*). From what was said by Dr Skaf, I would like to highlight the following: the degree square monthly frequency maps prepared by FAO for the recession period 1963–1984 (excluding 1968, a plague year), when compared with those prepared by the Anti-Locust Research Centre for the 1939–1962 plague period, show marked differences; of particular significance is the fact that the major high-frequency spring breeding grounds in northern Africa and the Near East are not reached by recession populations. This is evidently because they fly by night and are thus subject to lower temperatures and different atmospheric conditions than the swarms that fly by day. The implications are far-reaching; we know from Waloff (1966), who studied the dynamics of plague upsurges and declines in great detail, that as a rule, major upsurges have followed a successful double-generation spring breeding, (let us point out *en passant* that this was yet again the case during the last plague upsurge, which found its impetus following 1987–88 winter-spring breeding, despite the massive control of over 5 million hectares). It follows that if we could prevent locusts from reaching the spring breeding grounds in numbers, this would help towards plague prevention.

It seems that we are now yet again in a recession period: what strategy should we adopt to prevent a recurrence of plagues in the future? The majority of us probably agree that plagues start from a successful build-up and gregarization of initially non-swarming low-density locust populations, a process that is furthered by sequences of favourable rainfalls in time and in space. There are basically two schools of thought as to how this process can be prevented from reaching plague proportions; the first advocates survey of the recession breeding areas and control of any populations that begin to gregarise. The second (on the grounds that many minor outbreaks are abortive and that swarms represent the most cost-effective control targets), would delay control operations until most of the populations are in swarms. At present the former is the strategy, but in practice, the second is often implemented.

Taking western Africa, of which I have first-hand field experience, as an example, the first strategy was effectively practised there by the regional locust control organization (OCLALAV) until the decline of that organization in the late seventies. During the 1966–81 sixteen-year period, control of gregarizing populations was conducted during 11 years, the scale varying from one to tens of thousands of hectares. This strategy aimed at culling gregarious and high-density gregarizing populations, leaving sometimes fairly large areas of low-density populations uncontrolled. But the latter, by virtue of their solitarious nocturnal flight behaviour failed to reach the high-frequency spring-breeding grounds, and remained confined to the recession area with the prospect of having to survive the adverse winter desert conditions. During the 1966–82 period this strategy effectively prevented locusts from reaching the spring breeding grounds in any numbers, except on two notable occasions: the first in October 1968, when swarms originating in the Central Region traversed the continent in little more than a week, reaching southern Morocco, where they were effectively controlled; and the second, in 1980, by which time OCLALAV had ceased to be an effective control organization and had failed to prevent swarm formation in the Mali and Niger outbreak areas and their escape to Algeria. There is surely a lesson to be learnt here.

The weakness of the second strategy, which advocates delaying control until swarms are formed, is that major population build-up may occur in areas where no control is possible. The 1986–88 plague upsurge provides a good example of this.

Reference

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J. Roffey (*FAO, Rome, Italy*). I would like to draw attention to two issues: the suddenness with which the Desert Locust numbers increased and the qualitative changes associated with these increases. The first upsurge, which with hindsight we can see led to the plague, occurred at the end of the summer of 1985, the year when the drought of 1982–84 ended. In 1985 there were good rains which triggered off big increases of grasshoppers in the Sahel, of *Locusta migratoria* in Sudan and the first significant increases in Desert Locust numbers at both ends of the Sahel: in Mauritania and in the Red Sea Basin. Then in 1986, 1987 and 1988 there were good rains over much of the area infested with Desert Locusts. So by October 1988, with two generations during the winter-spring and two in the summer, there had been 12 or 13 generations and the populations had risen by about five orders of magnitude. There was a multiplication rate of about three per generation but in some areas it was much higher and in others lower. Some control was conducted against all these generations, but it was not until the last quarter of 1988 that such measures had a significant impact on the largest infestations. Dr Skaf has pointed out many of the reasons for this, which included the lack of security in Eritrea, in northern Chad, western Sudan, and the Western Sahara, and technical deficiencies in the application of the insecticide and the limitations imposed on the use of dieldrin. Equally important, however, were qualitative changes in the populations. These started off with the switch from night flying to day flying in late 1985, but by 1988 the locusts became much more vigorous than we expected standard gregarious locusts to be, as evidenced by a number of remarkable migrations. These included the eastward one from West Africa across to the Yemen during the late spring and early summer of 1988, and the migrations across the Atlantic Ocean to the Caribbean, with repeated invasions of the Cape Verde Islands, in October and November 1988. But there were also numbers of migrations northwards to the U.K., Italy, Greece and later in the year to Turkey, Syria and Lebanon from the southwest, that is, across the Mediterranean Sea. If you have insects whose performance can greatly exceed those of the normal animal, this means that forecasting during upsurge situations is going to be particularly difficult: it will be much more difficult to predict plague upsurges than it has been over the last two or three decades.

R. S. Scorer (*Imperial College, London, U.K.*). I well remember the occasion when Dr Rainey came to the Meteorology Department to try out his ideas about locust migration on me and my colleague Frank Ludlam. When we had spoken for a bit he suddenly stopped; and when we indicated that we awaited the controversial points he had warned us to expect, he said 'that's all'. We completely agreed with his thesis as being in accord with our ideas about air movements. The point of this remark is to show that I still (35 years later) do not understand the stubbornness of doubts among many non-physically oriented thinkers to recognizing the primacy of air motion for an airborne species.

I do not agree with Dr Rainey's suggestion in the opening remarks that a campaigning organization would be appropriate to make an assessment of the case for and against the use of dieldrin. An economist would probably be better equipped to assess the overall advantage of various anti-pest strategies. What we need is a widely supported case for dieldrin from a variety of scientific disciplines, clearly showing the quantitative advantages.

J. HEWITT (20 *Hartington Road*, *Chiswick*, *London*, *U.K.*) The real problem facing operations of any kind during years of recession is that governments, while responding to crises, never anticipate them.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES