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DESERT LOCUST TECHNICAL SERIES

Preparedness to prevent Desert Locust plagues in the Central Region an historical review

Part 1. Text

PREPAREDNESS TO PREVENT DESERT LOCUST PLAGUES IN THE CENTRAL REGION, AN HISTORICAL REVIEW

Part 1. Text

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INTRODUCTION

1. The 28 million km^2 invasion area of the Desert Locust extends from the Canary and the Cape Verde Islands off the Atlantic coast of west Africa through the Near East and Arabia to eastern India and from northern Turkey southwards to southern Tanzania. During plagues, swarms and hopper bands intermittently infest parts of this vast area. Plagues arise, however, in the recession area of 16 million km^2 that occupies the arid and semiarid core of the invasion area. Desert Locust breeding is synchronised with rainy seasons and adults (swarms and non-swarming individuals) migrate between complementary breeding areas where summer, winter and spring rains fall. The resulting partially closed migration circuits divide the invasion and recession areas into four Regions, the Western, Central North, Central South and the Eastern Regions (see appendix 3, figure 1) because movements within a region are more frequent than those between regions.

2. In classical locust plague prevention, teams monitor locust populations in permanently infested outbreak areas and control populations to minimise the risk of swarms emigrating into the invasion area to start a plague. The first Desert Locust plague prevention strategy was formulated in 1938 (Brussels, 1938a) and its fundamental function, locating and controlling populations as they gregarize, remains unchanged. In contrast, its biological basis had to be modified from expecting plagues to start within small well defined outbreak areas to realising that they occur when rains activate a series of seasonal, but geographically separated, breeding zones between which the locusts migrate. Equally, the organization of locust control and its infrastructure altered radically from an intended international basis through regional systems to national units having prime responsibility for implementing the strategy. Furthermore, control agents, techniques and perceptions of their environmental acceptability have changed over time making direct comparisons between periods problematic.

3. In 1969, when the Food and Agriculture Organization of the United Nations (FAO) adopted the long-term policy to prevent plagues, experts accepted that large control campaigns against upsurges were likely and that plagues might develop. Consequently, FAO instituted a plan to improve detection of outbreaks and to find stable finance during recessions to ensure that teams were equipped to use the latest anti-locust techniques and were able to mobilise reserves rapidly during upsurges (FAO, 1969). FAO established International and Regional Trust Funds to share costs between affected countries but this mechanism raised insufficient money to fund major upsurge and plague suppression campaigns and external donors have to date provided the shortfall. Donors were initially countries with responsibility for plant protection in their respective colonies. Now, although more numerous, donors have locusts as one amongst many competing priorities for their development and emergency humanitarian aid budgets.

4. One or more years may separate the first initiating rains and the establishment of a major plague and the best time to intervene is still debated. Research (Bennett, 1974, 1975, 1976) suggests that culling the initial gregarious sections of a population fails to end upsurge sequences, whereas, control applied later when the entire population is gregarious and infests a much-reduced area ends upsurge sequences. MacCuaig (1970) postulated that control implemented early in an upsurge would result in a smaller population at the onset of the plague but noted that control late in an upsurge would maximise efficiency in terms of kill per unit of insecticide. Courshee (1990) and Symmons (1992) extended this latter concept by arguing that swarm control is more efficient than hopper control particularly when using non-persistent chemicals. Symmons (1992, 1997) and Posamentier and Magor (1997) emphasized the logistical, economic and environmental cost implications associated with prevention tactics other than upsurge elimination. Opponents of this view contend, however, that unculled populations might be too large to return rapidly to recession levels. They also maintain that band treatment is easier and more certain than waiting to control migrating swarms. In conclusion, they emphasize that early preventive control has never been implemented throughout all the infested areas early in an upsurge but admit that the reason is often insecurity in key breeding areas (e.g. Lecoq, Duranton and Rachadi, 1997). A final factor that should not be overlooked is the lack of funding to maintain preparedness and enable early mobilization of sufficient, appropriately equipped and trained control teams. The difference of opinion on the impact of early versus late interventions remains unresolved and in turn, leads to different perceptions of the success and failure of the strategy.

5. The failure to prevent the 1977-1979 upsurge and short plague led FAO to investigate the resources required to prevent upsurges becoming plagues in the Central Region (FAO, 1984b, 1985b). The review revealed that locust units would need considerable strengthening to operate the plague prevention strategy that had been reduced in response to overstretched plant protection budgets and to recession workloads in which many years have few outbreaks. Strengthening was not achieved before the 1985-1989 outbreaks, upsurge and plague began during which the provision of external funds totalling about $300 million [$462 million[1]] prompted renewed calls to review the strategy, to use safer pesticides and to maintain preparedness. The upsurges between 1992 and 1998 gave rise to fears that such events were becoming more frequent so that effective early warning and control systems were needed. FAO responded by establishing The Desert Locust Component of the **Em**ergency **Pre**vention **S**ystem for Transboundary Animal and Plant Pests and Diseases in the Central Region (EMPRES/CR) to strengthen the capabilities and capacities of national, regional and international organizations. An objective of the EMPRES/CR programme and its extension in the Western Region is to ensure that teams are fully equipped to prevent future plagues.

The review

6. EMPRES CR commissioned this review to analyse information on early warning and control capacities in order to compare the region’s current and former preparedness to prevent plagues. The review also considers the adoption of post 1985 recommendations and technologies. Six steps were envisaged.

- Review preventive control strategies 1929-1990, their implementation, failures and proposed remedies.
- Review the adoption of post 1985 technological improvements in early warning and in control with recommendations for achieving sustainability.
- List assumptions used to estimate preparedness of the Central Region to prevent plagues in 1985 and in 2003.
- Assess the current [2003] level of preparedness to prevent plagues in Central Region countries.
- Compare current and 1985 preparedness to prevent plagues in the Central Region.
- Recommend improvements leading towards sustainability.

7. The original report and this revision are presented in two parts to make it easier to locate material referred to in several chapters. Part one contains an introduction and the review divided into six chapters. Part two contains a consolidated bibliography, all figures and appendices. Early chapters provide background information for discussing control strategies and tactics. Chapter one examines the evolution of the current plague prevention strategy. Control strategies need to be adapted to a pest's population dynamics and few people are familiar with the history of Desert locust outbreaks, upsurges and plagues within the whole Desert Locust area. Consequently, chapter two describes the spatial and temporal characteristics of pre-plague populations since the 1920s to give readers an appreciation of the scale of the task involved in plague prevention. Chapter three contains methods used to assess the locust threat. The 1985 assessment of preparedness to prevent plagues in the Central Region is described in chapter four as are methods used more recently. The control technology used when the 1985 assessment was made has been replaced so that comparing preparedness then and later is problematic. Changes in control technology since 1985 are outlined in chapter five. Chapter six brings together factors limiting sustainability so that managers can evaluate the relative importance each has in his country and assign priorities to removing limitations according to available funding sources.

8. The review revealed that divergent views on important topics originated when plague populations were present in one or more regions in most years and from research undertaken at least 30 years ago. The dispute on the origin of plagues was resolved when it became apparent that plagues seldom develop from swarms already present in an area but start with a series of wet seasons in which the non-swarming populations that are always present in the recession area, concentrate, multiply and form bands and swarms. Analyses have yet to resolve differences of opinion on the best time to initiate control to

[1] $US equivalent updated from 1988 to 2006

prevent a plague developing and how soon in the plague development process, this objective can be achieved. Placing the control strategy in its historical context will, we hope, lead to a better understanding of the issues and lead to new analyses, a task that will require high quality data to be collected during the now rare large-scale control campaigns.

Terminology

9. As views changed and knowledge improved some Desert Locust terminology became outdated. Consequently, when the FAO formally accepted that Desert Locust plagues do not originate within permanent outbreak areas (FAO, 1956), experts recommended abandoning the term 'outbreak' that had originally been used to describe plagues and later to describe their onset. They also recommended that zones where *solitaria* are transformed into *gregaria* be called ‘gregarization' not 'outbreak areas’. Unfortunately, a new definition of 'outbreak', cited below, arose to describe gregarizing populations with the result that the term 'outbreak areas', with its implications of classical plague prevention, remains in general use. The new definition fails to distinguish ‘local outbreaks’ from the more numerous and widespread 'contemporaneous ones’ present as upsurges start, a distinction emphasized by analysts (Waloff, 1966; Roffey et al., 1970; Bennett, 1976). The term 'recession' for inter-plague periods also came into general use in the 1970s but owing to the subsequent increased concentration on pre-plague populations, now tends to be restricted to years with few gregarious populations.

10. The ambiguities in contemporary terminology exemplify Waloff’s (1966) warning to regard Desert Locust definitions as provisional in the absence of quantitative values for recession and plague fluctuations. Indices available then, and now, are incompletely reported changes in the extent of affected areas and the numbers of locust sightings in them. Several of Waloff's provisional definitions (1966, 1976) reveal additional complications as they are based on information from different sections of complementary breeding areas over a period of one or more years. Such terms can be assigned only retrospectively and when the history of events over a wide area can be reconstructed plausibly.

11. Definitions below for terms currently in general use were derived from those in Waloff (1966, 1976), FAO (1980a 2001f), Magor (1994) and Van Huis *et al*. (2007). They are descriptive and the boundaries between terms are subjective and imprecise so that one person’s outbreak may be another person’s early upsurge; a similar uncertainty exists between late upsurges and early plagues, and between plague declines and the re-establishment of recessions.

- **Recessions** are periods between plagues. They are also defined as periods without widespread and heavy swarm infestations during which the species reverts to transient and solitarious phases. Reports of swarming populations mostly refer to small and often transitory assemblages of adults or small hopper infestations. Recessions may be regional. In major recessions, sometimes called ‘deep recessions’, all three regions may be free from swarming populations.
- **Outbreaks** occur when concentration and multiplication cause a marked increase in locust numbers and densities so that individuals gregarize and, unless checked by control, form hopper bands and/or swarms.
- **Upsurges** are periods in which a widespread and very large increase in locust numbers initiates contemporaneous outbreaks followed by two or more successive seasons of *transiens*-to-gregarious breeding that occupies an expanding area in complementary breeding areas in the same or neighbouring desert locust regions.
- **Incipient plagues** occur when two or more successive generations of transient to gregarious populations are produced, they are often small-scale and are usually confined to neighbouring complementary areas.
- **Plague upsurges**, especially of a major plague, are an unbroken succession of gregarizing and/or gregarious populations, increasing in size from generation to generation and occupying an expanding area.
- **Plagues** occur when widespread infestations of swarms and hopper bands affect extensive areas and generate large numbers of reports during the same year and in each of several successive years (Waloff, 1966, 1976) or in one or more years (FAO, 2001a, 2001f).

12. In this review, 'outbreak area' is used only in its classical definition of a restricted area within which all upsurge and incipient plague developments of species such as the Red and Migratory locusts occur.

For other species, the term is replaced by 'gregarization area or zone'. The terms incipient plague and plague replace the original meanings for outbreak. No terms were found that distinguish 'local outbreaks' from the more widespread, numerous, and contemporaneous ones found as upsurges begin. Preventive or proactive control, the terms currently most frequently used when discussing the Desert Locust control strategies, lack precision. Consequently, wherever possible they were replaced by stating whether the author was referring to outbreak, upsurge or plague prevention.

13. Many countries have changed names during the study period (1920-1999). Names current as the review was written (2003) were used and the name cited in the source document(s) was added, in parentheses, the first time it appears in the text. Control expenditures are cited in United States dollars with an updated value appended in square brackets. Monetary estimates were converted to 2006 values (Officer and Williamson 2007a) to make them more comparable. Values originally cited in pounds sterling were converted to United States Dollars (Officer and Williamson, 2007b) before being updated to 2006 equivalents. It should be remembered, however, that differing control methods are unlikely to have equal costs. In addition, costs may not have increased in line with the GPD inflator index, which Officer and Williamson advised for updating capital investment and government expenditure.

1. DESERT LOCUST PLAGUE PREVENTION STRATEGIES 1920-1999

J I Magor

BRIEF OVERVIEW[1]

1920 to 1929	**1916** International meeting on locust control postponed until 1920 by World War I. **1920** Locust Convention lacked control focus and signatories unrelated to locust invasion zones. **1921** Phase theory published, which suggests control in outbreak areas as a plague prevention strategy. **1926** Phase change observed among Desert Locusts in the Sudan. **1929** UK establishes ALRC to investigate locust plagues and the means to control them.
1930 to 1939	**1930** ALRC starts to collect, map, analyse and archive infestation data from the Desert Locust area. **1930-38** Four international conferences planned research on control, biology and migration. Results: outbreak zones found; migration and breeding related to seasonal rains making permanently infested outbreak areas improbable; economic impact of locusts estimated for 1925-1934. **1938** International Plague Prevention Organization for Central and Eastern Regions proposed.
1940 to 1949	**1941** First Plague Alert issued; 1943-48 monthly Bulletins & forecasts used to plan campaigns. **1942-47** Regional campaigns coordinated and occur in deserts to prevent migration to distant crops. **1942-47** Traditional control techniques: trenching and burning replaced by sodium arsenite baits. **1943** BHC bait trials; **1944** aerial spray trials with synthetic insecticides; **1947** no swarm targets left. **1942-47** List of lessons to learn still valid e.g. locust attacks worsen whilst reserve funds sought.
1950 to 1959	**1950** Plague starts before civilian national and regional plague prevention units re-established **1949, 1950, 1951** Insufficient funds available for early suppression campaigns to end plague. **1950s** Downwind migration of locusts established, ulv spraying adopted, crop loss estimates 1949-57 **1955** DLCC, Commissions & Trust Funds established; **1956-59** interim scheme for plague prevention **1958-63** Large scale aerial campaigns substantially reduce regional populations.
1960 to 1969	**1960s** Pre-plague groups, swarms & bands controlled as an interim plague prevention system **1960-70** UNDP (formerly UNSF) project builds research, early warning and control capacity. Non-persistent pesticides sought to safeguard environment. Dispute on how plagues start resolved. **1968** onwards, plagues suppressed rapidly and none reaches pre-1960s size and geographical extent. **1969** Interim plague prevention strategy adopted with action plan to improve implementation.
1970 to 1979	**1972-74** Drought curtails upsurges, early cessation sometimes misjudged as plague prevention. **1974-76** Studies of 1966-69 campaigns indicate unsprayed scattered locusts can continue upsurges. **1972** Early Warning System has five regional forecast centres that miss 1978 inter-regional invasion. **1978** DLCC calls for resource inventory to improve plague prevention capacity during upsurges. **1978** Early Warning System recentralized at FAO.
1980 to 1989	**1983-85** Plague prevention needs identified but not supplied before locust and grasshopper outbreaks **1986-90** FAO ECLO established to coordinate emergency response. High cost and pesticide use prompted formation of Pesticide Referee Group (1989) and 1990s research programmes on: best control practice, environmental impact and safeguards, biopesticide development, GIS for Early Warning Systems, and on the economic and social impact of locusts (see chapter 5)
1990 to 1999	**1994** FAO with donor support launches EMPRES to strengthen national capacity in monitoring and reporting for early warning and in early and safe control reaction to outbreaks and upsurges. **1995** EMPRES becomes operational in nine recession area countries in the Central Region. **1996-2006** FAO and then national units obtain GIS to manage early warning data and mapping. **1998** Affordable satellite products begin to distinguish sparse locust vegetation from desert soils.
2000 to 2006	**2000** eLocust allows digital transmission of survey data from field into RAMSES, the national GIS. **2002** FAO establishes a single Desert Locust Control Commission for the Western Region. **2003-05** Delays in external funding allow a short plague to develop; training to monitor non-target impact and health begin; results of biopesticide trials promising. **2003-06** EMPRES for Western Region not fully funded and operational until 2006

[1] Recessions including outbreaks and upsurges (dotted line); plague onset and decline (narrow line); peak plague years (broad line)

LEARNING ABOUT DESERT LOCUSTS 1920-1941

1. Pest managers usually control pests infesting crops to protect agricultural production but for some migrant pests, including the Desert Locust, the strategic aim is to prevent swarms from invading major cropping areas. For locusts, the exact strategy chosen and the means of control have varied as more became known about them and new pesticides and application methods became available. Two factors are inherent to the success and failure of locust control strategies. Desert Locusts ignore international boundaries, so that lasting solutions require international cooperation and intervention against all "significant" populations. In addition, locusts are an intermittent problem (Fig. 2)[2] and interest in, and funds for control and research, rise during plagues, when swarms threaten major cash-crop areas, and fall during recessions. This lack of sustained interest may account for the fact that control teams are ill equipped and ill prepared to use the latest techniques each time a plague begins.

2. Modern locust studies began when Uvarov (1921) proposed the phase theory to explain the origin and disappearance of locust plagues. He had observed Migratory Locusts (*Locusta migratoria migratoria*) develop into a form previously thought to be a solitary living grasshopper when their numbers were reduced by control. Faure (1923) had seen comparable changes in South Africa among Brown Locusts (*Locustana pardalina*). Uvarov postulated that the associated changes in behaviour, physiology, colour and shape were responses to changes in population density. He observed that low density populations persist in restricted habitats and intermittently increase in numbers to form swarms that emigrate and start a plague. This characteristic led Uvarov to conjecture that controlling populations to prevent gregarization within outbreak areas would prevent plagues. Initially scientists assumed that all locust species had similarly functioning outbreak areas and that the ecology of such areas could be modified to prevent plagues once sufficient was known about plague initiation (Uvarov, 1951). Uvarov (1923) suggested that phase change also occurred in the Desert Locust when he revised the taxonomic group, Cyrtacanthacrini. Johnston (1926a, 1926b) confirmed this hypothesis when the progeny of solitarious locusts formed concentrations exhibiting gregarious appearance and behaviour, which were lost by the less dense survivors of control.

3. From the earliest attempt at international cooperation, maintaining the momentum of locust activities during recessions was difficult. In 1916, at the height of the 1912-1919 plague, the Permanent Committee of the International Institute of Agriculture in Rome decided to hold an international conference on locust control. The First World War delayed the meeting until 1920 by which time a locust recession had started. Uvarov (1951) reported that neither an overly ambitious and uncosted scheme for a worldwide permanent anti-locust commission to inspect suspected outbreak areas nor a more modest and practical proposal to start with regional cooperation was agreed. Instead, the conference adopted a draft international convention that pledged signatories to take measures against locusts, exchange information on locust movements and submit reports on locust control to the International Institute of Agriculture in Rome (Rome 1920). He found the degree of agreement disappointing, since only 10 states widely distributed around the world signed the convention. For Desert Locust areas, although France and Italy signed for their territories in Africa, the British, Portuguese and Spanish territories were outside the convention as were Egypt, Ethiopia (then Abyssinia), all Near Eastern and southwest Asian countries. The locust information sent to Rome was stored and summarized in publications but was not analysed.

4. In contrast, cooperation improved when a new plague (1926-1933) threatened Africa, the Near East and Southwest Asia. In 1928, large swarms reached the Sudan (then the Anglo-Egyptian Sudan) Kenya and Tanzania (then Tanganyika). In response to this threat, the UK Government appointed a Locust Sub-committee in April 1929. The committee realized that their task would require the collaboration of all affected countries and set up a small unit, run by Uvarov, within the Imperial Institute of Entomology. This unit's functions were to centralize information, organise research, search for outbreak areas and find the means to destroy gregarious populations. Uvarov received, mapped and analysed a regular flow of information from affected countries on current and past infestations. He stressed the importance of a centralized information service arguing that, without one, invasions came as a complete surprise. Furthermore, countries did not regard the moderate impact of initial invasions as a warning of worse to come and so failed to make timely preparations for future campaigns (Uvarov, 1951).

[2] Updated to 2006 for this revised review

5. The collaboration achieved by this unit was agreed formally at a series of international anti-locust conferences. In 1931, a Conference in Rome confirmed the United Kingdom's (UK) centralized approach (Rome, 1931). A second conference (Paris, 1932) endorsed the regular collection, exchange and analysis of information at a central location. A locust information centre, originally located in London (1931-1978), and then at the Food and Agriculture Organization of the United Nations (FAO), Rome has existed ever since. The Paris Conference also recommended holding annual international conferences to manage the general direction and coordination of anti-locust research. In response, delegates met every two years until interrupted by the outbreak of war in 1939 (London, 1934; Cairo, 1937; Brussels, 1938a).

6. Analysis of data amassed in the 1930s, extended reliable knowledge about the Desert Locust to most of its distribution area, then thought of as an area invaded by plagues that originated in permanently infested outbreak areas (Fig. 3). The systematic collection and mapping of plague infestations showed that breeding coincided with the wet season and that swarms migrated between the seasonal breeding areas. Detailed fieldwork by Rao (1937a, 1942, 1960) showed that adults in the solitarious phase also migrated seasonally. Thus, the importance of climate and vegetation for predicting outbreaks and seasonal distribution of locusts began to emerge. Scientists located outbreak areas along the Red Sea Coasts (Johnston, 1926a, 1926b, Hussein, 1938; Maxwell-Darling, 1936, 1937), in Pakistan (then in pre-partition India) (Rao, 1937b 1942, 1960), in Algeria (Volkhonsky and Volkhonsky, 1939), and suspected that others existed (UK, 1937). Sodium arsenite baits augmented and began to replace traditional methods of control such as trenching, beating and burning. The first organized large-scale defensive campaigns protected crops in a few countries but did not affect the course of the plague or prevent re-invasion in subsequent years (Uvarov, 1951). In addition, Uvarov and Bowman (1937) conducted the first evaluation of the economic importance of locusts. They used affected country statistics for the period 1925-34 on crop and livestock losses, expenditure on locust control, famine relief and revenue losses from tax remissions in badly affected areas. This topic was revisited in the 1950s (FAO, 1958) and in the 1990s (Joffe, 1995, FAO, 1998) and still requires improved and validated methodologies (FAO, 2006 para. 62).

Proposed plague prevention scheme 1937-1938

7. During the recession that started in 1934, delegates to international locust conferences began to develop plans to prevent locust plagues. A scheme for permanently monitoring outbreak areas of the Desert Locust was first mooted at Cairo and the conference noting that outbreak areas exist around the Red Sea and that recent incipient outbreaks had been successfully suppressed by control, recommended an approach very similar to current plague prevention.

- Concerned Governments should arrange for a trained entomologist, preferably one with previous experience of the Desert Locust, to patrol these areas, periodically at the appropriate season each year, with a view to suppressing incipient outbreaks (Cairo, 1937).

8. A detailed proposal for a permanent international organization for the preventive control of the Desert Locust in Eastern Africa and Western Asia' (UK, 1938) was presented and approved in principle at the next conference (Brussels 1938a) at which the related resolution (Brussels 1938b) emphasized that the proposal should be implemented without delay as an incipient plague was being reported.

9. The functions of the proposed organization were similar to those of current plague prevention strategy, but its structure was a very different.

Proposed Functions:

- To implement the permanent supervision of known outbreak areas and any others subsequently identified by frequently patrolling to discover incipient swarming.
- To destroy incipient swarms in those areas immediately they are seen.
- To study the habitats and ecology of solitary locusts in outbreak areas.
- To explore any additional areas suspected to be outbreak areas.

Proposed Organization:

- Port Sudan would be the most suitable headquarters for the contiguous outbreak areas in Eastern Africa. A subsidiary station should be opened at Jeddah, but as the known areas in Arabia are more scattered it may be found advisable to change the position of this station or to add others.

- The staff to be one chief entomologist and two assistant entomologists who would work under the direction of the International Anti-Locust Committee, whether specially engaged or seconded by one of the contributing Governments. In the latter case, their responsibility would be directly to the International Committee.
- The International Committee should in general be responsible for the organisation, with each contributing Government having full right to inspect the work through its own representative.

10. Estimated capital expenditure for this organization was £3 800 [$226 000][3] and included a contribution of £1 000 [$60 000][4] to a cumulative Reserve Control Fund. The estimated, annual recurrent expenditure for other staff, transport and control products was £8 200 [$476 000][5] and included an allocation of £400 [$24 000][6] to support the Anti-Locust Research Centre (ALRC) in London. The eight contributing Governments were to be Great Britain and the then British Territories (Uganda, Kenya, Tanganyika, British Somaliland, Palestine, Transjordan), Egypt, the Sudan, Italy, pre-partition India, Iran, Iraq and the Soviet Union for Armenia and the current Central Asian States of Kazakhstan, Tadjikistan, Turkmenistan and Uzbekistan. Proposed budget allocations for each Government were based on the importance to each country of the Desert Locust, their financial ability to contribute and their expressed approval of the scheme and readiness to participate (UK, 1938).

11. The Conference recommended that the UK Government discuss the scheme with other interested countries. Uvarov (1951) records that no useful action occurred before the onset of war in 1939 and the proposed scheme was postponed. Funding for UK activities was reduced in the immediate pre-war period when the Desert Locust was in recession and contemporaneous Red and Migratory Locust plagues were declining. Field investigations ceased and laboratory research ended. With the onset of World War II, the directing body of ALRC was disbanded. Then from 1940, the Colonial Office sponsored anti-locust activities.

12. Fortunately, the information service was not disbanded and was sufficiently well established to continue working with minimal interruption throughout the war. The previous decade's investment in the collection, systematic mapping and analysis of affected countries' reports paid off. ALRC issued a general warning of an impending plague in 1941 and the monthly locust bulletins correctly forecast most imminent invasions and were used for planning and running seasonal control campaigns from 1943 to 1947 (Uvarov, 1951).

RETHINKING PLAGUE SUPPRESSION AND PREVENTION 1940-1969

Plague campaigns coordinated, plague prevention restructured 1940-1952

13. For the first time during the 1940-1948 plague, the strategic objective was to suppress the plague by destroying bands and swarms not only where they represented an immediate danger to crops but also in the deserts where, although harmless locally, they nevertheless constituted a threat to crops in distant areas. National plant protection agencies covered many crop areas but special anti-locust units were needed to implement the new strategy in desert areas where otherwise locusts would have bred undisturbed. Local and British campaign managers who met at regional conferences, to coordinate the international control campaigns, widened their discussions to include control during recessions to prevent plagues. Uvarov (1951) reported that these exploratory semi-official discussions indicated that not all Governments were likely to agree to finance operations or to allow freedom of access to regional and international teams, a pre-requisite for a plague prevention scheme of the type discussed at Brussels.

14. In 1948, therefore, the Eastern Region Governments of Pakistan, India and Iran continued to maintain permanent anti-locust organizations but changed their focus to concentrate on the prevention of swarming in gregarization areas. In the Central Region, the British wartime anti-locust organizations were disbanded. In their place, the Governments of the East Africa High Commission established Desert Locust Survey (DLS) in October 1948. DLS maintained a regional approach as its function were to survey and supervise gregarization areas around the Red Sea, the Gulf of Aden and in Oman from

[3] $US equivalent updated from 1938 to 2006
[4] $US equivalent updated from 1938 to 2006
[5] $US equivalent updated from 1938 to 2006
[6] $US equivalent updated from 1938 to 2006

which East Africa might be invaded. The DLS mandate covered Somalia, British Somaliland, Ethiopia, Eritrea, the Aden Protectorates (now part of Yemen), Saudi Arabia, Yemen and Oman. Initially, field teams were based in Asmara, Hargeisa and at Bureiman near Jeddah leaving Persian Gulf and southern Arabian gregarization areas to be monitored in later years (Desert Locust Survey, 1951). The complementary and closely linked organization, Desert Locust Control[7] (DLC) was established in 1950, when reports indicated that a new plague was imminent. Remaining gregarization areas in the Central Region were supervised by the Governments of Sudan and Egypt working closely with DLS along the western Red Sea coasts. Egypt also monitored the northern Tihama of Saudi Arabia. Pakistan sent teams to work in the United Arab Emirates (then Trucial Oman) and a British Liaison Officer worked with the Iranian authorities (Uvarov, 1951).

15. The Western Region was omitted from the original draft prevention scheme (UK, 1938) on the assumption that outbreaks in the east and west might arise independently and that the scheme could be extended later to include suspected gregarization areas in coastal Mauritania and near isolated mountain massifs of the southern Sahara (Uvarov 1951). In 1943, the French Office National Antiacridien (ONAA) in Algiers replaced the French Committee for the Study of Locust Biology and a regional system developed. French experts based in Dakar and at ONAA in Algiers helped to coordinate research and monitoring in Senegal, Mauritania, Mali (then French Soudan), Burkina Faso (then Upper Volta). They also coordinated control operations from 1952 until 1958 when the Organisation Commune de Lutte antiacridienne (OCLA, later to become OCLALAV) was established for these countries and for Chad, Benin (then Dahomey), Ivory Coast and Niger. National locust units in Morocco, Algeria, Tunisia and Mauritania exchanged technical information but there was no coordinating body until 1966 when FAO established the North West African Desert Locust Research and Control Coordination Sub-Committee, which became the Commission for Controlling the Desert Locust in North-West Africa in 1972.

16. Control teams and campaign managers had learned much during the 1941-1947 plague and introduced many new techniques. They established radio links to provide rapid communication between distant field teams and headquarters. Central Region managers extended their knowledge of Desert Locust distribution and behaviour to include Arabia and Ethiopia, two important areas previously largely unvisited. They built strategically placed bait factories and began to replace sodium arsenite with benzene hexachloride, a safer chemical more readily accepted by pastoralists. New chemical pesticides when sprayed or dusted promised to reduce the vast quantity of labour and transport required for baiting. Field trials to spray settled Desert Locust swarms from aircraft in 1944 and 1945 promised more effective and efficient control. Operational research improved control equipment and aerial spraying trials continued in 1947 against settled Red Locust swarms. Trials of a new technique for spraying flying swarms in Somalia had to be cancelled when none appeared owing to the decline of the Desert Locust plague. This recession was short and the 1950-1963 plague began before the control units were trained and equipped to use these new control techniques.

17. The lessons learned during the 1941-47 campaigns remain relevant today and include:

- Funding and consequently expertise diminish as plagues end.
- Strategically planned offensives are feasible but require all countries to cooperate.
- Control strategies need appropriate legislation. The wartime interstate coordinated campaigns required legislative changes to make governments and not landowners responsible for control.
- Campaigns must be planned well in advance, as they require much organization and international coordination.
- Annual costs of protecting crops in the invasion areas in Africa, the Near East and southwest Asia from 1941-1947 were high, £1 million [$45 .million][8] , but the scale, geographic extent and damage were small in relation to those of earlier plagues.
- Requests for supplies are often exaggerated and their eventual use is not always locust control.
- New control methods may demand profound changes in the organization of control and require the amendment of anti-locust legislation and practices.
- Improved techniques have to be actively promoted.
- Physical difficulties are easier to surmount than political ones.

[7] In 1962, Desert Locust Control Organization for Eastern Africa (DLCO.EA) superseded DLS and DLC
[8] $US equivalent updated from 1945 to 2006

- Some research opportunities exist solely during plagues.

18. An additional lesson soon to be learned was that anti-locust organizations take longer than locusts to mount a concerted attack. Whilst the international community were dismantling wartime organizations and developing civilian replacements, heavy rains fell in inaccessible parts of the interior deserts of eastern Arabia in the winter of 1948/49 initiating a new threat, which developed into a plague before adequate prevention measures were financed and implemented. In the spring of 1949, loose swarms invaded the United Arab Emirates (then Trucial Oman), Yemen and Aden Protectorates. Others drifted eastwards from the Emirates and reached Pakistan and India where they bred twice during the monsoon season so that numbers increased rapidly, and swarms formed. In the summer and autumn of 1949, gregarization also occurred in southwestern Arabia from which scattered locusts and swarms migrated to northern Somalia where heavy rains fell at the end of the year which from January 1950, gave rise to an additional focus of serious breeding. Eastern Region swarms migrated westwards in November and December 1949, most to the winter-spring breeding areas of Pakistan and Iran with a few reaching Oman. From February 1950, the heaviest spring breeding was in Pakistan and Iran, which unless successfully controlled, posed a severe threat to India and Pakistan during the summer.

19. Events from 1949 to 1951 highlight the fact that campaign managers need rapid access to reserve funds if they are to prevent plagues. Experts from India, Pakistan, Iran, Egypt, East Africa and UK met in Karachi in October 1949 (Ahmad, 1950), planned plague prevention measures and recommended that special efforts be made to mount survey and control in all affected regions. The limited finances available in spring 1950, however, precluded control teams, not yet fully equipped for aerial or ground spraying, from mounting campaigns on a scale sufficient to prevent a plague developing in the Eastern Region. Elsewhere, the progeny of widespread spring breeding in Arabia and Somalia spread the plague from Somalia to Kenya and from Arabia to Eritrea, the Sudan, Chad (then in part of French Equatorial Africa and westwards to Niger, Mali and Mauritania (all then in French West Africa) (Uvarov, 1951; Lean, 1965; Waloff, 1966).

20. Experts who reconvened in New Delhi in November 1950 were probably the first to ask FAO to provide technical assistance for Desert Locust control (Lean 1965) but no administrative mechanisms existed to respond until June 1951 when the Twelfth Session of the FAO Council recommended that the Director-General of FAO explore the issue. The Chief of the FAO Plant Production Branch was then able to attend the Advisory Committee of Desert Locust Survey in Nairobi in July 1951 and hold exploratory discussions with interested governments and organizations. FAO then hosted an International Conference in October 1951 to discuss Desert Locust control (Lean, 1965). Conference delegates believed that the withdrawal of the plague from the Western Region in mid 1951 offered hope of preventing its further development. They prepared lists of equipment, including aircraft and supplies for immediate distribution and for holding in strategic pools. Unfortunately, the estimated cost of $10.4 million [$68.4 million[9]] was not available from FAO or elsewhere and a third and final opportunity to check the plague was missed. The locust situation deteriorated seriously and the plague continued for 10 years (Lean, 1965). Conference delegates agreed that campaign activities needed to be coordinated throughout the Desert Locust area and recognized FAO as the agency best placed to achieve this objective. The Sixth Session of the FAO Conference held immediately after the conference accepted this coordinating role and the FAO Technical Advisory Committee on Desert Locust Control was established on which Uvarov acted as a consultant (FAO, 1952).

21. The FAO Technical Advisory Committee (TAC) gave advice on a wide range of technical and organizational issues including the coordination of the International Anti-Locust Campaigns in the Arabian Peninsula from 1953 to 1963 and on operating strategic reserves of equipment and pesticides. TAC also recommended developing a regional coordination system for plague suppression elsewhere. The Desert Locust committee structure evolved during this period. FAO established the Desert Locust Control Committee (DLCC) in 1955 and in 1957 the committees for coordinating campaigns on the Arabian Peninsula (established 1953) and in Eastern Africa (established 1956-1957) became DLCC Sub-Committees. FAO established three trust funds to supplement limited budgetary allocations for Desert Locust control from the Extended Technical Assistance and Regular Programmes, Trust Fund No. 01 was created in 1954 to help finance Arabian campaigns, Trust Fund No. 61 followed in 1957 to provide vehicle and insecticide reserves for campaigns in eastern Africa. Finally, FAO invited all affected countries to contribute to Trust Fund No. 90 established in 1958 to provide additional funds to

[9] $US equivalent updated from 1951 to 2006

finance some long-term aspects Desert Locust control to which. This Trust Fund met part of FAO's costs for the FAO/UNESCO[10] ecological survey of breeding zones, which later become a major activity of the United Nations Special Fund (UNSF) Desert Locust project that ran from 1960-1966 when further reorganization of the Desert Locust infrastructure and funding arrangements took place (see Para. 30).

Interim plague prevention strategy developed 1956-1963

22. The FAO Technical Advisory Committee (TAC) although concentrating on the means to suppress the 1950-1963 plague did not overlook their prevention in the longer term. Uvarov presented revised views on establishing 'an effective preventative policy of Desert Locust control' at the fifth TAC session (see Appendix 1 in Lean, 1965) and the committee recommended that a small Panel of Experts convene to consider the topic (FAO, 1955). The Eighth Session of the FAO Conference endorsed this recommendation and authorized the Director General to formulate a long-term policy of research and investigation designed to prevent Desert Locust plagues.

23. The resulting deliberations of the TAC and three Panels of Experts not only set criteria for suppressing plagues but for preventing them. The first Panel investigated the long-term policy of Desert Locust control (FAO, 1956). The other two studied the use of aircraft for Desert Locust control (FAO, 1959a) and the strategy of Desert Locust plague control (FAO, 1959b). These reports assembled a vast amount of technical and historical data for the first time and their findings greatly influenced subsequent developments at national, regional and international levels. The Panels' findings guided organizational changes, research and training, including that within the United Nations Special Fund (later UNDP) Desert Locust Project, 1960-1970 (FAO, 1968) which provided funding for much base-line data for future actions.

24. The Expert Panel, which met in 1956, concluded that Desert Locust plague dynamics were still insufficiently known to recommend a scheme for 'preventative control'. In particular, it was uncertain how plagues arose (FAO, 1956). One view favoured carry-over of swarms during recessions whilst another emphasized the role played by concentration of scattered locusts in areas temporarily made suitable by rains for population increase leading to gregarization. A combination of these processes was also possible. It was agreed, however, that it was no longer tenable to assume that Desert Locust plagues would arise in a few permanent outbreak areas. The 1956 panel and the subsequent panel on the use of aircraft (FAO, 1959a) advocated that countries adopt the following interim measures for preventing plagues.

- Maintain at least a reduced survey and control capacity during recessions.
- Control populations as they concentrate in areas suitable for gregarization as a potentially important plague prevention measure.
- Establish an effective reporting system, in all countries during recessions, to collect and exchange locust and concurrent weather data both for immediate use and as a basis for developing long-term plans.
- Centralize locust and weather information from the whole distribution area for mapping and analysis and the production of summaries and forecasts.
- Coordinate research required for developing plague prevention schemes.
- Develop contingency plans for rapidly reinforcing recession control units during emergencies with additional national or international support.
- Whilst not relying solely on regional aerial units, recognize that they might have a valuable role in reconnaissance and emergency measures despite anticipated administrative problems.
- Establish international or regional reserves of insecticides, transport and equipment at strategic locations.

Changes in knowledge, control and organizations 1949-1966

25. New control methods and tactics were developed during the 1949-1963 plague. The persistent organochlorine poison, dieldrin replaced the contact pesticide aldrin during the 1950s (Lean, 1965). As a result, spraying barriers or a lattice of dieldrin on to vegetation became an effective method of killing mobile hopper bands, which marched across one or more barriers and died after ingesting and accumulating sufficient sub-lethal doses. The development of ultra low volume (ULV) spraying

[10] United Nations Educational, Scientific and Cultural Organization

equipment also resulted in techniques for air to ground and air-to-air spraying of swarms. FAO encouraged the adoption of these more efficient methods but their social and economic implications aroused opposition in some areas. The new techniques removed an important source of employment and revenue for the vast local labour force used in baiting campaigns (Lean, 1965) and they were not finally replaced for another 50 years. Knowledge of the Desert Locust had also increased. Rainey (1951, 1963a) had demonstrated that swarms drift downwind towards areas of wind convergence where rain falls. The first attempts to quantify populations and control efficiency began during the 1951-1963 plague, particularly in the Central Region (Joyce, 1962b).

26. The recession in the 1960s coincided with a rapid reversion in the global wind systems to a regime which prevailed before 1890 (Lamb, 1979, Rainey et al., 1979; Roffey, 1982), a period containing a recession lasting from 1882-1888. The post 1960s weather was also notably drier (Fig. 4) and of the eight upsurges in the Central Region, four developed into plagues (Fig. 2; Chapter 2, Table 1). The plagues were shorter and less extensive than those before 1964 and, if one includes years when initiating rains fell, occurred in 1966-1969 (Bennett, 1974, 1975, 1976), in 1976-1979 (Roffey, 1982) and finally in 1985 or 1986-1989 (Chandra, Sinha and Singh, 1988; Gruys, 1994; Pedgley, 1989; Showler and Potter, 1991; Skaf, 1990) and 2003-2005. Nevertheless, the relative roles of improved control, drought and migration to unsuitable habitats in the diminished duration of plagues remained unclear. These need to be determined so that the true risk of plagues being generated by the weather can be separated from the effects of control in ending upsurges and plagues. Upsurges requiring extensive control occurred in 1972-1974 (Karrar, 1974; Hemming *et al*., 1979; Skaf, 1978; Venkatesh, 1975); in 1980 (Castel, 1982), in 1982-83 (Chandra, 1985), in 1992-94 (FAO, 1994c; Showler, 1995), 1995-97 (FAO, 1997, 1999a,c) and 1996-1998 (Cressman, 1998; FAO, 1997, 1999a,c)..

27. Rainey at a later stage (1989a) emphasized the potential importance of the change in weather patterns in the 1960s. He accepted that control must have contributed to curtailing upsurges as well as ending the 1950-1963 plague. He speculated, however, that the more restricted north-south movement of the inter-tropical frontal system, invoked by Lamb to explain observed changes in rainfall patterns, had also led to an abrupt change in the extent and severity of Desert Locust migrations. He expected a sudden reversal to pre 1960 wind patterns sometime in the future and urged the locust community to continue monitoring and making retrospective studies of the overall locust situation in order to update guidance on the long-term control policy. This suggestion is revisited in Chapter 3 as an important and unfulfilled aspect of evaluating possible variation in the Desert Locust threat.

28. The UNSF Desert Locust Project Team organized extensive training on locust biology and control from 1960-1966 as well as undertaking operational research under the following major headings

- Ecological survey
- Coordinated research at field stations
- Reporting and forecasting
- Training, exchange visits and fellowships
- Operational research including evaluating an inter-regional anti-locust aerial unit.

29. Findings of the Desert Locust Project team (FAO, 1968) and a study of populations preceding plagues (Waloff, 1966) helped resolve the controversy relating to plague initiation. The findings showed that plagues did not arise solely from swarms present during recessions but that gregarization was important and followed the build-up of non-swarming populations over several generations. Consequently, Roy (in FAO, 1968) concluded that plague prevention could not be the quick and simple matter of aeroplanes searching areas suspected of harbouring swarms as proposed for investigation by Joyce (1965). Instead, managers would need to organize ground and aerial monitoring of seasonal breeding areas and after rains, organize aerial surveys to detect habitats containing green vegetation and then at suitable intervals send ground surveys to search for 'dangerous' locust populations (FAO, 1968, paras 358-365).

30. Discussions from 1962 at TAC and DLCC meetings on financing the extension of the FAO/UNDP[11] Desert Locust Project led to changes to the structure and funding of plague suppression and prevention. FAO established International Trust Fund No. 161 (later 9161) for use as Governments' counterpart cash contributions to the project. At the same time, the existing FAO DLCC committee structure was modified and extended to the Eastern and Western Regions. A proposal to establish an

[11] Formerly the UNSF Desert Locust Project

FAO Commission for controlling the Desert Locust in the Eastern Region was discussed in 1962 and 1963 with the four Member Governments (Afghanistan, India, Iran, Pakistan) and in 1963 at the eighth session of the DLCC. In 1964, FAO council approved the text of the convention, the governments deposited instruments of acceptance, Trust Fund 123 was initiated and in December, the first session of the commission took place. Similarly, the FAO Near East Commission and its Trust Fund 409 was established in 1967 (FAO, 1967b). This commission subsumed the FAO Arabian Peninsular Desert Locust Control Sub-Committee, its member states were Iraq, Jordan, Kuwait, Lebanon, Saudi Arabia, Sudan, Syria, Turkey, UAR (Egypt), Yemen and the first session was held in 1969. The Desert Locust Control Organization for Eastern Africa (DLCO.EA) was established in 1962 to replace DLS and DLC as reported above (para. 14). An article in the DLCO.EA convention for a joint agreement to ensure close cooperation with FAO remained provisionally in force from 1963 until the formal agreement was signed in 1966. In 1964 and 1965, FAO discussed setting up a Desert Locust Control Commission for Northwestern Africa with the Governments of Algeria, Libya, Morocco and Tunisia. The proposal was not fully acceptable and instead, the FAO Northwest African Desert Locust Research and Control Coordination Sub-committee and Trust Fund 169 were established and held sessions from 1966 to 1972. Finally as reported above (see para. 15) OCLA (later OCLALAV) was established in 1958 as an independent intergovernmental organization outside the framework but in close contact .with FAO.

IMPLEMENTING PLAGUE PREVENTION, 1964-1999

Long-term strategy of plague control refined and adopted 1964-1969

31. The recession that spread across all regions between 1961 and 1963/64 offered opportunities for implementing the interim strategy of Desert Locust control and in 1966, FAO commissioned a study to examine the role that reporting and controlling important populations had in maintaining the recession. Populations from July 1963 to September 1967 defined as ‘important’ were reported bands and swarms, populations that were controlled and, potentially ‘important’ populations. The latter contained numbers estimated in the order of millions or, had relations in time and space to other important infestations or weather systems (FAO, 1967a). Rainey and Betts (1979) later wrote that this latter, category contained only two populations. One was an unconfirmed report of a swarm in Jordan; the other was groups and recently fledged isolated desert locusts and other acridids seen for at least 11 nights at light in Oman.

32. Evidence leading to two tentative conclusions was omitted in the working paper presented to the DLCC (FAO, 1967a). First, that controlling 'important populations' in India and Pakistan in the summer of 1964 may have prevented an upsurge similar to that of 1949. Secondly, that control could be assumed as cumulative because 'important populations' were not independent of each other[12] . FAO estimated operational costs for survey and control as a plague prevention measure as $350 000 [$1.7 million][13] in 1967. This estimate excluded salaries, capital costs and the special surveys being financed by FAO and the UNDP project in areas which otherwise would have remained unmonitored.

33. There was no suggestion from FAO or delegates that they considered a plague was imminent when this study was presented at the 11th Session of the DLCC in September 1967 (FAO, 1967b). Yet in December 1967, FAO issued the initial warning of this potential threat. In May 1968, a second warning revealed a deteriorating situation since, if further rains fell, breeding would be sufficient, unless checked, to give rise to a plague. The warning was heeded. Effective control occurred in Northwest Africa before the swarms matured and bred and 4000 km^2 of the Tihama in Saudi Arabia was blanket sprayed with dieldrin to destroy an incipient outbreak (Bennett, 1976): a control technique, which today would be considered environmentally untenable. This control, accompanied by poor rains ended the upsurge and short plague early in 1969.

34. The 13th session of the DLCC meeting (FAO, 1969) approved a long-term strategy of Desert Locust plague control. Preventing plagues was still the ultimate aim but the DLCC recognized that additional progress in five areas was needed to achieve this objective:

- improving survey techniques including the application of aerial photography and later (FAO, 1975a) remote sensing imagery;
- using the latest spraying techniques and applying concerted action against infestations particularly at times of year when their extent is restricted;

[12] see chapter 2 paragraphs 54-56 for a more detailed description of this study
[13] $US equivalent updated from 1967 to 2006

- concentrating field research on improving survey and control techniques;
- maintaining adequate survey and control resources at national, regional and international levels during recession as well as during plagues;
- financing initial emergency operations from a reserve fund.

Annual expenditure in the ten years to 1969 averaged just under $1million, [$5.5 million[14], 4.5 million][15] of which, UNDP and participating governments of the Desert Locust Project had contributed about half. Managers had, therefore, to anticipate a shortfall in funding the strategy from 1969 when the UNDP project was due to end.

35. FAO in the final reports of the Desert Locust Project (FAO, 1968; Roy, 1965) advocated survey and control in potential outbreak areas to prevent upsurges but recognized a number of obstacles that stood in the way of achieving this goal:

- maintaining support for locust units during long recessions particularly as buying equipment and pesticides require hard currency (Roy, 1965 p. 2);
- defining roles for national, regional and international anti-locust units that would achieve effective detection of gregarizing populations (Roy, 1965 Section 5);
- detecting non-gregarious, cryptically behaving scattered populations (FAO, 1968, para. 356);
- recognizing dangerous populations in each of the numerous habitat types in the absence of objective quantitative assessment methods (FAO, 1968, para. 357);
- providing adequate control capacity within the short timescale demanded when swarms form rapidly and simultaneously in several locations, as occurred in 1949, and which may characterize all upsurges (FAO, 1968, para. 360).

36. FAO Conference, in November 1969, extended the range of the FAO Working Capital Fund for the Control of Livestock Diseases to include financing initial control measures during Desert Locust emergencies. In any one biennium, grants of up to $500 000 [$2.2 million][16] could be released to prevent delays in responding to rapidly developing locust emergencies (FAO, 1970). The 1975 Conference changed the amount available each biennium to $700 000, [$2.1 million][17] and extended the cover to other migratory and introduced pests. A Panel of Experts on Emergency Action against the Desert Locust was set up in 1969 to enable the Director General of FAO to:

- decide whether and how funds should be allocated to meet emergency situations regarding the Desert Locust in a particular area;
- determine the nature and magnitude of threat posed by the plague and the danger of it spreading to other Member Nations;
- establish logistics bases and to estimate needs for insecticide, equipment and personnel.

37. The Panel met three times to consider Desert Locust issues. In 1971, they met to define events that could constitute an emergency (FAO, 1971). In 1978 and 1979, they reviewed emergency actions funded from the reserve during the previous year and planned further responses to the 1977-1979 plague (FAO, 1978, 1979). The Panel was not consulted during the 1986-1989 emergency and was abolished in 1993. Instead, in August 1986, the Director-General of FAO established an Emergency Centre for Locust Operations (ECLO) as a temporary focal point to coordinate national, regional and international actions, to maintain direct contact with donors and affected countries and to mobilize the necessary finance and supplies for the grasshopper and locust campaigns in progress. The Director of the Plant Production and Protection Division was given extensive delegated authority to permit rapid decisions and to expedite procurement and delivery of supplies. ECLO operated until 31 December 1990. Other mechanisms for financing the initial stages of an emergency are discussed in paragraphs 58-61.

[14] $US equivalent updated from 1960to 2006
[15] $US equivalent updated from 1969 to 2006
[16] $US equivalent updated from 1969 to 2006
[17] $US equivalent updated from 1975 to 2006

Sustaining plague prevention capacities

38. The 1977-1979 plague focused attention on the gap between the theory and practice of preventing plagues and in 1979, the DLCC recommended that an evaluation be made of the minimum structure able to prevent plagues (FAO, 1979). The reports that FAO commissioned were worded rather differently, in that Roy, Ashall and Popov were asked to assess the resources required to prevent seasonal upsurges developing into a plague in the Central Region (FAO, 1984b). Roy (1985 p.13) in his findings succinctly encapsulated the extent of the problem, “At this moment, the control framework is not viable. One is tempted to talk of a dangerous fiction”.

39. Popov (in Roy, 1985) delimited potential recession breeding grounds in the Central and Eastern Regions where control to prevent plagues might be required. He provided frequency of infestation maps (1964-1977) to denote important areas and indicated potential seasonal population movements. Ashall (1985), in a related study, used control in the region for the previous 20-year period, (1963-1982) as the basis for his recommendations. He envisaged a two-stage plague prevention system in which countries would maintain adequate control capacities for locating and controlling gregarizing populations in the early stages of an upsurge. In the second phase, countries would use the early warning system to initiate the mobilization of regional and international reinforcements for the larger campaigns that occur later in an upsurge. Roy, drawing on the findings of Popov and Ashall, reviewed the development of three previous upsurges and presented a general outline of an early warning and plague prevention strategy for the region. These issues are revisited in Chapter 4, which looks at evaluating preparedness to prevent plagues.

40. The three studies were reviewed by nine consultants (FAO, 1985b) who, despite the existing lack of preparedness and finance, reported optimistically that plague prevention was now possible and that the key to success lay in effective national teams. This optimism was partly based on work rates that assumed the continued use of dieldrin for barrier spraying despite growing concern over its environmental impact and potential replacement by less persistent insecticides. They presented an imprecisely defined guide indicating which recession populations could safely be left uncontrolled. They estimated the number of teams required by each country to implement the strategy. The estimated cost of additional equipment and pesticide to make national teams and DLCO.EA operational was $1.8 million [3 million][18]. The consultants urged FAO to seek international finance mainly for capital items but also for operational costs arguing that unless all affected countries participated, plague prevention would fail and that prevention is better than cure. They recommended FAO to direct Desert Locust International and Regional Trust Funds towards training and strengthening national survey and control teams and urged affected countries to allocate an autonomous budget to finance the operational costs of these teams.

41. No significant improvements in funding and operational structures were in place when following heavy widespread rains in sub-Saharan Africa in 1985 initially grasshoppers, then in 1986 the African Migratory, Red, Brown, Tree and Desert Locusts threatened to reach plague proportions. In response to these developments, FAO called Emergency Donor Meetings (FAO, 1986b). Affected countries re-instated steering committees for local officials, FAO Country Representatives and donors to coordinate requests for aid. Creaking infrastructures, streamlined to reflect recession workloads, could not respond to the sudden upsurge. Institutions, had forgotten much knowledge hard won in the 1950s and 1960s and retired but experienced personnel as well as consultants with little or no locust experience came to assist young plant protection specialists facing a plague for the first time. Again, donors moved from development to emergency funds and provided approximately $300 million [$462 million][19] assistance to suppress outbreaks of grasshoppers, Desert Locust and four other species of locust from 1986 to 1989.

42. Three factors were involved in the rapid collapse of the plague in late 1988 and early 1989, but their relative importance is uncertain.

- Large scale spraying in 1988 and 1989, particularly in Saudi Arabia and Morocco.
- Large-scale emigration of swarms into the Atlantic in October and November 1988.
- Failure of breeding due to lack of rains in the winter of 1988/89 and to an unknown cause in the summer of 1989 in the Sahel (Gruys, 1994)

[18] $US equivalent updated from 1985 to 2006
[19] $US equivalent updated from 1988 to 2006

43. The above review of events up to 1989, show that locust organizations lacked an adequate combination of experienced staff, equipment, funding and administrative mechanisms to respond sufficiently swiftly to prevent intermittent upsurges and short-lived plagues developing. Subsequent upsurges are briefly described in Chapter 2. The long-term plan adopted in 1969 anticipated such failures until a five point corrective plan (para 34) was successfully implemented. Recent upsurges and plagues may indicate that Roy's (1965) obstacles still exist (para. 35) or that the five-point plan has still to achieve and maintain the amount of preparedness required to prevent plagues. On the other hand, studies of events in the intervening 30 years suggest that the circumstances under which plague prevention is achievable may need to be reconsidered and redefined.

Plague prevention tactics for outbreak and upsurge populations

44. A major complication when considering the Desert Locust control strategy is that many authors champion a 'preventive control strategy' but fail to state what they are trying to prevent. It is clear that initially Uvarov (1951, para. 175-188) expected Desert Locust plagues to begin in permanently infested outbreak areas so that preventing outbreaks, that is the emigration of swarms, was a feasible option. Later, he rejected this hypothesis (1951, paras 220-223) and it was officially accepted in 1956, that permanently infested outbreak areas did not exist for the Desert Locust. Consequently, classical plague prevention - stopping swarms escaping from permanently infested outbreak areas - ceased to be an option and the objective became to prevent outbreaks or to prevent, suppress or eliminate upsurges (Fig. 5). In practice, all four tactics are applied sequentially as an upsurge develops and locusts migrate between successive seasonal breeding zones. Echoes of the original view may persist in the view that outbreak prevention - the control of gregarizing populations early to prevent swarms as an upsurge begins - will prevent further plague cycle developments. Figure 5, used to discuss plague prevention in Bamako, (Posamentier and Magor, 1997) has been modified to include upsurge suppression, the culling of gregarizing and gregarious sections of the population early in an upsurge, as well as upsurge elimination, that occurs as an upsurge ends when most or all infestations are gregarious. All locust emergencies, since 1965, have ended at this stage without the incipient plague becoming fully established.

45. From analysing observations on recession populations between 1963 and 1967, Roffey, Popov and Hemming (1970) concluded that outbreaks, upsurges and plagues belong to a single continuum. Gregariously behaving populations were frequently observed in recessions during non-upsurge periods but were smaller and less dense than those typically found in plagues and frequently dispersed. The largest swarm seen between 1963 and 1967 was 3.7 km^2 (Hemming et al., 1979). Considerable post-gregarization increases are needed during an upsurge before such populations reach the sizes and densities characteristic of swarms observed in the 1951-1963 plague. Those being controlled by DLS aircraft from 1953 to 1960 whilst held each autumn in the wind convergence zone in northern Somalia together measured between 200 and 1300 square miles (500-3500 km^2) at densities ranging from 20-150 million per km^2 (Joyce, 1962a).

46. The vast, sparsely inhabited recession area and the seasonal mobility of the Desert Locust present major problems in establishing the population dynamics that precede outbreaks and upsurges. Roffey (1965, 1981) summarized findings on these gregarious and low-density populations and noted that the pest's mobility had prevented multigenerational studies. Consequently, during upsurges and early plague analyses, intergenerational distributions have been and may always have to be based on known swarm movements providing plausible but circumstantial evidence of migration between the scattered and gregarizing infestations seen by survey teams

47. Bennett's (1974, 1975, 1976) detailed study of the 1965-1969 upsurge and short plague revealed evidence suggesting that plague prevention control might always be protracted when locusts encounter habitats favourable to breeding for a number of successive seasons once outbreaks have occurred. She identified four initially separate upsurge sequences in 1966 and identified interregional migrations of adults between them from the autumn of 1967 onwards. Two sequences started on the Arabian Peninsula, a third linked the Red Sea coasts with the interior of the Sudan and the fourth linked the mountains of Tibesti and southern Algeria with each other and with the Sahel. The main sequence started in southwestern Arabia where heavy rains fell between March and May 1967. and was traced for seven generations as it developed in spring 1968 along the Red Sea coasts and the interior of Saudi Arabia, in summer 1968 in the interior of the Sudan before migrating to Morocco and the Red Sea in late 1968 and early 1969 (Fig 6a). The initial population build-up in southwestern Arabia was largely

unreported and continued when unusual monsoon rains fell there in July and August (Figs. 6a, b, FoF_1; Fig. 7c, d). Bennett found that the gross infested area which needed to be searched to find the reported infestations, first expanded very rapidly from 20 000 km^2 to over a 100 000 km^2 as population numbers increased from less than 1 x 10^9 to 6 x 10^9 (Figs 6a, b, F_2-F_4). Subsequently, the gross infested area shrank dramatically, as the locusts became increasingly gregarious due not only to aggregation and subsequent concentration but also to emigration. Half the population moved eastwards from the interior of Saudi Arabia (Figs 6a,b, F_4) and left this sequence which was only partially compensated by immigrants from Somalia amounting to about 50 km^2 (Fig. 7f). The estimated gross area infested by bands within the main sequence then fell from 10 000 km^2 to 5 000 km^2 as numbers continued to grow from 18 x 10^9 to 30 x 10^9. It was at this point that aerial campaigns and large-scale barrier treatment of bands began, numbers fell and the sequence ended (Figs. 6a, b, F_5 F_7).

48. Bennett (1974, 1976) used the main upsurge sequence and three other campaigns to evaluate the control strategy (see Ch. 2, paras 76-80 for details) and emphasized two results that affected control success. First, the infestation area involved falls when populations are gregarious and secondly control methods should be appropriate to the scale of the infestations. She concluded that controlling the gregarious and gregarizing portions of early upsurge populations could prevent swarm formation but left sufficient unsprayed scattered locusts to continue the upsurge. She rejected spraying the scattered locusts citing as evidence the early 1969 campaign in which 4000 km^2 of the Saudi Tihama was blanket sprayed to kill 150 million locusts, the equivalent of a 3km^2 swarm whereas, aerial spraying the same quantity of pesticide in 1968 had eliminated swarms that together totalled about 200 km^2. She concluded that the aerial campaigns when all populations were gregarious had played a major role in the short duration of the plague. Complementary causes were poor rains in a number of areas: first in the Eastern Region and in southeastern Egypt in summer 1968, then in Yemen in late 1968 and finally, early in 1969, rains were poor on the Red Sea coasts and swarms migrated to unfavourable habitats in the highlands of Ethiopia. She attributed egg and early instar hopper mortality in Egypt autumn 1968 to unrecorded parasitism or predation, an alternative explanation is that females had acquired sublethal doses of dieldrin, a known cause of eggs and hatchling mortality (Watts, 1969).

49. Bennett (1974, 1976) plausibly suggested that the atmospheric circulation pattern, associated with widespread winter and spring rains preceding upsurges, is not present in other years. If substantiated, it follows that controlling outbreaks in other years would be unnecessary in terms of plague prevention. Bennett continued that the only way to avoid 'unnecessary' control, as future rains allowing upsurge continuation were unpredictable, would be to delay control, except for crop protection, until the upsurge was well developed. Advantageously, at this point, the fully gregarious populations would be concentrated into a smaller area and marching hopper bands could be treated by barrier spraying. Bennett introduced the term 'upsurge elimination' (Fig. 5) for this tactic which runs counter to the general rule that early action minimizes problems that develop and grow over time.

50. Bennett (1976) raised three objections against waiting to control fully gregarious populations. First, control teams might be unable to treat the larger infestations that would result. Secondly, the gross area requiring treatment would diminish but the area to be searched to find them might not. She stressed this point because searching for infestations in a seasonal breeding area can be costlier than controlling them. Bennett (1976) concluded that aerial control against the first fully gregariously behaving generation, offered the best combination of method and timing to prevent a plague in the 1966-1969 emergency but was unable to establish whether bands or swarms were the better target In addition, she concluded that implementing upsurge elimination would create a series of practical but very real difficulties. These ranged from the need for beneficiaries to jointly fund upsurge elimination activities, protests if large populations were left untreated and the danger of crop losses, which were reported as slight between 1966 and 1969.

51. Campaigns in areas where swarms regularly become concentrated in convergence zones greatly assisted plague prevention. Such areas included northern Somalia between June and October and south of the Atlas Mountains in Morocco in the autumn. Joyce (1965) had speculated that control resources might in the future be concentrated in these and other areas of wind convergence to attack incoming swarms. Bennett could not gauge from a single upsurge the opportunities afforded to attack swarms concentrated into small areas should upsurge elimination be implemented. She concluded, however, that such a tactic would place a high burden on the countries concerned and would require a sophisticated and internationally funded aerial strike force of the type available during the Desert Locust Project. This aerial unit was not retained when the project ended as it could neither achieve, at short notice, the inter-regional and inter-country mobility needed to play a major role in anti-locust control nor obtain

reliable information on locust populations during recessions, a task suited to ground survey (Roy in FAO, 1968). Courshee (1965) had previously argued that controlling gregarious infestations maximized efficiency in terms of kill per unit of insecticide and MacCuaig (1970) had begun to discuss the best time in an upsurge to start plague prevention measures. Two factors encouraged the targeting of swarms, first, band zones are larger than the area of swarms they produce, and secondly, bands infest only 2-5 percent of such zones (Courshee, 1965, 1990; FAO, 1968; Symmons, 1992). Symmons (1992, 1997), and Posamentier and Magor (1997) emphasized the logistical, economic and environmental cost implications associated with eliminating an upsurge at an earlier stage.

52. Symmons (2003, 2004) provided simple models for managers to investigate the potential impact of control capacity maintained during recessions would have on the bands, groups and loose swarms that form "sprayable targets" as an upsurge begins. In addition, to determine the optimal method of destroying populations first, as the threat of a plague becomes imminent and secondly at the 'upsurge elimination' stage when all populations are behaving gregariously. Symmons concludes that detecting and controlling a high proportion of outbreaks in the early stages of an upsurge is beyond the capacity of ground control teams maintained during recessions and that aerial control rapidly becomes the only option. He also suggests that swarm control is the most efficient and feasible method of population reduction.

53. Campaign managers advocate retaining the interim strategy of controlling gregarizing populations given the reservations attached to upsurge elimination (FAO, 1969). Some ultimately expect to achieve outbreak or upsurge prevention (Ould Babah, 1997; Showler, 1997). Others (Lecoq et al., 1997; Lecoq, 2001; 2003) advocate intervening from the outbreak stage to prevent the problem worsening and speculate that early control of the 1988-1989 plague was a major factor in its swift decline. They fear that the unculled populations associated with upsurge elimination might be too large to return rapidly to recession levels, a doubt also expressed by Bennett (1976). They also maintain that band treatment is easier and more certain than waiting to control swarms that migrate. Lecoq, Duranton and Rachadi (1997) note that control has never been simultaneously implemented throughout the Desert Locust area acknowledging that this is sometimes caused by insecurity making key breeding areas inaccessible, to which should be added lack of funding to maintain preparedness and to mount large early upsurge campaigns. This difference of opinion on the tactics to adopt remains unresolved and in turn, leads to different perceptions of the success and feasibility of the strategy.

54. Only Bennett (1976) has related the presence and eventual absence of partially gregarious insects in populations and the corresponding size of infested areas as a plague upsurge develops. A characteristic of plague upsurges is sequences of above average rains lasting for several successive generations that allow populations to increase and become more gregarious (Waloff, 1966). This characteristic suggests that destroying initial gregarizing populations and not those at lower densities will not end an upsurge whilst the sequences of favourable rains in complementary breeding areas continue. Nevertheless, continuously monitoring and controlling sprayable targets among these populations with appropriate means is a way to provide evidence for testing the role played by early control in the success of upsurge elimination and the rapid decline of incipient plagues since 1968.

Table 1. Visibility of pre-outbreak locust populations (after Popov, 1968)

Rains	Numbers	Observations
Pre-November 1966 rain	n	F_0 locusts not noticed
Post November 1966 rain	n x 10	F_1 locusts not noticed
Post April 1967 rain	n x 100	F_2 locusts seen only by trained observers
Post June 1967 rain	n x 1000	F_3 Locusts seen by all travellers

55. Roy (in FAO, 1968) noted that the cryptic behaviour of scattered populations was an obstacle to recognizing whether or not they are sufficiently large to gregarize rapidly. Popov (1968) pieced together a plausible reconstruction of events in Oman at the beginning of the 1966-1967 upsurge from travellers' reports, which indicate a plausible timeframe when initial populations are sparse. He assumed very few locusts were present to breed after the initial rains in November 1966 but that a plausible tenfold multiplication for each subsequent generation resulted in a substantial population increase. This high multiplication rate is consistent with the few multiplication rates derived from fieldwork in Eastern Africa (FAO, 2003b; Joyce, 1962b; Stower, 1962a). Popov also suggested that locusts would be noticed by few travellers until gregarization occurred which in this instance was the F_3 generation (Table 1).

56. One or two locusts were seen during the F_2 generation and a geophysical party observed small groups of the F_3 generation in the autumn of 1967. Popov surmised that multiplication occurred over at least three generations before gregarization enabled travellers to notice them. Analysis of reports from locust survey teams suggests that as an upsurge begins they too fail to detect and report the population increases occurring within large expanses of vegetation. Once concentration and gregarization begin, however, the widespread and substantial increases in numbers suddenly become apparent. In this context, Stower (1962b) warns that population estimates produced from transect counts are consistently 25-50 percent lower than those made using more accurate methods. Transect counts are used, however, because they are quick to do and allow teams to sample a much larger area than the more accurate methods would. There are still no objective quantitative methods of assessing ‘dangerous’ populations in different environments, another of Roy’s obstacles to initiating control aimed at preventing upsurges (para. 35). To date, although it is possible to make qualitative statements that plagues start with heavy and appropriately timed rains in complementary breeding areas, it is not possible to provide reliable quantitative parameters for such rains or to provide reliable forecasts of them and the location of locusts a season ahead. This topic is discussed in Chapter 3 as it affects when early warnings and forecasts can be made.

Financing plague prevention emergencies during upsurges

57. Hewitt (1990) commented that the real problem facing operations of any kind during recessions is that governments, while responding to crises, never anticipate them. In addition, the post-colonial period saw many new or restructured organizations and staff changes. One result was that plague prevention, originally conceived as an international activity, and later a regional one, was modified in favour of primarily using national units. A regional organization, the Desert Locust Control Organization for Eastern Africa (DLCO.EA formerly Desert Locust Survey), has a mandate to assist its Member States[20] during emergencies (Desert Locust Survey, 1963).

58. Lean (1965) records that up to 1960, FAO’s Desert Locust programmes were funded from the Organization’s Expanded Programme of Technical Assistance (EPTA), a grant of $150 000 [$753 640][21] and three Trust Funds. The latter were set up between 1954 and 1958 to help finance international aspects of the Arabian Campaigns, to provide regional reserves of vehicles and pesticides and to fund some aspects of long-term control. Lean reports, however, that the voluntary contributions to the Trust Funds were limited and diminished with time. Strategic stores of reserve equipment and pesticide were also set up but were drawn down rapidly during the severe locust years of 1952 to 1954. Critics argued that reserve stores encouraged a false belief that FAO had unlimited funds to disburse equipment and insecticides (Lean, 1965). In 1960, the United Nations Special Fund (UNSF later United Nations Development Programme) with contributions from most affected countries financed the Desert Locust project

59. Gurdas Singh (in FAO, 1970) noted that the locust situation deteriorated seriously whilst FAO was mobilizing money, technical staff and material to combat the upsurge that developed into a short plague (1966/67-1969). Gurdas Singh stressed that a major aspect of the UNDP (SF) Desert Locust Project had been the accumulation of funds for an emergency reserve but that these funds together with those accumulated from unallocated balances of Regional Commissions were in no way adequate for dealing with an emergency. Accordingly, the FAO Working Capital Fund (see paras 36 and 37) was extended to include Desert Locust emergencies.

60. Skaf (1986) and Skaf, Popov and Roffey (1990) concluded that plague prevention was also vulnerable to complacency brought about by what they termed ‘the long recession from 1964-1984’ even though this period contained at least one if not two upsurges that became short plagues. Institutional memories are particularly vulnerable under these circumstances and a new generation of managers with no experience of large plagues moved finance from locust control to more pressing agricultural needs. Financial support by Member States for the regional control organizations, Organisation commune de Lutte antiacridienne et de Lutte antiaviaire (OCLALAV) and DLCO.EA declined in the absence of frequent plagues. External donors interpreting this as lack of interest in regional control rather than a response to financial constraints also began to withdraw support. One consequence was that in the 1970s, UNDP, FAO and some donors supported the merger of locust control within plant protection services although such emphasis was unlikely to provide adequate

[20] DLCO.EA Member States are Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan, Tanzania, Uganda
[21] $US equivalent updated from 1953 to 2005

survey in Desert Locust gregarization areas, most of which are hundreds of kilometres from the nearest non-subsistence crop areas (Skaf, 1986).

61. Emergency stocks of equipment and pesticides envisaged by the 1969 strategy proved counter-productive in light of infrequent use and changes in perceptions of pesticide safety. A potentially better option was the pesticide bank used in the 1985-1989 emergency. The Emergency Fund required by the 1969 five-point plan was set up and later abandoned in favour of mobilizing funds as required. Certainly, funds have materialized during emergencies but it is less certain if they are either available or disbursed early enough, or if adequate funding exists without international support to maintain adequate monitoring and early upsurge control as envisaged by Ashall (1985). No comprehensive study on the financing of Desert Locust control exists to gauge the effectiveness of each modality used to supplement national anti-locust budgets. Such a study is long overdue.

Applying the latest survey and control techniques

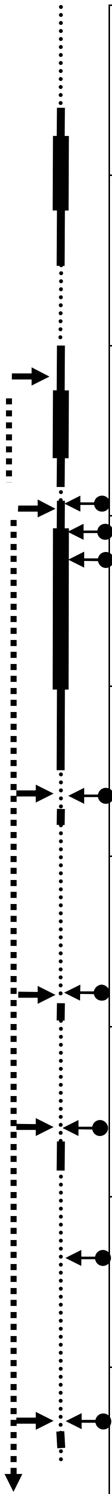
62. This review shows that parts of anti-locust technology change during and shortly after each plague but that additional funds needed to re-equip and train teams do not arrive until after the next emergency has started. In the 1950s, teams were not adequately equipped for ground and aerial spraying (see para. 19). From the 1970s, dieldrin was being replaced by non-persistent contact pesticides but acceptance of the resultant more expensive and logistically harder control method was still being resisted during the 1985-1989 upsurges and plague (Skaf, Popov and Roffey, 1990). Control teams need regular training for new members to learn current techniques and for all to adopt new anti-locust measures. Details of control methods and tactics need to be available for this training and to train the reserves called upon during emergencies. Agreement on essential principles of ULV spraying (US-FAO, 1989) were needed but not realised until after the 1985-1989 emergency.

63. The increased awareness of potential environmental pollution by chemical pesticides during and after the 1985-89 upsurge and plague led to funds becoming available to develop biopesticides, for studies to test the effects of locust campaigns on human health and on non-target fauna. Other, projects were commissioned that introduced geographical information systems (GIS) for managing, analysing and mapping locust, weather and habitat data used in the early warning system. These projects and their potential impact are described in chapter 5. At the same time, farmers were being encouraged to practice integrated pest management (IPM) so that future control campaigns will need to respond to crop protection protocols associated with IPM. EMPRES, operational in the Central Region since 1997, was designed to strengthen anti-locust teams but had not become fully funded and operational when an emergency arose in the Western Region in 2003.

2. RECESSION AND UPSURGE POPULATIONS 1920 TO 1999

J I Magor

BRIEF OVERVIEW[1]



1920 to 1929	**1929:** ALRC established to map 1926-34 plague, determine its origins and means of suppression. **1926-27**: Plague upsurge started independently in Central and Eastern Regions. **1927**: Swarms invade Western Region in October. **1928-31**: Peak years of the last plague without monitoring and coordinated control organizations.
1930 to 1939	**1934-38** International conferences: centralize locust data, plan research and plague prevention. **1932:** Plague ends in Eastern Region (drought) and Central Region South (cause unspecified). **1933**: Plague ends in Central Region North (poor summer breeding 1932; none, spring 1933). **1934:** Plague ends in Western Region. **1935-39**: Outbreaks and short upsurges occur in recession. 1939, upsurge starts in Western Region.
1940 to 1949	**1940**: Upsurge starts in Eastern Region (cyclone Oman + good monsoon). Swarms reach C Region. **1941**: W Region spring dry but upsurge builds in E and C Regions and swarms invade W Region. **1942-45:** Peak plague, campaigns aim to reduce population levels in all infested areas. **1946-48**: Plague ends E Region (swarms to poor habitat), 1947 C Region (dry), 1948 West (dry). **1949**: New upsurge starts Central and Eastern Regions good rains Red Sea, Oman, Indo-Pakistan.
1950 to 1959	**1949-51:** Appeals fail to produce funds and resources for early plague suppression campaigns. **1950**: Eastern and Central Region upsurge grows. Swarms augment smaller Western upsurge. **1951-59**: Plague peak but regional recessions occur (1951-53 West; 55-58 East 1956-57 Centre). **1951-59**: Aerial control of swarms and barrier control of bands reaches scale to suppress plagues, although other causes augment these measures (see Table 3).
1960 to 1969	**1960-63**: Plague ends: West (60); most Central South (61); Central N&S (62) Eastern Region (63). **1964-67**: Monitor & control start in recession area breeding zones as a plague prevention measure **1966-mid-68**: Rains initiate and maintain upsurge in Central and Eastern Regions. **1967**: Plague Alert in December is the first issued immediately an upsurge apparent. **Mid 68-early 69**: First plague with no peak years before decline: causes control and poor rains.
1970 to 1979	**1973-78**: Early Warning System modified. Bulletins from 5 regional offices, FAO writes overviews. **1972-74**: Rains do not sustain Central Region upsurge, or Eastern & Western Region outbreaks. **1974-76**: Analysis suggests control leaves scattered insects to continue upsurge unless rains fail **1977-79**: Upsurge and plague. Finances, techniques & organization for prevention cause concern. **1978-79**: Plague ends rapidly once resources delivered at plague onset stage.
1980 to 1989	**1980-Oct-85**: Rain curtails upsurges in all three regions. Nov 83 no gregarious populations (dry). **1985**: Training and equipping plague prevention teams recommended but not implemented before Rains: Brown, Red, Migratory and Desert Locusts gregarize and grasshopper outbreaks occur. **1986-89**: Upsurge in Western and Central Regions develops to plague in centre and invades west. **1986-89**: Plague declines rapidly at onset stage (control + dry weather) once assistance delivered.
1990 to 1999	**1990**: Short upsurge Eastern Region **1992**: Upsurge on Red Sea Coasts. Lack of resources and armed conflict impede early reporting. **1993-94**: Upsurge spreads to Eastern and Western Regions. Ends Centre and East 1993; West 1994. **1994**: FAO and donors establish EMPRES in Central Region to improve plague prevention capacity **1994-98**: Upsurges occur in all regions but not sustained to plague levels.
2000 to 2006	**2003-05**: Upsurge and short plague occurs, which not part of this reviewed. **2003:** Alerts and appeals start as upsurge threat becomes apparent in Western and Central Regions. **2004-05:** Plague in West invades centre. Plague ends rapidly when full assistance delivered. **2006:** EMPRES Western Region is financed and fully operational. Issues relating to developing sustainable plague prevention are summarized in chapter 6.

[1] Recession & upsurges (dots), plague onset & decline (narrow line) and plague peak (broad line). Bulletins issued (squares) Initial plague alert (arrows). Appeals (arrow + circle)

INTRODUCTION

1. A strategy for preventing plagues requires an understanding of population numbers, their seasonal distribution and downwind displacements. Consequently, this chapter provides an analysis of pre-plague populations of the Desert Locust in the period 1920-1999. The text describes when and where gregarization led to upsurges, their course and which developed into plagues. The terms, 'recession, outbreak, upsurge'[2] indicate pre-plague fluctuations in Desert Locust population numbers and changes in behaviour that mark stages in the pest's population dynamics. The stages are not synchronous throughout the recession area and the direction of population change is reversible at any stage in the continuum from deep recession to major plague. Waloff (1966) warned that no quantitative values of recession and plague fluctuations exist. The indices available then, and now, are reported changes in the geographical extent of affected areas and numbers of locust sightings within them. Waloff's provisional definitions (1966, 1976) reveal further complications. Those for 'incipient plague', 'plague upsurge', 'upsurge' and 'plague'[3] require information from complementary breeding areas over a number of generations. In addition, the boundaries between terms are subjective and imprecise so that one person's upsurge may already be another person's plague.

2. Waloff (1966) analysed recession populations for the period 1920-1964 to determine whether plagues started from swarming populations persisting throughout recessions or whether increased numbers and gregarization among non-swarming populations was involved. She found intervals without swarming populations lasting through several successive generations in each region. Moreover, she could not demonstrate any unequivocal evidence that gregarious populations persisted between plagues even when she considered feasible inter-regional migration of swarms. She also suggested that recession populations gregarize and dissociate frequently as their numbers fluctuate around a relatively low level keeping them mainly in the unstable *transiens* phase. Waloff also considered the practical implications of her findings for early warning and control systems. Her results lie behind decisions to monitor populations regularly during recessions.

3. Waloff divided the period from 1920 to 1964 into recession and plague years and sub-divided plagues into three: periods of plague upsurge and geographical spread, of peak development and of decline. Symmons and Cressman (FAO, 2001a) divided years from 1861 to 1999 into 'recessions, upsurges, plagues and declines'. Their table shows that plagues were shorter after 1964. They also identified four upsurges after 1970 that did not develop into plagues. Waloff also describes upsurges during recessions that did not develop into plagues and shows control to limit gregarization and against outbreaks and upsurge populations occurred during these periods. Terms used by Waloff to describe populations show that she considered 'outbreaks' as being within the broader term 'upsurge' and that both belong within a major category 'recession'. She used the term 'plague upsurge' to cover sequences preceding a plague, a term that she applied retrospectively. Roy (1985) used three plague upsurges (1948-1949; 1967-1968, 1977-1978) to illustrate the logistics and coordination issues faced by control managers, in preventing plagues when each of them is responsible for controlling only a part of the locust population. Waloff and Roffey (1981) provided a more detailed account of these same plague upsurges, which are among the best documented. Nevertheless, earlier upsurges are described in this chapter because they illustrate plague initiation and decline before control measures became effective and when rainfall averages were higher.

4. For this chapter, the years 1920-1999 were divided into recession and plague periods and Table 1 was updated to 2005 for this revision. Waloff's three plague sub-divisions were kept to place recent

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[2]*Recession*: Period between plagues. Period without widespread and heavy swarm infestations.
Deep Recession: The species reverts to *transiens* and solitarious phases and most reports of swarming populations refer to small and often transient assemblages of adults or small-scale hopper infestations in restricted areas.
Outbreak: A marked local increase in locust numbers by concentration, and /or multiplication accompanied by gregarization which unless checked leads to the formation of hopper bands and swarms.
Upsurge: A period in which a very large increase in locust numbers initiates contemporaneous outbreaks followed by two or more successive seasons of *transiens*-to-gregarious breeding in complementary seasonal breeding areas in the same or neighbouring Desert Locust regions
[3]*Plague upsurge*: An unbroken succession of gregarizing and/or gregarious populations, increasing in size from generation to generation and occupying an expanding area.
Incipient plague: The production of two or more successive generations of *transiens*-to-gregarious populations that remain small-scale and usually confined to neighbouring complementary areas.
Plague: Widespread swarm and hopper band infestations occurring in the same year and in each of several successive years. Plagues affect extensive areas and generate large numbers of sightings.
Major plagues arise in, or rapidly affect more than one region.

plagues in context. A pragmatic approach proved necessary for identifying pre 1960s upsurges because data collection was neither systematic nor regular before the 1930s and did not occur in many key recession countries until the 1940s or later. In addition, routine monitoring of recession populations was absent until the 1960s and is still incomplete. In an upsurge, population numbers increase, locusts gregarize and move between complementary breeding areas. Unfortunately, Waloff could not always deduce links between successive generations with confidence. For this study, links between complementary breeding areas were assumed if swarms or unexpectedly large numbers of immigrants arrived in a breeding area.

Table 1. Desert locust plagues and recessions 1920-2005 (after van Huis et al. 2007)

Recessions	Outbreaks and upsurges during recessions			Plagues		
	Western Region	**Central Region**	**Eastern Region**	**Spread**	**Peak years**	**Decline**
1920-1925	1922-1923		1922-23			
	1925	1925	1925	1926-1927	1928-1931	1932-1934
1934-1939	1935	1934-1935	1935			
		1936-1938				
	1939-1940	1938-1939		1940-1941	1942-1945	1946-1948
1948-1949		1948	1948	1949-1950	1951-1959	1960-1963
1964-1966			1964			
	1967	1966-1967		1968	none	1968-1969
1971-1977	1974	1972-1973	1973-1974			
		1977	invaded 1978	1978	none	1978-1979
1980-1987	1980-1982	1980, 1981,				
		1982-1983	1982, 1983			
	1985-1986	1985-1987	1986	1987-1988	none	1988-1989
1989-2002	1993-1994	1992-1994	invaded 1993			
	1994-1997	1994-1996				
		1996-1998	1997			
2003-2004	2003-2004	2003-2004		**2004**	none	**2004-2005**
		invaded 2004				

Note: Years in bold font denote that FAO continued to use the term upsurge for these periods

5. This chapter contains brief descriptions of populations in the Central Region during each recession since 1920. The geographical area was extended to all regions for each plague upsurge and spread period and was extended earlier if inter-regional displacements were suspected. Peak plague years are not described. Accounts of plague declines were included to draw attention to the contribution that drought and migration to hostile habitats may contribute to the effect of control in ending plagues and upsurges. A summary precedes each plague upsurge and decline section and notes suggested causes of each plague upsurge and its decline as well as significant organizational changes. The main sources used to identify and describe outbreaks, upsurges and the rains associated with their onset and decline are cited at the beginning of each account. Sources for additional descriptions are cited within the text. The latitude and longitude of towns but not regions is given the first time they are mentioned. Appendix 5 is a consolidated gazetteer.

PLAGUE INITIATION AND DECLINE IN THE CENTRAL REGION 1920-1963

Data source 1920-1963

6. Waloff (1966) is the main source of descriptions for populations up to 1963. She used locust records from affected countries that had accumulated at ALRC since 1929, published accounts of specific events with associated rainfall and other meteorological data stored in the ALRC archive[4]. She separated reported facts about each year's locusts, weather and habitat from her interpretations of developments. Some, but not all, of the migration links she proposed between breeding areas were established by tracing locust displacements in relation to concurrent windfields. The boundaries between the three Desert Locust Regions were refined during this research. Each region contains complementary seasonal breeding areas that are linked by migration circuits. Locust movement occurs more frequently within than between regions. Her original boundaries differ from current ones in that she placed Oman and the United Arab Emirates east of longitude 50^{o}E in the Eastern Region and the

[4] Now held in the Entomological library store of the British Museum (Natural History), Wandsworth, London, SW18 4NX

parts of Libya and Chad east of longitude 20^{o}E in the Central Region. Currently, the whole of the Arabian Peninsula is within the Central Region and the whole of Libya and Chad are in the Western Region. References to Regions that she used in her accounts and findings were altered to the new boundaries.

7. Waloff used the qualitative terms 'widespread, medium, moderate, restricted and nil to negligible' to describe the scale of gregarious breeding during plagues. She also sought to provide a more objective, though still approximate measure of the scale of gregarious populations by comparing the number of degree squares[5] recording hopper bands for a particular season and region with the corresponding maximum total for the period 1943-1963. Accordingly, her qualitative terms are retained in this chapter. Her reasons for using degree squares and limitations these units impose are discussed in Chapter 3. Waloff did not provide maps summarizing the postulated links in plague upsurge sequences similar to those in Appendix 2 and project time did not allow their preparation for this review...

Central Region recession populations 1920-1924

8. Waloff (1966) found no information about recession populations in the Central Region before 1925.

Plague upsurge and decline, 1925-1934

9. *Waloff's (1966) interprets these events cautiously as there are geographically extensive gaps in reporting in the Central Region. Locust sightings in the Western Region came from incidental reports by travellers and occasional visits by locust experts. This plague began with rains initiating separate outbreaks in all three regions in 1925. The most likely sequence of subsequent events is that populations developed to plague proportions solely in the Central and Eastern Regions during 1926 and 1927 and subsequently invaded the Western Region in the summer of 1927. The plague ended in the Eastern Region in 1932 when following a dry spring, swarms migrated eastwards across India and failed to return westwards to the summer breeding areas so that only solitarious locusts bred in the Eastern region. Why it also ended in the south Central Region in spring 1932 is not recorded. The plague continued in the North Central Region until the summer of 1933 and in the Western Region until summer 1934.*

Plague upsurge and spread 1925-1927

10. Although incomplete, records for **1925** provide some indication that swarming populations existed in all three regions but there was no indication of inter-regional links. Waloff concluded that most **West African** swarm reports referred to *Anacridium*. However, the deep pink coloured locusts seen moving through the Hoggar in southern Algeria after mid-September indicated unreported gregarious breeding by Desert Locusts somewhere in the West Africa region during the summer. Good autumn rains in parts of the **Central and Eastern Regions** proved significant and were the first indication that an upsurge could develop. Population increases in Pakistan must have preceded the reports of damage in June but the increases were not sustained due to poor summer rains. Abundant autumn rains fell in three areas: Baluchistan, southern Iran, and the Sudan. Exceptionally heavy rains in the Sudan in November and December initiated population increases. Port Sudan (19^{o}38N/37^{o}07E) recorded 401 mm and Suakin (19^{o}08N/37^{o}17E) 253 mm, values that were respectively 5.4 and 2.7 times greater than normal. Waloff doubted two reports of swarms in 1925 that were made available only many years later. One report, in a letter dated 1929, claimed swarm invasions of Iran during the five previous springs. The other was a statement from a 1938 locust conference paper stating that southern Ethiopia experienced swarm invasions from 1925 to 1934.

11. Few reports emerged from the **Western Region** in **1926**. Waloff assumed that the locusts seen the previous autumn in southern Algeria bred since in April 1926, yellow individuals were reported in widely separated areas along the road to In Salah (27^{o}12N/02^{o}29E). Important plague developments continued in the **Central and Eastern Regions** and Waloff postulated an inter-regional movement from Indo-Pakistan to Arabia in autumn 1926. In the **Eastern Region**, abundant rains fell at suitable intervals and an upsurge developed. Rain fell in the winter-spring breeding areas of southern Iran and Pakistan in October 1925 and January 1926 and more rain fell in Pakistan in March. Swarms appeared in Iran in March. Winter breeding occurred in Pakistan on the Mekran coast and new generation swarms migrated

[5] A degree square is 1^0 latitude x 1^0 longitude

inland. Spring hatchings continued until June 1926 in parts of Pakistan and the resulting swarms from Pakistan and farther west moved to the summer breeding areas where rains supported two summer generations. Some progeny moved northwest and westwards reaching Afghanistan and Iran, though many over-wintered in India and Pakistan. Events in the **Central Region** were less completely reported but equally serious. In the Sudan, a population of hopper bands was present on the coast from Tokar ($18^o27N/37^o41E$) to Port Sudan in the spring of 1926 but only scattered locusts remained following control. Waloff found insufficient evidence to decide definitively that the gregariform parent generation arose from breeding by initially scattered locusts. An alternative source was a northward migration during the previous autumn of the putative swarming population in Ethiopia. An invasion of the Hadhramaut (southern Yemen) and breeding there in summer 1926 suggests that unreported winter-spring breeding had occurred in Arabia. Similarly, undetected summer breeding in the Central Region in Ethiopia and the Sudan must have preceded the invasion of Eritrea in the autumn. These swarms moved eastwards to the coast and subsequent events suggest that some may have crossed the Red Sea to Arabia.

12. The plague spread to all regions during **1927** when it affected most of the invasion area and reached serious proportions in the Central and Western Region. Waloff does not mention rainfall but she deduced several inter-regional migrations, which, in the early summer of 1927, spread the plague to Chad and possibly farther across the Western Region. The **Eastern Region** reported heavy and very widespread breeding throughout the year. In the spring, breeding spread northwards through Iran, Pakistan, and India and occurred in southern Afghanistan. Scattered locusts reached as far north as Turkmenistan. Their progeny migrated from May with some reaching as far east as the Orissa coast of India before returning westwards to breed in the desert areas of India and Pakistan from July to October. Swarms from this summer breeding migrated westward in October and again in November to Iran and probably Arabia. Contemporaneous developments show that events were severely under-reported in the **Central Region**. Waloff concluded that the damage recorded in Oman in spring 1927 suggested swarms formed there. Eritrea was the only country to report spring breeding and the resulting swarms moved inland onto the plateau in May. Further invasions of Eritrea led Waloff to conclude that spring breeding was undetected in central and northern Arabia as well as farther south, possibly around the southern Red Sea and Gulf of Aden. Summer breeding was heavy in Eritrea and the Sudan from July to September and probably occurred in Ethiopia. Young swarms moving to the coast of Sudan and Eritrea and across to Arabia in the autumn caused severe damage in Eritrea. Another movement took swarms northwards and northwestwards from Eritrea and Sudan to invade Egypt and Libya. Swarms also invaded southern Somalia for the first time in ten years and probably reached Borana Province in southern Ethiopia by the end of the 1927 and northern Kenya early in 1928. No Desert Locust populations were recorded in the **Western Region** until October 1927 when northern Mauritania and the Souss Valley in Morocco were invaded. These areas are frequently invaded during the autumn when summer breeding occurs in the Western Region but remain free from swarms in other years. Consequently, Waloff suggested that spring 1927 swarms from Arabia known to have reached as far west as Chad, probably bred there and farther west over the summer period with the resultant progeny invading northern Mauritania, Algeria and Morocco in the autumn. Uvarov (1933a, b) wrote a brief description of events during the subsequent plague (1927-1932).

Plague decline 1932-1934

13. Significant reductions in the scale of the plague began in **1932** with spring and summer breeding occurring at plague levels solely in the Western Region. The **Eastern Region** suffered a drought in the winter and spring of 1931/32. In Pakistan, no breeding was seen in Mekran and no bands occurred in Sind Province. Drought and a cold winter probably also ended the plague in Iran. Waloff postulated that the few swarms to reach the Indo-Pakistan summer breeding area came from Oman. The plague also ended in **South-Central Region** during the spring of 1932 although no specific cause was identified. In the north of the region, spring breeding occurred in many parts of the interior of Arabia and farther north in Syria and Iraq. The scale is uncertain but sufficient for new swarms to cross the Red Sea into Egypt and breed in the Sudan albeit on a smaller scale than in the previous three summers. In **1933,** there were few locust reports from the **Central Region.** Waloff concluded that spring breeding in Arabia was probably greater than reported. She based her conclusion on the large areas highly suitable for breeding following January rains and the scale of subsequent migrations which took swarms to southwestern Arabia, and also to Eritrea, Sudan, and Chad before any emigrated from Northwest Africa, the only alternative source. Summer breeding occurred on a small-scale in the Hadhramaut of Yemen but not elsewhere and the plague ended in the Central Region. It continued into **1934** in the **Western**

Region where a few swarms bred in Morocco and more widespread spring breeding occurred in Algeria. Their progeny reached West Africa and bred during the summer but produced swarms only in Mali. The gregarization that occurred in the Central Region is described below and Waloff suggested that the two swarms seen in the Eastern Region were remnants of those produced in 1933.

Central Region recession populations 1934-1939

14. *Gregarization occurred in the Central Region on the coasts of the Red Sea following heavy winter rains in 1933/34 and again in 1934/35. In spring 1935, infestations spread to the interior of Arabia. The threat of a plague upsurge developing ended when 1935 monsoon rains failed and the concurrent upsurge in the Eastern Region collapsed. Outbreaks continued to occur in the Central Region in each year to 1939. A warning of a potential upsurge around the Red Sea was issued in February 1937 but hopper bands were controlled and no swarms formed. A notable feature of this recession was the frequent appearance of swarms on the western Red Sea coast in the autumn and control of the progeny in spring.*

15. At least two generations of scattered locusts bred in the Suakin area of the Red Sea coast of Sudan following heavy rains there totalling 85 mm in October and 121 mm in November 1933. Parent swarms were not seen in this area and the first generation eggs were laid in November with the resultant hoppers fledging in January **1934** Adults matured and were sufficiently numerous to be *congregans* when they laid eggs in March. In April**,** bands fledged into small swarms, which emigrated in May. The Sudan coast again received heavy winter and spring rains in 1934/35 with Aqiq (18^{o}12N/38^{o}12E) recording 66 mm in November-December and a further 85 mm in January. *Transiens* coloured marching bands were controlled in April 1935 to prevent swarm formation. In Arabia, a small loose group of adults was reported near Mecca (21^{o}26N/39^{o}49E) in November 1934 where good rains fell in October and November. Waloff deduced that good winter and spring rains also fell in northeastern Arabia where pastures were described as "splendid" in April 1935. Breeding, though not reported, probably occurred in both areas as there was a report of locusts attracted to lights in Jeddah (21^{o}30N/39^{o}10E) in January 1935 and in April, a large adult population was seen flying but not in swarms for 450 km between Riyadh (24^{o}39N/46^{o}46E) and Kuwait (29^{o}20N/48^{o}00E). In addition, during the summer, a swarm, reported as *Schistocerca,* was seen in Eritrea in August and swarms and bands occurred from July to September in southwestern Arabia. Population increases associated with good winter spring rains in **1934/35** also occurred in the **Eastern Region** and were contemporaneous with the dwindling plague populations in the **Western Region** described in the previous section. Waloff (1966) accepted that the swarms seen in October and November in Mali did not reach Northwest Africa, which was reported swarm free throughout winter and spring. Instead she suggests either that the swarms bred in the Sahara, or that gregarization occurred there in spring 1935 as a few swarms reached Mali in summer 1935 and bred. The threat of a renewed plague receded in 1935 because summer breeding was light in West Africa and Arabia and was restricted in the Eastern Region when the monsoon rains failed.

16. A swarm reported in western Sudan in May **1936** may have been either *Anacridium* or *Locusta.* However, mature Desert Locust solitariform swarmlets invaded the Tokar area of Sudan initially in October indicating that summer breeding had probably occurred somewhere in the Central Region. Winter rains fell early on the Red Sea coast and swarmlets laid eggs in October, which produced numerous bands in November and December. Locally bred swarmlets, augmented by immigrant swarms, laid from December to February so that breeding and control continued throughout spring **1937.** The campaign ended in late March when the bands were successfully controlled (Anglo-Egyptian Sudan Delegation, 1938). In Arabia, following strong westerly winds, immature gregariform locusts were found near Jizan (16^{o}56N/42^{o}33E) in May 1937. They were in a 2 ha area containing locust excreta suggesting the recent presence of a swarm that probably arose from breeding somewhere in the Red Sea area. Exceptionally heavy rain fell over the Mediterranean coast of Egypt and Sinai in April and the contemporaneous explanation of the gregariform adults found with some gregaricolor hoppers in Egypt in mid-June was not gregarization but that a mature swarm had invaded the area and laid eggs. Bands did not form and control measures in June and July destroyed these populations. Waloff cites, as further evidence that an invasion occurred in the eastern Mediterranean, the small mature swarm seen in Jordan near Ma'an (30^{o}11N/35^{o}43E) in May and hoppers found in central Sinai sometime before July. Contemporaneous swarming populations were seen in Libya and Iran. The species of swarm seen in May near Benghazi (32^{o}02N/20^{o}05E) is uncertain but the groups seen in Tripoli (32^{o}58N/13^{o}12E) in May and June were Desert Locusts. Summer breeding was not recorded in Africa but small-scale gregarization occurred in India. Populations declined markedly in all regions in **1938.** An exception was

the gregarization found in southeastern Egypt and the adjacent coastal areas of the Sudan in March. Control continued into April but the swarm seen on the northern Sudan coast at Oyo (21°55N/36°06E) in June suggests that escapes occurred. A vague report in May of 'locusts' near the Jordanian border suggested that similar populations may have occurred in Arabia. In November, swarms reached Tokar and the area to the south and laid eggs. Band control continued in the Tokar area until January 1939.

17. A significant upsurge developed in the **Western Region** in **1939** but population increases in 1938/39 were not sustained in the other regions. In the **Central Region,** locally produced swarms laid in January 1939 in Tokar but the eggfields were dug up and destroyed. A swarm of unknown species, but probably *Locusta,* was seen on the coast in the Sudan in July. A swarm seen near Aden (12°50N/45°03E) in July was also of unknown species but Desert Locusts were present, as groups reached a ship a mile offshore in September. In the **Eastern Region**, numbers rose considerably in parts of Pakistan following good winter rains in 1938/39. No gregarization was recorded during the protracted spring breeding that continued in the interior of Pakistan until August. In India, population increases were arrested by poor summer rains.

The plague upsurge and decline, 1940-1948

18. *A reorganization of Locust Organizations to wartime footing was in progress when this plague started. World War II stopped the regular flow of information from the Western Region until late 1942. In contrast, the international organization of regional campaigns to prevent swarms reaching major crop areas provided information regularly from Arabia and Ethiopia for the first time (Uvarov, 1951). The plague upsurge began with a large influx of locusts into India and Pakistan in the summer of 1940. The potential source areas were southeastern Arabia and/or Iran. Monsoon breeding was protracted and produced swarms that spread northwards within India and Pakistan and westwards to Iran and Arabia. Excellent winter and spring rains in the Central and Eastern Regions sustained the upsurge. A cyclone brought heavy rain to southeastern Arabia in November 1940 and in spring excellent breeding conditions extended to many central and eastern areas. A general warning of a new plague was issued by ALRC on an unknown date in 1941 (Uvarov, 1951, para. 95). In 1941, spring breeding by swarms extended from Pakistan to Arabia. Many swarms were produced from this spring breeding and spread to summer breeding areas in both Regions. At the same time, a separate upsurge developed in the Western Region. Widespread summer breeding in all three regions in 1941 was augmented by winter breeding around the Red Sea and on the Somali Peninsula and a sustainable plague began.*

19. *The plague decline started in the Eastern Region when swarms from restricted spring breeding in 1946 moved eastward across the summer breeding area but failed to return westwards to breed. The plague continued in the Central Region North until the summer of 1947 when rains and laying were late in the Sudan and widespread hatching was controlled. The decline in the Central Region South started when many eggfields failed to hatch after poor Short Rains (October-January) in 1946/47. In contrast, Long Rains breeding (April-June 1947) was good and many swarms emigrated to northern Somalia and to adjacent parts of the Rift Valley where they were joined by swarms from Arabia. Summer rains were late in Sudan delaying egg laying until the second half of August. After control Sudan became swarm free from September 1947. The plague ended in the Central Region South after the Short Rains (October 1947-January 1948 failed and by March 1948, there were no swarms left in the area. Breeding in the Western Region was restricted in summer 1947 and spring 1948 and the plague ended when the spring swarms dispersed before breeding probably because the summer was dry.*

Plague upsurge 1940-1941

20. During **1940**, an upsurge in the **Western Region** diminished when drought inhibited spring breeding. In the **Central Region,** the Sudan was clear of swarms in spring 1940 and there was no information from Eritrea. Good winter rains fell in eastern Arabia in January, and although no locusts were reported, Waloff postulates that breeding occurred in this part of Arabia during the spring and that the progeny invaded the **Eastern Region** in July. An alternative or additional source of immigrants at the start of this plague upsurge was Iran. Whilst all confirmed swarms in Iran during the spring were *Dociostaurus*, the pink swarm, reported by nomads close to the Iran-Pakistan border in June, could indicate that Desert Locusts had bred and gregarized during the spring. Contemporaneous spring breeding in Pakistan was light and initially, few locusts arrived in the summer breeding area where egglaying started in June. Rains were widespread in July and above average in some parts of Rajasthan in August. Locust numbers increased in July as *transiens* immigrants and some bright yellow (mature)

swarms arrived and subsequently bred. These immigrants, probably from Iran or Arabia, may have arrived as individuals and formed swarms when concentrated by rainstorms or when attracted to green areas. Some of the swarms produced by this first summer generation bred locally in Rajasthan in September and October, whilst others spread from the breeding area northwestwards into northern Baluchistan and the Punjab, and eastwards to Delhi and by mid November into eastern Uttar Pradesh. Meanwhile, swarms from the first and second generations also moved westwards through southern Baluchistan into Iran with some probably reaching eastern Arabia. .Summer breeding in the **Central Region** was light; hoppers were seen on the coast of southern Yemen in June and July 1940. Central and eastern Arabia were reported to be dry in the autumn before a cyclone brought heavy rain to large stretch of coast around Mukalla (14°34N/49°09E) which recorded 85 mm on November 13. Analogy with better-documented cyclones suggests that the rain probably also affected inland areas.

21. When in **1941** the general warning of a new plague was issued is uncertain (Uvarov, 1951, para 95) but large swarming populations were present in the Eastern and Central Regions from the beginning of the year and by July an upsurge was well underway in the Western Region. In the Eastern Region swarms laid along 150 km of the coastal area of Iran in December 1940 and early January 1941 with bands appearing from February. Rains inland in the Jaz Murian Basin (27N/58E) also produced swarms during the spring. Small swarms began moving eastwards in April. The scale of breeding in Iran is uncertain but was probably greater than reported. Further east spring breeding occurred in Afghanistan and northern Pakistan and new generation swarms appeared from May. The summer breeding area of Rajasthan was invaded by swarms from the third week in June and swarms from Iran and/or Arabia moved along the coast of Pakistan and into Sind at the end of the month. Invasion from the west continued into July and swarms became widespread in much of Pakistan, Rajasthan and Western India.

22. In the **Central Region**, swarms from the Eastern Region bred in eastern and central Arabia where abundant spring rains had fallen possibly augmented by locusts from undetected breeding in parts of southern Arabia affected by the November 1940 cyclone. Swarms reported on the Batinah coast of Oman in February and early March 1941 apparently reached Pakistan, as specimens collected in both areas were morphologically identical. Elsewhere in eastern Arabia, swarms and hoppers were present in April in Qatar, Bahrain and between Hofuf (25°20N/49°34E) and Dhahran (26°18N/50°05E) and from mid-May onwards, swarms arrived and bred in the Hasa, Al Kharj and Riyadh areas. The subsequent dispersal of young swarms produced in these areas to northeastern Yemen, the Hadhramaut as well as to western Arabia and Africa lasted from May until mid July and suggested that spring breeding in Arabia was very under-reported. The African section of the Central Region had received abundant winter rains and locusts that bred in southeastern Egypt and in Tokar gregarized. Control measures were undertaken against spring breeding in Tokar in February and in Egypt until early June. Swarms from Arabia crossed the Red Sea in mid June and again in late June and early July. They spread through Egypt to the Nile Valley and then to Kordofan in Sudan and to Nacfa (16°40N/38°30E) in Eritrea. Swarms also reached eastern Ethiopia on 15 July, most probably from southwestern Arabia.

23. Waloff noted that the upsurge in the **Western Region** was independent of activities elsewhere. Its origins are uncertain, as reporting in West Africa was sporadic during this period. Here, as in Waloff (1966), it is assumed that the upsurge was initiated by heavy rains in the winter and spring 1938/39 in Central Algeria and declined briefly a year later. Spring rains and breeding were on a smaller scale in **1940** than in 1939 and the locusts moving south from central and southern Algeria that were seen in the Hoggar were almost all adults that had over wintered in Algeria without breeding. There were no reports of summer breeding in the Western Region. Nevertheless, it apparently occurred on a considerable scale as a traveller in October 1940 reported 'an immense area in Niger north of Agadez (17°00N/07°56E) covered in locusts'. Heavy rains fell, between August and December 1940 in southern Algeria, causing wadis northwest of the Hoggar and in Tademaït to flood several times and to remain suitable for breeding until April **1941.** Breeding started in the south of this region in November and December 1940 and began in February farther north where cold weather delayed breeding. Areas unaffected by the autumn floods were drying out by February as spring rains failed in the south and southeast of Algeria. In contrast, heavy rains fell northwest of a line from Adrar in the west (27°N/00°17W) northwestwards to Ouargla (31°57N/05°20E) which included the Saoura valley north of Beni Abbès 30°08N/02°10W) in western Algeria. Waloff tentatively concluded that adults that had fledged in April or May in southern Algeria or in the Sahel reached the Saoura Valley during the spring rains. Gregarization occurred in the Saoura Valley, in Mouydir and near the Hoggar. The first immature swarm appeared in Algeria in the Hoggar and in Niger at Iferouane (19°04N/08°20E) in June, as fledging was ending in Central Algeria and before it started in the Saoura Valley of northwestern

Algeria. The swarms reached Kidal in Mali sometime in June. Swarms continued to move through southern Algeria and the adjacent parts of Mali and Niger in July, matured and began to lay eggs.

24. In summary by mid-1941, swarms were widespread in all three regions. Gregarious summer breeding was followed by some winter breeding on the Red sea and in northern Somalia. The resultant swarms assured the continuity of the plague until 1946. Uvarov (1951) provided a brief account of plague campaigns from 1942 to 1947.

Plague decline 1946-1948

25. The plague decline began in the **Eastern Region** but not elsewhere in **1946.** The restriction of spring breeding to southern Iran was the first indication of the decline The swarms that formed then migrated beyond the Indo-Pakistan summer breeding area where most disappeared instead of making the normal westward return to breed (Waloff and Roffey, 1981). Consequently, little gregarious breeding occurred during the summer and no gregarious spring breeding was reported in the Eastern Region in **1947**. There were, however, two reports of swarms of unknown origin in southeastern Pakistan and northern India during the summer. No gregarious summer breeding occurred but late in the year small swarms or swarmlets were seen in coastal areas of southwestern Pakistan and southeastern Iran.

26. In contrast, the plague continued throughout **1946** in the **Central Region** and did not finally end in the south of this region until March 1948**.** In the autumn and winter of 1946/47, notable winter breeding was reported on both sides of the Red Sea and in spring, swarms spread northwards and bred from Arabia to Syria. In the south of the Central Region the 1946/47 short rains (October to January) were poor and although reported swarm laying was widespread on the Somali Peninsula, in Kenya and northern Tanzania, no hatching occurred at many of these sites. In contrast, breeding from April to June **1947** was good in northeast Kenya, Ethiopia and Somalia and many swarms formed and subsequently migrated to northern Somalia and the Rift Valley area where they were augmented by swarms from spring breeding in Arabia. Spring swarms also migrated from Arabia to Sudan and Eritrea. Summer rains started late in the Sudan and laying was delayed until the second part of August. Hatching was widespread but successfully treated. Control and bird predation destroyed most hoppers in western Eritrea. No swarms emigrated to coastal Sudan in the autumn and the limited laying seen in Eritrea failed to hatch. The Red Sea coast in Arabia was free of swarm activity until December with no reports of gregarious breeding. Farther south in Ethiopia, summer breeding was heavier and swarms formed in Harar Province. A limited number of summer swarms together with Long Rains swarms that survived the summer in northern Somalia gave rise to widespread reports from Eritrea south to the Kenyan border in the last quarter of 1947. The Short Rains (October-December) failed and all swarms had disappeared without breeding by March 1948.

27. The plague continued longest in the **Western Region** where swarms existed until summer 1948. Spring breeding in the Western Region in **1946** was restricted to southwesterm Morocco, and a few localities in northern Algeria. Swarms formed and summer breeding was recorded in Senegal, Mali and western Chad and probably occurred in Niger where immature swarms were reported in September. The swarm invasion of Morocco, Algeria and Tunisia in the autumn was sufficient for the plague to continue and breeding occurred on a moderate scale in the Western region in spring **1947**. The resultant swarms moved south into the Sahel and summer breeding occurred in Mauritania, Senegal and Niger on a restricted scale. Swarms only invaded Morocco in the autumn and bred in the Souss Valley in spring **1948**. Emigration southwards began in June, which is consistent with reports of small, loose swarms in southern Mauritania in mid-July. Swarms seen in Mauritania in July were reported to have dissociated because it was dry. A swarm seen in Mali in December was probably *Anacridium*.

Central Region recession populations 1948

28. *This was a very short recession. A few swarms from the previous plague remained in the Central Region South until March 1948 and others in the Western Region did not finally dissociate until the summer. Rainfall was sufficient for gregarization to occur during spring in the Central Region and in spring and summer in the Eastern Region. These populations began the subsequent upsurge and plague (1949-1963).*

29. In **1948**, three separate areas of **Central Region North** reported important populations. The most significant population increases were initiated by heavy and widespread rains falling on the Saudi Tihama from Lith (20^{o}10N/40^{o}20E) to Hali (18^{o}38N/41^{o}22E) in late November 1947 followed by

intermittent showers from December to February 1948. Popov found only solitary locusts when he monitored the area between late January and mid-February 1948. In March, vegetation was drying out and gregarization was in progress as hoppers and adults concentrated into the remaining green areas. In April, night flights were frequent with adult groups and a few loose swarms seen flying by day. The last swarm sightings were in early May. The second population was on the western Red Sea coast where scattered adults and *transiens* hoppers were seen in Eritrea in January and *transiens* adults were found in June. Control of loose bands was undertaken north of Port Sudan in April and against hatchlings in May. In mid-June, swarms, possibly from the Arabian Tihama, appeared on the coast at Tokar and on the Nile at Shendi (16°41N/33°22E). At the same time, swarms reached the coast and highlands of Eritrea and persisted until July when further swarms arrived. No summer breeding was reported in either Sudan or Eritrea nor were swarms reported again until November when "flying locusts" were sighted at Halaib (22°16N/36°35E) on the coast near the Sudanese-Egyptian border. In December, there was an unconfirmed report of a swarm on the coast of Eritrea. The third area was Northwest Egypt. Heavy rains fell on the Mediterranean coast of northwestern Egypt in the winter of 1947/48, and Desert Locust hoppers were found in June, July and Augus that were mixed populations of *Schistocerca, Locusta* and *Anacridium*. The adults aggregated and drifted eastward in mid-August a few days before newspapers reported swarms near Aswan and in Wadi Halfa (21°55N/31°20E) in the southeast of Egypt.

The plague upsurge and decline, 1949-1963

30. *This plague started whilst civilian locust organizations were being re-established in the Central Region (Uvarov, 1951) and when FAO's Desert Locust programmes were beginning (Lean, 1965). There was no formal early warning system during the early stages of this plague and no Desert Locust Bulletins were issued by ALRC from November 1948 until January 1950 by which time there were serious locust infestations in the Eastern Region.*

31. *In late October 1948, a cyclone moved across southeastern Arabia and rain fell from Salalah (Oman) to the Trucial Coast. The area could not be surveyed and the first of several opportunities to prevent an upsurge was missed (Uvarov, 1951). The progeny emigrated and augmented two sequences of the plague upsurge during summer 1949. The sequence in the Eastern region produced many swarms. A special Bulletin was issued on 19 October 1950 as swarms emigrated westwards from the Eastern Region. Experts met at an International Anti-Locust Conference in November 1950 to plan joint campaigns in Arabia to contain the upsurge. A second sequence in southwestern Arabia remained largely unrecorded. Uncontrolled breeding occurred in Yemen in spring and summer 1949 and led to large-scale breeding in the interior of Arabia and on the Somali peninsula in spring 1950. Swarms from this breeding invaded African summer breeding areas in the Central and Western Regions. Heavy breeding followed establishing the plague in all three regions. Lean (1965) records a second attempt to suppress this plague when its extent was reduced during the 1951-1953 recession in the Western Region. Experts met again in November 1951 and planned campaigns to stop further developments but funding for control operations was unavailable. The plague continued with further regional recessions and upsurges until the decline started in 1960.*

32. *Waloff concluded that control campaigns in summer and winter 1960/61 effectively ended the plague in the Western Region. Both she, and Rainey, Betts and Lumley (1979) cite the restricted distribution of swarms in both seasons but not drought as a contributory factor. The plague continued at a reduced level in the Central Region in 1961. An unknown proportion of spring swarms were 'lost' in the Eastern Region in 1961 because many eastward moving immigrants failed to return westward to breed during the summer. Spring breeding in 1962 was exceptionally heavy in both regions and extended farther north than usual. Unusually, the progeny from Arabia all moved to India and Pakistan. This unusual seasonal displacement and control in Ethiopia and Somalia left only a few swarms in the Central Region after summer 1962. Summer breeding in India and Pakistan was exceptionally heavy in 1962 and lasted for three generations. Waloff suggested that aerial spraying of persistent pesticide barriers to kill hopper bands contributed to the success of the summer campaign Rainey, Betts and Lumley (1979) argued this view more strongly and suggested that sub-lethal doses of dieldrin pesticide absorbed by surviving females contributed to the death of their progeny and the end of the plague in spring 1963.*

Plague upsurge and spread 1949-1950

33. No gregarious populations were reported in the **Western Region** during **1949**. In the **Central**

Region, only solitary locusts were found in January and February 1949 on the Red Sea coast in northern Eritrea and southern Sudan. Breeding occurred and incipient bands were seen in mid-March in both areas. Hatching continued until mid-April. In northern Eritrea, an estimated 200 million hoppers were present in a 20 km^2 area of cultivations. Late instars grouped without forming discrete bands and began to march, eventually becoming a large, moving populations some 20 km wide and up to 6 km deep. Fledging began in May and control reduced the population. Populations in adjacent coastal plains of Sudan formed marching bands one of which had a 12 km front. After fledging, swarmlets formed. During May, the adults from both countries moved inland, some dispersing in the foothills of Eritrea. Further aggregation may have occurred as a few swarmlets reached the highlands of Eritrea in June. Contemporaneous breeding on the Saudi coast was light and fledglings disappeared in April.

34. In October 1948, a cyclone moved across southeastern Arabia and brought rain over a wide area from Salalah (17°00N/54°04E) (157 mm in four days) across Mugshin (19°40N/54°57E) in the interior of Oman, northwards through Wadi Ain to the Trucial Coast (Rainey, 1965) but no surveys were subsequently possible for physical and political reasons (Uvarov, 1951, para. 248). In February **1949**, however, **t**he results of undetected breeding became evident when late instar hoppers and loose concentrations of pink and yellow adults were found in Wadi Ain and the first loose swarmlet appeared in Wadi Liqtan to the southeast of Dubai (25°14N/55°17E). By the end of the month, scattered adults were located on the coast of the United Arab Emirates (then Trucial Oman) and some mixed maturity swarms arrived on the Batinah coast in Oman and moved inland two days later. By the end of March, breeding by scattered locusts gave rise to hopper populations of scattered to gregarious densities over an area of some 150 km^2 in the Wadi Liqtan and bands were seen between Dubai and Abu Dhabi (24°27N/54°23E). In mid-April, heavy breeding and hopper bands were reported from Buraimi (24°15N/55°45E). Fledging began in these areas in May and swarmlets and swarms formed. Some were seen in the Ras el Khaima area (25°48N/55°56E) and the Bedouin reported swarms to the northwest of Buraimi.

35. From early May 1949, some warms from winter spring breeding in southeastern Arabia emigrated into the Eastern Region and others moved westwards across Arabia. In the Central Region, they were initially reported in Wadi Mugshin and then in the Hadhramaut where several stayed. Others continued to the interior of Yemen. At the same time, reports of a swarm and an influx of scattered locusts came from the southern Saudi Tihama. In Africa, a local outbreak produced swarms on the Red Sea Coast in May. Some moved inland and apparently dispersed (para 33). Others may have migrated across the Red Sea and eventually reached the Gulf of Aden area to mix with those arriving from the eastern Arabia. Breeding started in May in many areas, one of which in Yemen exceeded 250 km^2. In August and September, an immature swarm and numerous scattered locusts were present on the Gulf coast of Yemen and near Jizan. Other scattered mature locusts and a mature swarm were seen in mid December south of the Hadhramaut near Riyan (14°40N/49°20E) and Mukalla. On the southern Gulf coast, only a few solitariform locusts were found in October between the Djibouti border and Las Dureh (10°10N/45°00E). In late November, however, numbers in Somalia increased, apparently from immigration by transient to gregariform mature adults. Laying occurred at Karrin (10°49N/45°47E) and on 1 December, fishermen saw a swarm flying towards Elayu (11°15N/48°54E). Farther east, there were reports in late November of an infestation between Heis (10°53N/46°54E) and Mait (10°58N/47°05E) and of swarms at Las Khoreh (11°10N/48°13E) where hatching began in December.

36. In the **Eastern Region**, locust populations were small in Iran, Pakistan and India until June **1949**. Then densities rose in the summer breeding areas of India and Pakistan in July as immigrants, including many from Arabia, continued to arrive. The Monsoon broke early, in mid-June. Maturation and egglaying quickly followed and hatching started in late June. Most of the fledglings appearing from late July were gregariform. Laying by scattered adults continued throughout August and in September dense adult concentrations were present. Swarms of the main summer generation began to lay eggs and serious hopper infestations followed until November. New swarms formed in November and December and some migrated to the winter-spring breeding areas of Pakistan and Iran. Scattered locusts, groups and some small swarms reached Oman. Other swarms remained in Pakistan and spread northwards through Baluchistan and the Punjab into southeastern Afghanistan. Gregarious spring breeding of moderate-scale started in Pakistan in February **1950** and in Iran in March and hopper bands were present in these areas from March until June. Swarms from these areas moved eastwards to the Indo-Pakistan summer breeding area in May and June.

37. In the **Central Region**, swarms, which appeared in southwestern Arabia at the end of 1949, began breeding early in **1950**. Some spread northwards to the Saudi Tihama coastal plain where gregarization

was reported. Spring breeding continued in these areas and spread further northwards along the coast and into the northern interior of Saudi Arabia. Numerous swarms from this spring breeding formed in May and June and moved to summer breeding areas in southwest Arabia, and to those in India and Pakistan. Other swarms reached Africa moving through southeastern Egypt into Sudan, Chad and probably as far west as Niger. Heavy spring breeding occurred on the north Somali coast that had been invaded the previous autumn (para 35). This breeding was augmented in March when mature swarms from the Arabian Peninsula reached the northern coast of Somalia and northeastern areas of Ethiopia. No gregarious breeding occurred on the Red Sea coasts of Sudan and Eritrea.

38. In the **Western Region** dense bands of hoppers were seen in western Tibesti (Chad) in January **1950**, three to four months after heavy rains fell in the area and 18 months after the last swarm report from Tibesti. Guichard (1955) did not collect this information until 1953 and the origins of this outbreak, assumed to be Desert Locusts, is uncertain. At the same time, no major populations were confirmed farther west. A swarm reported from Mauritania in January was probably *Anacridium* and the only other report was of scattered locusts in Tabelbala, Algeria (29^{o}23N/03^{o}15W) in March.

39. Summer breeding in 1950, occurred on a medium-scale in the **Eastern Region** and gave rise to considerable numbers of swarms in the autumn. In the **Central Region**, summer breeding was heavy in the Sudan, extended into Chad, and was moderate in Eritrea and Ethiopia. The numerous swarms produced started to move in September. Some emigrated north and northwestwards into the Western Region and joined swarms that had bred in Chad and possibly Niger during the summer. By November, they had spread widely through southern Algeria and from Morocco to Libya in northwest Africa. Swarms from the interior of the Sudan also moved eastwards from September into the Red Sea area and through Egypt to Arabia. Subsequently in Eritrea, local adults and scattered stragglers from immigrant swarms concentrated into a dense swarm following localised rains, which fell from 8-10 December. This swarm laid eggs a week later (Stower, 1959). Winter breeding on a medium scale in Somalia and around the Red Sea gave rise to additional swarms in the Central Region. The plague had started and had reached serious proportions in all three areas by the end of the year.

Regional recessions and an outbreak during the 1950-1963 plague

40. This plague was marked by notable regional recessions (Waloff, 1966, 1976). The **Western Region** experienced a recession after summer rains failed in **1951.** This regional recession lasted until early summer **1953** when the region was reinvaded by spring swarms from the Central Region. Another recession affected the **Eastern Region** from summer **1955** to spring **1958**. It began when swarms produced in the spring moved across the summer breeding area and continued eastwards through Bihar to west Assam and West Bengal. As in 1946, they failed to return westwards and died without breeding. An outbreak occurred in India in the summer of 1956 when scattered immigrants were concentrated by convergent airflow accompanied by rain. The resultant bands and adults were sufficiently numerous to require control and subsequently, the region remained free from gregarious populations until swarms from the Central Region invaded Iran, Pakistan and Afghanistan in spring 1958. Their progeny returned to the Central region in autumn 1958 and so the plague within the Eastern Region did not become fully re-established until a further reinvasion from the Central Region in winter-spring 1958/59. This time, the progeny migrated to and bred successfully in the summer breeding areas of Indo-Pakistan. An almost contemporaneous sub-regional recession started in the **Central Region South** when the Short Rains failed in the autumn of **1955**. Eggs were laid on the surface or failed to hatch and the southern part of the Central Region remained swarm free until spring **1957.** Heavy and protracted rains fell on the north Somali coast during the 1956/57 season and up to three generations of scattered locusts may have bred between October 1956 and April 1957. Bands were seen in November and December 1956 and again in April 1957. Swarms formed in May 1957. The campaign was made difficult by the frequent appearance of new bands and the dense green vegetation that reduced the effectiveness of ground control measures. Swarms totalling an estimated 75-125 km^2 formed by the end of breeding in June and re-established the plague in this area (Joyce, 1962a).

Plague decline 1960-1963

41. In **1960**, spring breeding occurred in all regions and swarms reached the summer breeding areas. In the **Western Region,** some swarms reached Niger but most concentrated in southwestern Mauritania and Senegal, which facilitated effective control measures and greatly reduced the number of summer generation swarms. The summer swarms surviving control moved northwards to Morocco in October and control teams attacked them for four months and they disappeared in February 1961 without having matured and bred, thereby effectively ending the plague in the **Western Region**. The plague continued

in the Central and Eastern regions throughout 1960.

42. **In 1961,** spring breeding was widespread in the **Central Region** and affected the Red Sea coasts, the interior of Arabia and extended northwards through the Near East to the Turkish border. In the Central Region South, spring breeding was almost entirely restricted to northern Somalia and the adjacent parts of Ethiopia, the exception being a report from northern Kenya. Summer breeding was moderate and the progeny bred successfully in Somalia and on the Red Sea coastal plains augmenting the plague population in the Central Region. In the **Eastern Region**, spring breeding was restricted possibly because a proportion of the 1960 summer swarms spread widely within peninsular India and perished. Nevertheless, spring generation swarms from the Central Region and Iran reached the Eastern Region's summer breeding areas in 1961. Medium-scale breeding followed and the progeny then spread to Pakistan, Afghanistan, Iran and Arabia between September and December.

43. The **Western Region** contained no major swarming populations in **1962** although in January there was an isolated swarm report from Tunisia. As in 1961, the **Central Region** recorded gregarious breeding in northern Somalia and Ethiopia between March and June but no contemporaneous Long Rains breeding farther south on the Somali peninsula. In contrast considerable spring breeding occurred around the Red Sea, in Arabia and the Near East extending into Turkey. Spring breeding was also exceptionally widespread in the **Eastern Region** and extended into northern Iran, Afghanistan, northern Pakistan and northwestern India. Large populations were produced in both regions. Unusually, all of the spring swarms moved eastwards to India and Pakistan, which experienced exceptionally heavy invasions. In contrast, only small-scale populations remained in the **Central Region** from summer 1962. In the **Eastern Region** exceptionally, heavy and protracted breeding by two or perhaps three generations occurred between July and November but very few swarms were finally produced. Why so few swarms were produced is unclear, although a contributory factor was probably the introduction of aerial spraying of dieldrin pesticide barriers at the end of the campaign, a very effective method of controlling hopper bands. The much reduced progeny moved west to Pakistan, Iran and possibly Arabia from October to December.

44. In **1963**, the plague finally collapsed in the **Eastern Region**. Swarms that had reached Iran and Arabia died without producing gregarious hoppers possibly because sub-lethal doses of dieldrin absorbed by female locusts can cause the death of their progeny (Rainey, Betts and Lumley, 1979). As a result, spring breeding was confined to northern Pakistan. The spring progeny reached the Indo-Pakistan summer breeding area but dispersed and solely scattered adults bred. Waloff associated dissociation with the hot dry weather that lasted until late July. A similar dispersal of swarms and failure to produce gregarious progeny had also occurred in 1935: another year when the monsoon was delayed. In the **Central Region**, a small swarm dispersed over a 30 km^2 area in Eritrea and bred. Both parents and hopper band progeny were eliminated by control and only a few fledglings were left by early April. Hoppers and adult groups were found over a 50 mile stretch of coast near Port Sudan in March but few locusts remained in mid-May. A few residual swarms were reported in Ethiopia and Somalia with the last confirmed sighting in June. No gregarious breeding occurred. A tropical cyclone brought heavy rain to southern Arabia in May but no locust developments followed. The **Western Region** remained clear of swarms although scattered breeding occurred in northwestern Niger in the autumn.

PLAGUE INITIATION AND DECLINE IN THE CENTRAL REGION 1964-1999

New concepts for evaluating plague prevention

45. Three important changes occurred as this period began: the weather became drier (Fig. 4), the focus of locust control moved from eliminating to preventing plagues and persistent pesticides began to be replaced with contact insecticides, which increased workloads and made control less effective. The recession starting between 1961 and 1964, allowed changes leading towards implementation of a plague prevention strategy to be introduced in 1969 (FAO, 1969). Affected countries were encouraged to monitor recession breeding areas regularly and control populations as necessary to maintain the recession.

46. No review of the whole period exists. Instead, studies cover a single upsurge or plague and their focus changed from establishing the origins of plagues to examining characteristics of upsurges and the effectiveness of control in preventing plagues. During the previous plague (1950-1963), field research teams worked closely with control teams in the Central Region to improve application techniques and aerial spraying of swarms, particularly those held in Somalia along the convergence zone between June

and October (Desert Locust Survey, 1956). Later, they used field estimates of locust numbers in bands and swarms to evaluate the effectiveness of campaigns. By 1959, control capacity was being mounted on a scale commensurate with the size of seasonal plague populations (Joyce, 1962b). Rainey, Betts and Lumley (1979) cite papers describing similar developments within francophone Africa (Perret, [*sic*] Perrot, 1956; Mallamaire and Roy, 1958; Besnault, 1963; Sayer and MacCuaig, 1961, Gilot, 1965).

47. Campaigns during the 1949-1963 plague in the Central Region and in West Africa had been organized regionally. Teams treated hopper bands in all breeding areas to avoid swarm invasions close to major agricultural areas that might be beyond the capacity of ground and aerial control teams. Desert Locust Survey were considering whether an alternative strategy of spraying swarms as they approached crops would become feasible as aerial spraying techniques improved. Control managers assumed then, as now, that this alternative technique might require prohibitive numbers of aircraft to prevent swarm invasions damaging crops (Desert Locust Survey, 1956). These experiences and ideas influenced how the plague prevention strategy evolved and topics covered in desk studies of subsequent upsurges. Most studies examined how the strategy could best be achieved and why failures occurred. The constituent analyses examined and assessed the plausibility of links between populations and the role of control and other factors in ending upsurges. Authors often mapped the upsurge sequences against which control was mounted. Debate still focuses on the stage of an upsurge in which control can reduce locust numbers sufficiently to stop further upsurge development and the relative emphasis to be placed on band or on swarm control. From the 1960s, the environmental safety of persistent pesticides was being questioned and these were gradually being replaced by non-persistent contact chemicals. The non-persistent chemicals increased workloads and required more accurate spray application.

48. Rainey and Betts selected and defined ‘important’ recession populations and their selection, summarized by Gurdas Singh (FAO, 1967a) represents the first attempt by FAO, its forecasters and technical advisers to determine which populations have the potential to initiate upsurges and which control tactics might maintain populations at acceptably low levels. Populations defined as ‘important’ were bands, swarms, infestations that were controlled and ‘potentially important’ populations. The latter were mainly infestations estimated to be ‘in the order of millions’. Two more populations were included to provide plausible links in space and time to other infestations and weather systems, which could have transported the locusts. One was an unconfirmed swarm report in Jordan in March 1967; the other was groups and recently fledged isolated Desert Locusts and grasshoppers seen at light for at least 11 nights in Oman in May 1967 (Rainey and Betts, 1979). The populations selected as ‘important’ were not controversial and similar selections were made for studies of subsequent upsurges. The contentious issue of the FAO study, discussed below, was that by overemphasizing migration between important populations as being sufficient to initiate a plague, the authors underemphasized the importance of locating other habitats made suitable for population increase and gregarization by recent rainfall. Waloff (1966) and Hemming *et al*. (1979), on the other hand, included both aspects in their papers but gave more prominence to population growth and gregarization than to links between ‘important’ populations.

Recession populations 1964-1967

Data sources

49. Rainey and Betts reviewed the period, July 1963 to September 1967 for FAO (1967a). Later they provided a fuller account extended to July 1968 (Rainey and Betts, 1979). Waloff (1966) described events in 1964. Bennett (1974, 1975, 1976) analysed the upsurge and plague period 1966 to 1969 that is described in the next section. 1965 was not analysed but accounts of the infestations appeared in Desert Locust newsletters 9 and 10 and a DLCC Report (FAO, 1965a, 1965b, 1966).

Recession populations in 1964 and 1965

50. In the **Western Region**, population levels were low at the beginning of **1964** with no swarms having been seen in the region since January 1962**.** Following spring breeding, transient populations were seen in southern Algeria, Tibesti and Libya. Only scattered adults were reported in the summer but breeding occurred somewhere on a scale sufficient to give rise to the groups and swarmlets seen in northwestern Algeria and northern Mauritania in the autumn and to the hoppers and swarmlets seen, following spring breeding in the Draa Valley, Morocco in May 1965. These gregarious populations, in **1965**, did not persist. Individuals that bred in the summer and their progeny were scattered populations.

51. Few locusts were reported in the first half of **1964** in the **Central Region.** Then in September, a

small immature swarm was seen over the Gulf of Aden and a swarm appeared in the south of Somalia in November 1964. No gregarious breeding followed and in **1965** only reports of scattered locusts breeding were received (FAO, 1965b). In the Red Sea area, local outbreaks of groups and bands occurred in Eritrea and on the Tihamas of Yemen and Saudi Arabia, following winter-spring breeding in late 1964 and early 1965. Numbers declined subsequently and only small-scale breeding in southwestern Arabia was recorded in summer 1965. Reports of small swarms of unidentified species in Kenya in April and Ethiopia in June 1965 were investigated but neither was confirmed (FAO, 1965b).

52. The previous plague had ended in the **Eastern Region** in the summer of 1963 and only scattered adults moved to the winter/spring breeding areas of Iran and Pakistan. By the end of spring breeding **1964**, small bands or groups of solitaricolor hoppers were present in the Mekran coast of Pakistan. A total area of 40 km^2 was affected but the main infestation was in 8 km^2 of cultivations. Emigration to the summer breeding areas in Indo/Pakistan, which began in May, included two very small swarmlets from Iran. These were augmented by considerable populations from Pakistan in June. Numbers rose in the Indo-Pakistani summer breeding areas and in mid-June, as a cyclonic depression moved through the area, a swarm may have formed and then dispersed into an area of 20 km^2 (Varma and Sharma, 1966) or more likely was transported on westerly winds from Pakistan into India (Venkatesh, 1971 and in van Huis et al, 2007). Heavy rains associated with the cyclonic depression fell over Sind and Rajasthan and subsequent reports indicate that the scattered population matured and laid eggs shortly afterwards. In July, rains were widespread in Rajasthan and adjacent parts of Bahawalpur but were scattered in the Pakistani summer breeding areas. Rains were widespread in August in northwest India and adjacent parts of the summer breeding area of Pakistan. As a result, favourable breeding conditions persisted from mid-June to August and continued in some localities into September (Waloff, 1966).

53. The immigrants from Iran and Pakistan had experienced some degree of grouping as hoppers or as adults. Those sampled in June were morphometrically solitariform to transitiform and were sufficiently numerous to form swarmlets and groups, at least temporarily. Egg laying was widespread in both space and time and although most were by scattered adults, some laying groups were seen. In early August, immigrants and rapidly maturing first generation fledglings were present and numbers were higher than earlier in the season. Some laying groups were seen among these adults but Waloff inferred from the mixed ages of the resultant hopper populations that scattered adults had laid many of the eggs. By October, populations were large and fledglings from untreated areas and that survived control formed several gregaricolor swarms totalling about 10-20 km^2. The swarms moved westwards but failed to produce gregarious progeny in spring **1965**. Reports later in the year were of only of scattered locusts. Populations in **1966 and 1967** led to the 1968-1969 plague and this period is considered below.

Interpreting fragmentary evidence during recessions

54. The different interpretations placed on events in the 1964-1967 recession highlight the difficulty of analysing populations for which datasets and knowledge of population dynamics processes are incomplete. Rainey and Betts (1979) point out that the locust data were too fragmentary to test the two contending hypotheses on the origin of plagues. Waloff (1966) looking at recessions over a longer period (1920-1964) concluded that plagues did not arise solely from gregarious populations persisting throughout recessions and that concentration, multiplication and gregarization lasting for a succession of generations in at least two complementary breeding areas were important contributory processes in the build-up of transient to gregarious populations before plagues. When she examined the origin of the 63 gregarious populations seen during recessions between 1920 and 1964, 41% were definitely or probably the F_1 progeny of swarms, 30% were F_2, 17% were F_3 and 12 % were the F_4 to F_7 generation from swarms. In contrast, Rainey and Betts (1979 and for FAO, 1967a) contended that that populations between August 1963 and July 1968 which they considered 'important' were potentially linked by migration routes that had been followed previously by swarms. They argued that the hypothetical links between the 50 populations provided circumstantial evidence that could be interpreted as sampling successively from the same population or its progeny. It would then follow that control could be considered cumulative in the sense that it could reduce the initial size of the subsequent target population. They also contended (Rainey and Betts, 1979) that their continuity hypothesis offered a better method for predicting Desert Locust upsurges than the older, alternative hypothesis that places greater emphasis on the build-up and gregarization of previously solitary-living populations.

55. The paper presented to the DLCC (FAO, 1967a) illustrates the difficulty of providing a balanced view within a short working paper of findings based on inconclusive evidence and an unproven hypothesis. The paper contains two tentative conclusions. One suggests that control can be envisaged as

cumulative because the sequences of populations involved are not independent of each other. This conclusion requires a high proportion of the proposed migration links to have actually occurred. Rainey and Betts (1979) leave no doubt that the links in their study, as in many desk studies, are based on circumstantial evidence and so should be considered hypothetical (Waloff, 1981).

56. The second conclusion reached is that control in India and Pakistan in the summer of **1964** may have prevented an upsurge similar to that of 1949. Rainey and Betts cite two facts to support this view. One was that the quantity of pesticide used for spraying and dusting in 1964 suggested an effective campaign whereas, trenching plus applying dust to only 8% of the infested area in 1949 did not. These differences strongly suggest control that was more effective in 1964 than 1949 but these differences do not indicate whether habitats in both years would have supported similar upsurge developments. The paper cites Waloff (1966) as noting similarities between the two years but leaves readers to locate and evaluate evidence she presents contrasting them. Waloff drew attention to significant differences in rainfall and concurrent populations but not between control efforts between 1949 and 1964 likely to affect population developments. She noted that both invading populations were scattered but that gregarious adults appeared as the first generation fledged in 1949, whereas, only scattered fledglings were produced in **1964.** Her interpretation was that the immigrant population was probably larger in 1949 than in 1964. Another difference she listed was that breeding ended in October 1964 after which some gregaricolor swarms formed and moved westwards but failed to produce gregarious progeny. In contrast, the 1949 monsoon rains continued to support breeding until December, so that two to three generations of swarms were produced before a large swarming population moved westward in November and December. Widespread gregarious breeding followed in the spring of 1950 in the Eastern Region and in the Central Region in Arabia and on the Horn of Africa where a concurrent upsurge was developing. Neither account describes ecological conditions in **1965** but another source suggests that it was dry because it reports the 1965 populations as the smallest for 27 years (FAO, 1966).

57. Authors studying subsequent upsurges sought evidence to test these hypotheses and they assessed the role of both control and migration on observed and inferred developments.

The plague upsurge and decline 1966-1969

58. *This upsurge (Figs 7a-h) started in the Central and Western Regions. Rains in the winter and spring of 1966/67 supported simultaneous outbreaks in both regions that developed into a series of upsurge sequences during 1967, the more serious being those in the Central Region. An initial warning was issued in December 1967 as the scale of infestations in the Central Region became apparent around the Red Sea, the Gulf of Aden and in Oman. Three or four generations had bred in Oman in 1967 before invading Iran in the Eastern Region and augmenting populations around the Gulf of Aden. Greatly increased populations bred around the Red Sea and Gulf of Aden during the winter and spring of 1967/68. Heavy rains supported further population increases in these areas and in the interior of Arabia and FAO warned that this was the last chance to prevent a plague developing.*

59. *The spread of the plague began in the summer of 1968 when spring swarms from the Central Region not only heavily infested local summer breeding areas but augmented swarms breeding in the Eastern and Western Regions. In the Eastern Region, summer breeding was unsuccessful mainly because the vegetation began to dry out in August and the plague ended in this region. The heaviest summer breeding was in the Sudan and western Eritrea that had received swarms from Arabia and the Somali Peninsula. The control campaigns were ineffective until aerial control was mounted against the fledgling swarms. This improvement came too late and swarms moved eastwards to the Red Sea coasts and westwards to northern Mauritania, Western Sahara and southern Morocco in September and October. At the same time, swarms that had spent the summer in northern Somalia moved southwestwards and began to mature and lay. During the winter and spring, the plague ended due to a combination of control, poor rains and migrations to unfavourable habitats.*

Data sources

60. FAO (1968) and Pedgley and Symmons (1968) provided initial analyses of this upsurge for the DLCC. The former examines the origins of populations present in April 1968 and effectiveness of survey, control and forecasting during the period. The latter looks more closely at the weather involved. These preliminary findings were examined in depth by Bennett (1974, 1975, 1976). Her accounts and maps form the basis for descriptions of the period from 1966 to 1969. She used the summarized data sent to the Centre for Overseas Pest Research (COPR formerly, ALRC) and supplemented them by

meeting national control teams to discuss key issues and to collect more detailed records available solely in affected countries. Non-swarming infestations included in her study were reported groups, groups interpreted from reported densities (Table 2) and, lower density infestations that were controlled or which the author deemed ‘might have been important’.

Table 2. Assigned limits for the class groups from reported survey densities (after Bennett, 1976)

Definition	Number /m^2	Number /km^2	Number/ traverse	
Adult groups or concentration	> 500/ha; 1/20 m^2	> 50 000/km^2	foot traverse >25/100 m	vehicle traverse >250/km
Hopper groups or concentration	Vegetation uniform 100/m^2 area >25m^2 10/m^2 area 25-250m^2 5/m^2 area >250m^2	Vegetation tufted 10-100/tuft area >2500 m^2		

61. Her methods of estimating numbers of locusts within swarming and non-swarming infestations from typical survey reports are discussed fully in Bennett and Symmons (1972a). She estimated the numbers of swarms taking part in seasonal breeding and their total area. She estimated the number of swarms by excluding probable duplicate sightings and multiplied this number by the average reported swarm size to give a rough estimate of the total swarm area. Bennett warns that the reported size of many swarms was overestimated because few were actually measured. She explains how she reached each estimate in her thesis but not in her 1976 article.

62. Her assessments of control effectiveness were based on methods and assumptions discussed in Bennett and Symmons (1972b). These methods allowed her to judge whether the quantity and type of pesticide applied was sufficient to kill the target population. She defined ‘gross infested area’ in her study as that requiring treatment to eliminate a population. Her method of calculating this value should be clarified if comparable studies are to examine the representative nature of her findings. Bennett used meteorological charts of the Desert Locust area plotted daily at COPR for her studies of synoptic weather situations. These were supplemented with Northern Hemisphere Data Tabulations published by the US Department of Commerce and published daily synoptic data and charts from affected countries that were archived at COPR. She used monthly rainfall data from the COPR archive including some collected specifically for her study. These were records mainly from meteorological and hydrological services but were supplemented by rain gauge records from locust control organizations and oil companies. Waloff and Roffey (1981) also describe this period.

63. Bennett’s (1974, 1975, 1976) detailed study of the 1966-1969 upsurge and plague provided evidence suggesting that control to prevent plagues might always be protracted. Her argument centres on her finding that most locusts early in the upsurge sequence did not behave gregariously and so were not control targets and survived to continue the upsurge. Here, as in Bennett (1976) population developments are described before details on the effectiveness of control are considered

Plague Upsurge

64. Bennett identified four within region upsurge sequences in 1966, which became linked by inter-regional migrations of adults from the autumn of 1967. Two of these sequences were on the Arabian Peninsula. The third linked the Red Sea coasts with the interior of the Sudan whilst the fourth linked the mountains of Tibesti (Chad) and southern Algeria with each other and with the Sahel (Figs 7a-d). Events in the **Central Region** in **1966** and **1967** include an important plague upsurge sequence that was traced back to three periods of heavy rains in the southeastern interior of the Arabian Peninsula. The first in November 1966 affected 20 000 km^2, and the second and third affected 200 000 km^2 between March and April 1967. Locust sightings, unreported until Popov's 1968 visit to the region, led to the hypothesis (Popov, 1968; Bennett,1976) that locusts bred three times within these areas to produce many gregarizing locusts and small swarms in autumn 1967 (see Chapter 1, paras 54 and 55). In December 1967, some locusts from Oman emigrated to the Eastern Region whilst others augmented migrants moving from a contemporaneous upsurge sequence that began in the interior of Yemen to the Gulf of Aden coast and across the Gulf to Somalia (Fig. 7c). This second sequence had been initiated by unusually heavy rains in southwestern Arabia from March to May 1967 associated with mid-tropospheric troughs that brought rain to southeastern Arabia in March and April. Locusts were poorly reported but it is probable that breeding occurred and that in some areas a second generation bred on the summer rains. By the autumn many scattered locusts were probably present but little gregarization

was inferred. In Somalia, population increases probably started after extremely heavy rains in May 1967 and continued during the summer as additional rain fell in June to August. (Pedgley and Symmons, 1968) Elsewhere in the Central Region, numbers increased in southeastern Egypt during spring 1966 following good local rains. The scattered adults were assumed to have moved to Sudan and bred during the summer.

65. In the **Western Region**, the initial build up of populations in **1966** and **1967** is even less clear (Figs 7a-d). A tentative link exists in September 1966 between infestations in Tibesti and the population in Mouydir, Algeria that bred in spring 1967. Alternative or additional sources were to the northeast and south of the Mouydir. Numerous progeny survived control and the population may have included small swarmlets. The locusts moved southwards in June, some to the Adrar des Iforas in northern Mali and others to the Sahel. Summer rains were heavy in both areas, which allowed successful breeding.

66. A major redistribution of locusts occurred after summer breeding in 1967 (Fig. 7d). The **Central Region** contained the largest numbers of locusts most of which were on the Arabian Peninsula. Emigration almost certainly took locusts from the southwestern interior to the Yemen and Saudi Tihamas on a small scale in the summer but in greater numbers in October. The southwest of Arabia is also the likely source of locusts that crossed the Red Sea in October 1967 to coastal Eritrea and Sudan and those that moved southwards to the Gulf coasts of Yemen and Somalia. Locusts from southeastern Arabia emigrated in December 1967. Some augmented a second migration from southwestern Arabia to the Gulf coast and to Somalia. Local breeding was in progress from September in Somalia and probably Djibouti. These areas received exceptionally heavy rains in October and November (Djibouti, November 282 mm compared to the average of 23 mm). Consequently, breeding conditions were excellent for the mature swarm that reached northwestern Somalia in mid December 1967 and laid eggs (Pedgley and Symmons, 1968). Other swarms from Oman moved on southerly winds ahead of a depression to Iran in the **Eastern Region** in December 1967 and by spring 1968, had moved eastwards and northwards to the Mekran areas of Iran and Pakistan. A third source of summer 1967 locusts in the **Central Region** was the Sudan. From there, some locusts probably moved directly to the winter breeding areas on the Red sea coast where they were joined by others from southwestern Arabia as noted above. Others bred from September to December along the migration route in small patches of cultivation totalling 50 km^2 in Kassala and Northern Provinces before emigrating to the coast in November and December. Emigrants from summer breeding in the Sudan may also have moved in the autumn to the Mourdi depression in Chad. It is more probable, however, that this area in the **Western Region** was invaded by a minority of the locusts from summer breeding in the Sahel, most of which moved to the Tamesna of Mali and Niger and took part in the well documented gregarization observed by Roffey and Popov (1968).

67. Widespread and heavy rains fell during the **winter and spring 1967/68** and breeding was successful in many areas (Figs 7d-f). As numbers and densities rose an increasing proportion of populations were reported as behaving gregariously and FAO issued a first special warning on 27 December 1967 that a plague could follow if spring breeding were successful. This was the first time that a warning was made so early in an upsurge. In mid May, following successful spring breeding, ALRC and FAO issued a second special warning that 'this was the last opportunity to prevent a plague'. The events leading to these warnings follow. After the redistribution of summer populations, the largest 1967 populations were in the **Central Region** on the coastal plains around the Red Sea and Gulf of Aden. Heavy rains fell in October and November 1967, breeding was successful and groups and some swarms formed in southern Yemen and on the Yemen and Saudi Tihamas mainly from January 1968 and continued to breed. In March 1968, many locusts moved from the Tihamas into the Arabian interior where 30 000 km^2 were suitable for breeding following rains in November and February. Breeding conditions were enhanced by rains averaging 50 mm falling in April over most of central and northern Saudi Arabia. Spring breeding took place within a gross area of 100 000 km^2 greatly exceeding anything earlier in the upsurge. Despite control, many swarms formed between late June and August. Gregarization also followed two generations of breeding on the Sudan-Eritrean border but very large control campaigns in both countries had killed most of these locusts by April 1968. The campaign against locusts breeding on the northwest Somali coast within a gross infested area of about 4000 km^2 was less successful. Heavy rains and luxuriant vegetation made access difficult and the locust targets remained diffuse until after the second generation had fledged in late April, when about 20 swarms formed. Most emigrated in May (see para. 70).

68. In the **Western Region**, winter and spring breeding in **1967/68** occurred in Chad, Mali, Niger, Algeria and northern Mauritania. In Chad, summer rains were limited and late autumn breeding was

confined to an area of about 20 km^2 and successfully controlled. Unusually heavy rain in northern Mali and Niger in August 1967 (In Abangarit, 17°54N/06°03E, 123 mm) allowed much larger scale breeding to occur. Roffey and Popov (1968; Roffey, 1981, 1994) first observed the waves of scattered immigrants concentrating preferentially in green areas and later within laying habitats. Hatching was successful and they estimated that the parent generation of 5 million had multiplied sixteen fold by the fourth instar in their 2500 km^2 study area. Bands, hopper and adult groups were produced. Some remained *in situ* whilst others moved northwards in December and again in February and March to the Hoggar of southern Algeria with some possibly reaching the Draa Valley of Morocco and adjacent parts of Algeria and Mauritania in February and March 1968. Heavy rains supported spring breeding in 1968 that produced swarms in northern Mauritania, the adjacent parts of the Draa valley in Morocco, as well as in the Hoggar of Algeria. Up to 10 small swarms moved from northwestern Africa in June and July southwards into central Mauritania where they dispersed before breeding. A slightly larger number of very small swarms (each about 1 km^2) formed in the Hoggar mountains of southern Algeria and moved to Adrar des Iforas in Mali and possibly farther south. Swarms found in Aïr and Tamesna in Niger in early summer either were immigrants from the Hoggar or had formed locally from late spring breeding.

69. Winter and spring breeding also occurred in the **Eastern Region** in 1967/68. The parts of Iran and Pakistan that were invaded during the previous autumn received heavy rain in February 1968. Amounts falling along the infested Mekran coast averaged over 70 mm. Hopper bands appeared on the coastal plain and further north and many swarms formed by June and moved eastwards to the Indo-Pakistan summer breeding area in July

70. In May 1968, the largest spring populations were in the **Central Region** in northern and central Arabia and on the Tihama when FAO issued a second Special Warning. When it started in late May **1968,** emigration southwestwards from Arabia to Africa involved mainly mature swarms and possibly scattered adults (Fig. 7f) whereas swarms of all maturities continued to emigrate in June. Half the population (swarms totalling 340 km^2) reached the summer breeding area in the interior of Sudan but a few groups and a swarm remained in southeastern Egypt and near Tokar to breed. In June, the direction of migration changed and swarms moved southwards through the interior of the Arabian Peninsula, a direction associated with sources in the interior (Karrar, 1972)[6]. A few of these swarms bred on the coastal plains of southern Yemen but most crossed the Gulf of Aden to Somalia from mid-August and began to breed in September. Swarms seen in Oman at Salalah and Sur (22°34N/59°32E) in July possibly represent the eastern edge of this emigration. An alternative source for the Oman swarms was Iran as there were unusual spells of north and northeasterly winds. Swarms were also produced on the Somali Peninsula during spring 1968 and in May, about 15 of the 20 swarms (totalling 50 km^2) moved west and then northwards through the Danakil and northern Ethiopia into Eritrea. In June, some swarms continued into the Sudan eventually joined those arriving from Arabia. In May, one or two swarms remained in the Railway area of Ethiopia whilst others moved eastwards along the convergence zone that lies close to the escarpment, and matured and laid in the northeast of Somalia (Fig. 7f).

The plague in 1968 and its decline

71. By summer, 1968 a plague had started and many countries were infested with gregariously behaving locusts. During the summer, drought and control reduced or eliminated some populations in all three regions (Figs 7f-g). The largest population was in the **Central Region** in the Sudan and adjacent parts of Eritrea. In Eritrea, hoppers bands were in very inaccessible valleys and many were probably not found. The hoppers that escaped control, fledged in June and July and a successful aerial campaign was waged against the young swarms. In contrast, summer breeding was very extensive in the Sudan but the large ground baiting campaign was unable to cope with the hopper bands located within an area of 11 000 km^2. As a result, many swarms formed and emigrated to the west and to the northeast in the autumn to continue the plague. Summer breeding elsewhere in Africa was on a smaller scale. In the southeastern desert of Egypt, poor breeding conditions and control killed the progeny of swarms that laid in late May and early June. In Somalia, one or two swarms bred and produced at least a similar number of progeny. In **West Africa,** breeding occurred in Mauritania, Mali and Niger but over a much smaller area than in Sudan and most locusts were controlled. In the **Eastern Region,** at least 14 swarms invaded the Indo-Pakistan summer breeding area but the monsoon rains failed and by autumn, the plague had ended in this region.

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[6] Karrar inferred that swarms from the interior of Arabia move south and eastwards but not westwards to the Sudan from observing that swarms reached the Sudan between 1940 and 1960 when the Tihama and interior of Arabia were infested but not when solely the interior was affected.

72. After summer breeding, the largest swarming population (estimated total 600 km^2) was in the interior of the Sudan (Fig. 7g). About half of the population moved westwards in the autumn and eventually concentrated south of the Anti-Atlas Mountains in Morocco where they were joined by survivors of control in the **Western Region**. Almost all were killed by aerial spraying during the **winter 1968/69** whilst temperatures were too low for maturation and egg-laying (Figs 7g-h). The other half of the population stayed in the **Central Region**. Swarms moved northeastwards from the Sudan with survivors from the Eritrean campaign to two areas bordering the Red Sea that were near the northern and southern borders of coastal Sudan. November rains were heavy enough for successful breeding in both areas. Barrier spraying within a 2000 km^2 area virtually eliminated the progeny in the south. Baiting and ground spray was sufficient to reduce significantly, but probably not to eliminate, the northern population as some fledgling swarms were seen. The subsequent complete decline of this more northerly population was tentatively linked to unrecorded predation or parasitism. The origin of the population on the Saudi Tihama in late 1968 is less clear and was considered mainly to be a new outbreak initiated by good rains in November 1968. Bennett (1974) suggests that a swarm crossed the Red Sea in autumn 1968 and augmented locusts in the northern Tihama. Farther south, solely scattered adults and groups of locusts from the southwestern interior of Arabia, formed the parent population of the spring 1969 hopper and adult concentrations. An estimated 450 million locusts, equivalent to about 9 km^2 of swarms, were located in three areas and were eliminated by large-scale ground and aerial spraying (see para. 80).

73. Elsewhere, swarms had moved through Saudi Arabia to southern Yemen in summer 1968 where they bred during the autumn (Fig. 7g). Rains were poor and the bands, limited to well-defined areas, were found easily and controlled. The swarms that had continued south and crossed the Gulf of Aden concentrated near the Somali-Ethiopian border where they were joined by a few swarms from summer breeding in northeastern Somalia. About 16 swarms totalling 400 km^2 were present of which around 25 percent was controlled before breeding started. Breeding was successful in autumn 1968 and 11 swarms (totalling 300 km^2) formed in January 1969 despite control against the hoppers. A short intense aerial campaign was mounted against these swarms as they started to move westwards. Not more than 75 percent were killed before the survivors moved into the Ethiopian Highlands where they died without producing any gregarious progeny (Fig. 7h). A critical factor in their destruction was the abnormal easterly rather than northerly component to the winds that took the swarms into the highlands rather than the more suitable breeding areas of Somalia and Kenya. In the **Western Region**, locusts that survived the summer campaigns did not return to Morocco but laid eggs in a few restricted sites in Mali, Niger and Algeria. Their progeny was successfully controlled. The plague had ended in all three regions.

Rainfall and successful breeding

74. Bennett (1976) considered the effect of rain and control on this upsurge and short plague and agreed with Magor (1962) that about 20 mm of rain falling in a short period or its equivalent in runoff provides suitable habitat conditions for widespread egg laying. Bennett also determined rainfall required for successful breeding which she defined as an increase in numbers from mature parents to filial fledglings. She considered rainfall in the month of laying and during egg development and suggested that the 25 mm required for the germination of the ephemeral plants, which provide food and shelter for hoppers, was the minimum amount for successful breeding. She found that an additional 5 mm was sometimes required during hopper development. During summer, she suggests using higher thresholds of 30 and 35 mm. This higher threshold is usually exceeded in summer breeding areas. Falls exceeding 25 mm in winter and spring over wide areas are most often associated with deep troughs in the mid and upper tropospheric westerly winds. Bennett adds that seasons in which many such troughs occur are associated with heavy rains falling several times in a season over many parts of the latitudinal belt in which breeding occurs. These seasons are often associated with weak zonal circulation bringing rain bearing depressions farther south during the winter and spring (Winstanley, 1973b).

75. Bennett further postulates that an upsurge, as opposed to local outbreaks, occurs when pre-breeding adult mortality is reduced. Two mechanisms were cited. The first was rains continuing to fall in source areas so that fledglings mature quickly and lay without emigrating to a complementary breeding area. Secondly, when rains in complementary breeding areas are sufficiently widespread for immature locusts to reach suitable breeding habitats when flying downwind in almost all directions.

Control and upsurge termination

76. Bennett used the most important plague upsurge sequence and three other campaigns to examine

the effectiveness of control at different stages in the upsurge. The main plague upsurge sequence, which started in southwestern Arabia in 1966, ended seven generations later in Morocco, and on the western coast of the Red Sea (Fig. 6a). This sequence began with heavy rains falling in southwestern Arabia between March and May 1967. The first two generations (F_0 & F_1) that bred in southwestern Arabia in April, May and July 1967 were not controlled. Little control occurred against the part of the F_1 generation that bred on the Tihamas of Yemen and Saudi Arabia in summer 1967. Bennett estimated the gross infested area[7] for subsequent generations. Three generations (F_2-F_4) bred on the Tihama and in the interior of Saudi Arabia between November 1967 and May-August 1968. The gross infested area (Fig. 6b) expanded very rapidly from 20 000 km^2 for the F_2 generation that spread along the Tihamas in autumn 1967 to a maximum of 100 000 km^2 when the F_4 generation spread into and bred across northern and central Saudi Arabia. At the same time, population numbers increased from less than 1 x 10^9 (F_2) non-swarming locusts to 6 x 10^9 (F_4) breeding adults some of which were still not gregarious. Subsequent generations were fully gregarious and the gross infested area is shown separately for bands and swarms. The diagram shows the gross infested areas of bands decreasing from 11 000 km^2 (F_5) to 5000 km^2 (F_6) whilst swarms areas are shown as between 200 and 300 km^2 as locust numbers continued growing from 18 x 10^9 (F_5) to 30 x 10^9 (F_6).

77. The areas and locust numbers presented by Bennett require careful interpretation. Arabia produced swarms totalling about 600 km^2, of which the Sudan received about 340 km^2. Consequently, the dramatic fall in gross infested area of bands is caused partly by only half the population produced in Arabia emigrating to Sudan in May and July 1968 and the shortfall being only partially offset by about 50 km^2 of swarms from Somalia joining the sequence in Eritrea and eastern Sudan. In addition, swarms of the F_6 generation in Morocco were virtually eliminated before spring breeding began. Nevertheless, a large rise in numbers whilst the gross infested area is falling is highly significant for control tactics. A large ground campaign (baiting and dusting) was mounted against hopper bands in the Sudan and Bennett argues that such a large area (11 000 km^2) should have been treated from the air. The ground campaign made little impact on locust numbers and about 600 km^2 of swarms formed. At this stage, aerial spraying began but only a small area of swarms (about 75 $km^{2)}$ was controlled before the rest emigrated. About half the surviving summer swarms emigrated to Morocco, which also received immigrants from the Western Region. The summer hopper campaign in Eritrea was in deeply incised valleys, mainly accessible only by pack animals, and an estimated 150 km^2 of swarms formed and moved to two areas of the western Red Sea coast. It was at this point that aerial campaigns in the Eritrean Highlands and Morocco eliminated most swarms before they bred and large-scale barrier treatment of bands on the Sudan-Eritrea border began. Locust numbers fell and the sequence ended early in 1969 (Fig. 6a). However, there was increasing realisation of the potential danger of using persistent chemicals, such as dieldrin, that accumulated in the food chain. Moroccan control teams began aerial spraying trials with contact poisons against swarms during this campaign and by its end, were using only non-cumulative pesticides.

78. Bennett (1974, 1976) examined the role of control in three other areas. One was northeastern Somalia where, in late 1967 and early 1968, attempts were made to find and destroy small hopper groups and bands in an area of about 4000 km^2. The wet weather and luxuriant vegetation made travelling and locating locusts difficult and the campaign was unsuccessful. Populations remained diffuse until the second generation when loose flights of fledglings and many small swarms formed. Spraying began but the locusts emigrated before many were killed. Most reached western Eritrea where a large proportion totalling about 50 km^2 were sprayed. However, since control was undertaken after eggs were laid, the sequence continued. Many resulting bands escaped control (see para. 71) but aerial spraying killed most young locally produced swarms and those arriving from Sudan before they reached the coast.

79. The second, in West Africa, showed that spraying a substantial part of early infestations stopped swarm formation but not the upsurge sequence. The sequence ended when gregarious populations were sprayed. This sequence started in the northern Algerian Hoggar in spring 1967. Hopper groups and bands formed in an area of about 2000 km^2. Ground control by baiting and dusting left many survivors that moved southwards in dispersed formation. Summer breeding was found only in two areas and a few targets were sprayed. A much larger dispersed population bred in the Tamesna of Mali and Niger in the autumn. About 2500 km^2 was infested and about 300 km^2 sprayed. This prevented swarm formation but

[7] Bennett defined gross infested area in her study as that requiring treatment to eliminate a population. Her method of estimating such areas is not specified. She may have derived these values from areas reported to be infested or from the area contained within a polygon drawn around an infested zone. The importance of establishing her methodology is covered in the discussion.

did not end the upsurge sequence. The many survivors dispersed and bred over a wide area in the Hoggar of southern Algeria in the spring and small amounts of spraying and baiting again failed to reduce the population greatly. Several small swarms formed around the Hoggar Mountains and ground teams treated them with little success. These swarms bred in the summer in the Adrar des Iforas and ground spraying bands in the much smaller area began to reduce numbers. Autumn breeding was limited and ground and aerial spraying of the bands in Mali and Southern Algeria ended the sequence.

80. The third example relates to an upsurge on the Saudi Tihama that was initiated by heavy rainfall in November 1968. This example indicates the size, cost and environmental risks involved in eliminating early upsurge stages using different spraying techniques. In spring 1969, the second generation was forming concentrations in three areas. Two infestations in the south near Jeddah measured 1400 km^2 and 2500 km^2 and contained an estimated 150 million non-gregarious locusts. These two areas were blanket sprayed from the air with 74 000 litres of 20% dieldrin. The third area at Khulais north of Jeddah measuring 500 km^2 was probably linked to a swarm arriving the previous autumn, as samples were more gregariform than those near Jeddah. In mid April 1969, the scattered locusts and late instar groups and bands at Khulais were treated by ground application of 4500 litres of 20% dieldrin sprayed as barriers across the line of marching bands and along wadi banks where hoppers were concentrating. Bennett estimates that the sprayed area was about 90 km^2 and that some less gregarious locusts survived. In May, a small (5 km^2) area of bands found 125 km farther north near Umm Lajj was successfully target sprayed. Elsewhere, only a few groups and scattered locusts were found that did not require further control.

Recession upsurge 1972-1973

81. *In July 1973, the Desert Locust Early Warning System ceased to have a central information and forecasting unit. Instead, five regional units based at the three FAO Regional Commissions (Northwest Africa, Near East and Southwest Asia) and the two Regional Control Organizations (OCLALAV and DLCO.EA) shared this role. FAO agreed to provide monthly summaries for the whole area and the previous central forecasting unit at COPR received reports and wrote six-monthly summaries of Desert Locust developments (FAO, 1972a). Documents from more than one of the regional forecasting organizations bore headings suggesting that they were intended as emergency warnings. Only those issued by FAO were accepted as such for the purposes of this report.*

82. *This upsurge involved population increases in southeastern Arabia, around the Gulf of Aden including the interior of southwestern Arabia and along the shores of the Red Sea. Karrar (1974) concluded that winter breeding around the Red Sea and Gulf of Aden were more important than the uncontrolled breeding in Oman in initiating this upsurge and that timely control and lack of good spring rains caused its end. He postulated links between this upsurge and an outbreak in the Eastern Region in 1973 (Pedgley and Betts, 1981) but not others in 1974 in the Eastern (Venkatesh, 1975) and Western Regions (Skaf, 1978)*

Data sources

83. Unfortunately, no analysis of the build up of populations before the autumn of 1972 exists. Two DLCC Reports describe events in the **Central Region** during this period (FAO, 1972a, 1973). The Desert Locust Information Service at COPR, which prepared the summaries for FAO, had access to reports exchanged by affected countries, or made on FAO special surveys. They also had access to daily weather charts of the area and rainfall records. Karrar (1974) studied one winter-spring period (October 1972 to May 1973) in the Central Region. His text and acknowledgements suggest that he used summarized reports from affected countries around the Red Sea and Gulf of Aden, spoke to campaign managers and had access to synoptic weather maps to support his migration studies and rainfall records for assessing the suitability of habitats for breeding.

Upsurge populations

84. Important developments occurred in Arabia, in Somalia and in Djibouti before the period covered by Karrar's study. In the Gulf of Aden area, rain fell on part of the north Somali coast in every month from November 1971 to June 1972. Breeding caused substantial population increases in **Somalia and Djibouti** and control started in March and ended in the beginning of July **1972**. Two areas in **Arabia** also experienced notable summer breeding in 1972. In **southeastern Arabia** breeding started after a tropical storm brought heavy rains to southern Oman in December 1971. Rains continued to fall, within Oman, each month until May 1972 and then again at the end of June and beginning of July. FAO

mounted special surveys to investigate locust numbers after these rains. The first in March found few locusts but another in May and June found extensive areas infested by bands and fledglings and the largest (80 km^2) contained day-flying adults. Emergency control measures were undertaken and few locusts were found by the follow-up survey in late July. It was postulated that swarms seen in India during July had arrived from Oman. Poor rains in India during the summer prevented further upsurge developments from this sequence. Other locusts were assumed to have stayed in unsurveyed parts of Oman and bred on the summer rains to give rise to the young immature swarms and high density adults found during a survey in southeastern Oman during September. Summer breeding also occurred in **southwestern Arabia.** Breeding was in progress in the Hadhramaut (Yemen) and an unconfirmed report of a loose swarm occurred nearby in August 1972. Farther west, in the interior of southern Yemen control occurred against bands and groups in August. Breeding spread to the coastal plain and control occurred in September and October. Other areas infested with scattered breeding during the summer were the Asir, the southern Tihama of Saudi Arabia and the Yemen Tihama.

85. Karrar described reported infestations in each country around the southern Red Sea and Gulf of Aden from October 1972 to May 1973 and sought the most probable links between them to explain the appearance of swarms at Tokar in the Sudan in mid-December 1972 and in the Qunfidah (19^o09N/41^o07E) area of Saudi Arabia in January 1973. He did not investigate the origins of summer population in these areas and in Oman. He did suggest that swarms seen in Oman in September 1972 may have moved westwards on seasonal easterly winds from October and have been the source of a swarm seen in El Abr (16^o08N/47^o14E) in southern Yemen in early December 1972. Karrar did not discuss the possibility that the El Abr swarm was produced locally.

86. Karrar argues plausibly that the mature yellow swarm seen in Tokar on 13 December was from elsewhere because the locusts looked quite different from the previously solitarious local populations and were judged to be too numerous to have developed from the small infestations in Sudan and Eritrea. Larger mature populations were present on the Saudi coasts including a mature swarm seen on November 17 and having identified winds favourable for a Red Sea crossing on 9, 12, 13 December, Karrar concluded that the swarm in Tokar had originated on the Saudi Tihama although no swarms were seen there between 17 November and mid January. Karrar did not discuss breeding in the interior of the Sudan during the summer and autumn as a potential source of the Tokar swarm. Karrar did not discuss the origins of the swarm report in Qunfidah on 17 November and concluded that the swarms seen there from mid January were mainly of local origin. Suitable winds existed to transport swarms from the Sudan and Eritrea but too few adults were present for this to have been the source. Karrar also rejected as implausible swarms from Oman via the southern coast of Yemen moving northwards to Qunfidah along the Yemen and Saudi Tihamas without detection.

87. The Desert Locust Bulletins issued from August 1972 until the end of the year carried warnings that the locust situation was potentially dangerous. Good early winter rains fell on the Red sea coasts and breeding started in Sudan, in Eritrea and on the southern Tihama of Saudi Arabia. Control began in December 1972 continuing only in Saudi Arabia where the campaign ended in April. Elsewhere, two cyclones brought heavy rains to northern Somalia, Djibouti and southern Yemen in October and November 1972. The cyclones probably also transported locusts into these areas and surveys in Somalia recorded increased numbers of locusts after their passage. The locusts bred and control began in December and continued throughout the spring.

88. The situation in December 1972 closely resembled that preceding the 1968 plague. Consequently, COPR warned FAO (on 22/12/72) that good spring rains could precipitate a plague. The FAO press release on 22 January 1973 noted that the population increases were potentially serious and were being investigated. In the event, spring rains were not conducive to continued population increase and control measures gradually ended the upsurge. Pedgley and Betts (1981) inferred that adults from this upsurge invaded the Eastern Region during April and May 1973 and moved with local adults to the summer breeding area where gregarization occurred. In March (02/03/73), FAO issued a **Special Warning** noting that a serious situation had been averted on the Tihama but continued in Somalia and a Special Report on 24 May, ignoring the poor rains, states that ‘extensive control had averted the threat of a plague arising'.

Central Region recession populations 1974-1976

Data sources

89. No detailed account exists of Central Region Desert Locust populations in these three years.

Accounts used here appeared in Desert Locust Newsletters (FAO, 1974, 1975b, 1976a, 1977). For each month in 1975 and 1976, the types of populations seen in each country were tabulated (FAO, 1976a, 1977). FAO noted that 1962 to 1976 was a longer recession than any recorded by Waloff (1976) and concluded that the coordinated control campaigns at national, regional and international levels against upsurges were responsible for the absence of plagues lasting seven or more years during this period and for the one in 1968 ending within one year (FAO, 1977). Central Region populations at the end of 1976 took part in the 1977-1979 upsurge described in the next section.

Outbreak and Upsurge populations

90. Upsurges took place in the **Eastern and Western Regions** in 1974 (Venkatesh, 1975; Skaf, 1978). An upsurge or at least a series of major outbreaks occurred in the **Central Region** but no case-study was written. Ground and aerial control of bands and swarms took place on the Saudi Tihama during spring breeding **1974**. Subsequently, summer breeding conditions were favourable in southwestern Arabia and control took place against bands and groups between July and September. In the autumn swarms and groups reached the Saudi Tihama and bred. On the western Red Sea coasts of Sudan and Eritrea, extensive aerial and ground control took place against similar spring populations in 1974. An immature swarm reached northern Eritrea in July when groups of hopper and adults were seen in Djibouti. Scattered adults moved to the interior of Sudan but breeding was not observed until September when groups of mature adults were controlled in Kassala. In October, bands and immature groups that appeared between the Nile and the Eritrean border probably arose from populations breeding in the summer. In November, swarms and groups invaded the western Red Sea coasts and laid eggs. Teams found no evidence to confirm the report of swarms from the north Somali coast in the autumn.

91. Control against spring populations occurred again in **1975**, in Arabia against bands and adults, which declined during March, and in the Sudan against groups of adults. Summer breeding and control was on a smaller scale in Arabia than in 1974. Despite good ecological conditions, only scattered adults were recorded during the summer in the Sudan but the re-appearance of groups on the coast in the autumn suggests that summer breeding had occurred in the interior. Bands that formed on the coast in the autumn were controlled successfully.

92. In **1976**, good rains fell for the third successive year and **all three regions** produced gregarious populations that were controlled and by the end of the year only low density populations remained. FAO issued two press releases in 1976. The first on 7 July, as summer breeding was starting indicated that a Desert Locust emergency was a distinct possibility. The second, on the 21 October noted that the locust had been brought under control but that populations could again become dangerous.

93. In the **Central Region,** spring generation bands, swarms and groups were controlled on the Saudi Tihama within an area of 4000 km^2 from January to April. In the interior only scattered adults were found but farther east heavy rains fell in Kuwait, Central and Eastern Saudi Arabia and in Oman and led to population increases requiring control. Scattered locusts were present in Oman in February and March. Bands with fledglings were seen south of the Hajjar Mountains in April and a swarm formed at the end of the month. Control was mounted against these locusts and surveys later in May and June found only scattered adults. Bands were also controlled on the Kuwait/Iraq border in May and the area was reported locust free by June.

94. Locust numbers were low in the Yemen from January to May 1976. Rains fell on the Yemen Highlands in May and June and on the southern coastal plains in early May. An immature swarm reached Sana'a in June and late instar hoppers were controlled west of Aden. Summer breeding habitats were not favourable and no large population increases occurred. Only low numbers were found in the autumn despite good conditions on the southern Saudi Tihama. Little rain fell in Yemen where scattered locusts were seen. Scattered locusts were also present on the Batinah coast in November.

95. In the African part of the Central Region, a potentially serious situation existed on the Red Sea coast of the Sudan from January to April. Swarms and bands were controlled in the Tokar Delta and south towards the Eritrean border. Similar populations were probably present in Eritrea where Massawa had received a record daily total of rain in December (346 mm) and a further 58 mm in February. Winter/spring breeding started in November in the Sudan and control began against groups of first to fifth instars hoppers and fledglings in December. Mature adults and hoppers were also present on the northern Eritrean coast in December.

96. On the Somali Peninsula, scattered adults were present from January to April and moderate to

heavy rains fell over the Harar Hills and northwestern Somalia in April and May. Successful breeding followed and bands formed in June. Control occurred in July and August against hoppers and fledglings and continued into September against adult concentrations and some hoppers. Scattered immature adults were widespread in October and in December, mature locusts were present on the north coasts where breeding conditions were good.

The plague upsurge and decline, 1977-1979

97. *When this upsurge began, the Early Warning System still had five regional units, which were insufficiently staffed to absorb upsurge workloads. Consequently, as staff organized control campaigns, mapping and analysis for forecasting became inadequate and a major inter-regional migration was not predicted. The conclusion relearned was that forecasters require access to data from the whole distribution area and a centralized forecasting unit was established at FAO, Rome in August 1978 (FAO, 1979).*

98. *Six separate groups issued warnings as the situation deteriorated but only those issued by FAO are recorded here. FAO having concluded that control could prevent or curtail plagues (see para. 88) overestimated the capacity available to control plague upsurges. The warnings reflect this confidence. The first of two press releases in July 1976, warning that a locust emergency was a distinct possibility was followed in October by a second reporting that populations were again under control but could explode again. No warning was found in the 1977 archives although following good rains populations increased. The first special report (3 February 1978) was issued to counter press claims that a plague was developing because campaigns were expected to contain the potentially dangerous situation. By 8 March, however, FAO realized that the Central Region had insufficient supplies to maintain adequate air and ground control. Later that month, FAO released money from the Working Capital Fund. Roffey (1982) lists the amounts released by FAO and contributed by donors. Experts planned anti-locust action against the upsurge in June 1978 and called it a plague when they next met (November 1978).*

99. *Roffey (1982) identified four upsurge sequences, renumbered here, that started within the Central Region in 1977 and suggested tentative links back to earlier populations (Figs 8a-d). Areas initially involved were the interior of the Sudan (sequence 1), the United Arab Emirates (sequence 2), southwestern Arabia (sequence 3) and the Yemen and Saudi Tihamas (sequence 4). Roffey postulated several migrations linking sequences. Locusts from sequence one may have moved from the Sudan to Saudi Arabia (sequence 4) in autumn 1977 and from southern Eritrea to the railway area of Ethiopia (sequence 2) in May 1978. Roffey also inferred that swarms left southern Eritrea (sequence 2) in May and bred from mid June 1978 in the highlands of Ethiopia (sequence 1). Infestations reached early plague levels when in summer 1978 they had spread within the Central Region and had invaded the Eastern Region. Subsequent campaigns applied sufficient control measures and this short plague ended in March 1979.*

100. *Sequence one began in the interior of the Sudan in the summer of 1977. It was traced for five generations between the Red Sea coast and the interior of Sudan and was ended by control early in 1979. Sequence two, the most important, was traced for seven generations. It started with heavy rains after which three generations (F_0, F_1, F_2) bred, first in the United Arab Emirates and then in Oman. The resultant progeny that was gregarizing emigrated to southern Yemen, Somalia, Djibouti and possibly southern Eritrea in autumn 1977 where timely rains supported increases among local populations augmented by immigrants for the next two generations (F_3, F_4). The destination of resultant swarms differed. Emigrants departing in April and early May 1978 moved inland across Somalia. Other swarms continued breeding in northeastern Somaliland and immigrants, probably from Eritrea, bred nearby in the Railway area of Ethiopia (F_5). Early June emigrants from Somalia reached the summer breeding areas of the Eastern Region. After two successful campaigns in India and Pakistan (F_{5b}, F_{6b}) only a few swarms moved westward and dissociated ending this part of the sequence. Swarms (F_{5a}) that had stayed in Somalia migrated southwestwards from late September 1978 and then bred possibly augmented by swarms originating from summer breeding in Eritrea. Control eliminated the hoppers (F_{6a}) in Somalia but in Ethiopia, young swarms appeared and bred again (F_7) from January 1979. This sequence ended in March 1979 when surveys found no locusts in Ethiopia. Sequences three and four were short. They occurred during the winter and spring 1977/78 but Roffey could not link them with certainty to earlier and later infestations. The third sequence was in southwestern Arabia from which Roffey postulated emigration to the Eastern Region and to northern Somalia (both sequence 1). The fourth involved the Tihamas of Saudi Arabia and the Yemen. These areas are often interlinked with the interior of Yemen and probably were in spring and summer 1978.*

Data sources

101. Roffey (1982) is the main source used. Briefer accounts of this period were presented to the DLCC (FAO, 1978, 1979). Roffey's analysis of the 1977-1979 upsurge and very brief plague is based on records received at FAO. He acknowledges help in obtaining additional data on control and on the vehicles, equipment and insecticides supplied with emergency assistance funds. He notes that official forms had ceased to be used and that, in many cases, the records lacked details available during the 1949-1963 plague. Roffey also used rainfall and habitat data sent with reports and ten-day rainfall summaries for Sahelian countries. He had access to Meteosat imagery for estimating rainfall between the sparse rainfall network and received copies of meteorological charts indicating convergence zones that were prepared for DLCO.EA by the Kenyan Meteorological Department. Synoptic charts for the whole Desert Locust area were not produced between August 1978, when the service moved to Rome, and May 1979. Consequently, Roffey could not study all locust immigration in relation to concurrent windfields and synoptic weather systems. Instead, he used swarm displacements established in earlier studies to determine the likely role of available sources. This account describes the four upsurge sequences identified by Roffey. Maps, (Figs 8a-d) show these sequences in relation to one another. The discrepancies between the text and maps probably arose because Roffey's account contains inferred events and his maps show only reported facts.

Sequence 1: the western Red Sea coasts and the interior of Sudan

102. The most westerly sequence, identified by Roffey, began in the **interior of the Sudan** in the summer of **1977**. It was preceded by population increases leading to gregarization in two areas during the previous winter-spring breeding (Fig. 8a) which followed rains on the Red Sea coasts of Sudan and Eritrea in November 1976 and heavy January1977 rains in Libya. Control was mounted in both areas. Roffey tentatively suggests that survivors from Libya as well as from the Red Sea coast moved to the interior of the Sudan in the summer and bred. The progeny (F_0) migrated to the Red Sea coasts of Sudan and Eritrea by early October (Fig. 8b). Adults and swarms may have left this sequence and migrated to Saudi Arabia (sequence 4) between October and December 1977. The Sudan coast received the heaviest October rainfall ever recorded at Port Sudan; 64 mm fell whereas the average is 6 mm and the average for the wettest month, November is 43mm. Additional rainfall in December and January allowed two generations (F_1, F_2) to breed on the coastal plains and interior wadis between October 1977 and March **1978**. Roffey speculates that breeding in southern Eritrea was more extensive than reported and postulates emigration from this area to the Railway Area of Ethiopia and to the Eastern Region (sequence 2) in May 1978. The seasonal movement from the coast to summer breeding areas in the interior of the Sudan also began in May and continued into June.

103. Roffey does not assign the swarm migration into the Ethiopian Highlands in early June 1978 to any sequence. Possible sources are spring breeding on the coasts of Eritrea (Fig. 8c), or Somalia and the Railway area of Ethiopia where sequence two swarms were forming. Swarms must have laid eggs in the Ethiopian Highlands in mid June before heavy rains fell there in late June because hoppers were found in early July (Fig. 8d). Heavy rain and low cloud hampered the July aerial campaign. In August, the hopper infestations were estimated to be within an area of 4000 km^2 and ground spraying and aerial barrier spraying of laying swarms, eggfields and hoppers continued. Some areas were barrier sprayed in September before bad weather intervened. A new generation appeared and the campaign continued into October when some swarms began to move towards the winter breeding area on the coast where they augmented the populations in sequence one moving from the interior of Sudan. Other swarms that moved southeastwards into the Danakil were not traced subsequently.

104. Locusts that moved into the interior of the Sudan in May and June 1978 also experienced widespread rains in July. Wad Medani (14^{o}24N/33^{o}29E) received 348 mm in 48 hours and rains farther north caused widespread flooding. In August, heavy rains fell in the neighbouring provinces of Kassala and Red Sea and the Tokar delta reported the heaviest floods for many years. Breeding conditions were excellent, numbers and densities rose and the F_3 generation fledged and formed swarms from mid September. Some moved to the Red Sea coasts of Sudan and to Saudi Arabia (F_{4a}, F_{5a}) where winter rains had fallen but most bred again in the interior before their progeny (F_{4b}) migrated to the Red Sea coast in mid November and bred (F_{5b}). Control ended this sequence early in 1979.

Sequence 2: southeastern Arabia, the Horn of Africa and the Eastern Region

105. The second and the main sequence also can be traced from the winter of **1976/77**. It began in the **United Arab Emirates** following widespread rain in late December 1976 and early January 1977 (Fig. 8a). Locusts bred from February to mid April **1977** (F_0) and in June, a cyclone brought heavy rain to the

eastern Batinah coast that supported further breeding from late June to late September by one or possibly two generations (F_1, F_2). The progeny moved to southwestern Arabia, Somalia and possibly the southern coast of Eritrea, all areas where it had rained heavily in October 1977 providing exceptionally favourable breeding conditions for this sequence (Fig. 8b). In Hargeisa (09°31N/44°02E) 250 mm fell, whereas, the long term average is 16 mm. In Somalia and Djibouti, additional heavy rains fell between November 1977 and February 1978.

106. In northern Somalia, the early stages of breeding by local populations and immigrants from Oman were not reported, as there were restrictions on ground and air movements. Ground surveys began in January 1978 after travellers had reported infestations. Two generations (F_3, F_4) bred in rapid succession between November 1977 and March **1978** but, particularly in northern Somalia, flooding hampered initial ground survey and control. Aerial spraying began in March. Some swarms began to emigrate inland in April reaching Ok (08°55N/46°37E) on 9 May and Garoe (08°24N/48°29E) by 16 May (Fig. 8c). Others that continued to breed in northern Somalia fledged in mid-May 1978 (F_{5a}) as did the contemporaneous progeny of the mature swarms that reached the Railway Area of Ethiopia, probably from the Red Sea coast of Eritrea, in late March and early April. Control against the resulting bands and fledglings and all but one locally produced swarm had ended by 20 May when numerous reports of immature swarms came from the coastal escarpment between the Railway area and Erigavo (40°E to 47°E). These swarms had originated from breeding in Somalia, Djibouti, eastern Ethiopia, southern Eritrea and possibly southwestern Arabia and had concentrated along the seasonal convergence zone that forms each year as the Inter-tropical Convergence Zone (ITCZ) moves northwards and causes locusts to drift eastwards. Control was mounted where possible and swarms were sprayed by three aircraft in Ethiopia and a fourth in Somalia in late May. Adequate survey and control could not be mounted from Boroma (09°56N/43°11E) or Hargeisa during the eastern displacement of swarms and in late June, an estimated 600 km^2 of thin to medium density swarms were held against the escarpment. Intermittent reports of these swarms lasted until late September when northeasterly winds set in and they started to migrate southwestwards (Fig. 8d).

107. It is probable that some swarms moving along the Somali escarpment were transported on strong southwesterly winds to the **Eastern Region** at the beginning of June when several immature swarms reached Kutch in India. Ships reports from the Arabian Sea and locusts being washed ashore between Kutch in India and the Las Bela coast in Pakistan suggests that the invasion took place on a front of about 500 km for about a week (Fig. 8c). Roffey rejected the uncontrolled infestations in the eastern lowlands of Yemen as a major source of locusts reaching the Eastern Region stating that numbers were insufficient. Locusts matured and bred in India and Pakistan in the summer and infestations were thought to have been controlled by the end of July (F_{5b}). The reappearance of mainly mature swarms in August suggests, however, that unsurveyed areas along the border had also been infested. Roffey argues that these new generation swarms had matured rapidly in hot weather. The intensive air and ground campaign was renewed but second generation egg laying had already occurred and hopper and adult control (F_{6b}) continued until November (Fig. 8d). A few swarms moved westwards through Pakistan and Iran but none was reported after December. Groups that reached the United Arab Emirates and Oman in November were sprayed. The Eastern Region was possibly also the source of pink locusts that dispersed in southern Yemen in mid November.

108. In the Central Region, the southwest monsoon started to withdraw in late September and swarms moved southwestwards from the Somali escarpment (Fig. 8d). Teams sprayed the swarms as they matured and laid eggs from mid October in the north and east of the Short Rains breeding area, a restricted distribution that had not occurred since 1927. The subsequent campaign against hoppers and fledglings in Somalia lasted until early December. At the same time, breeding of unknown extent occurred in the adjacent part of Ethiopia from which some swarms escaped. They matured quickly and laid eggs after heavy rain fell in the Harar (09°20N/42°10E) area. Hopper control in Dire Dawa (09°35N/41°50E) using dieldrin began in early February and ended in mid March **1979**. Nearby, successful trials took place with propoxur and deltamethrin, two quick acting potential replacements for dieldrin. Widespread searches found no other gregarious populations, ending this plague sequence.

Sequences 3 and 4: the eastern Red Sea coasts and southwestern Arabia

109. The third of Roffey's sequences started in the **interior of Yemen** in December 1977 and ended in summer 1978. Earlier, a few locusts were seen in southwestern Arabia in spring **1977**. Widespread rain fell in April and there were showers during May and June. Hopper concentrations were controlled in April and hoppers and fledglings were controlled in May (not mapped). Breeding continued and an

8 km^2 area of *congregans* breeding was found and controlled in July 1977. Rains fell again in August but Roffey reports that locust numbers had fallen by September.

110. Heavy rains fell in southern Yemen in the second half of **October**, and again in November 1977. Small but increased numbers of locusts were found at the end of the year possibly indicating immigration from southeastern Arabia (sequence 2). Breeding and control were recorded in inland Yemen early in **1978** (Fig. 8c). Numbers increased in several coastal areas after rain in February and control began. Numbers again rose inland in April and an area of 300 km^2 in Wadi Hadhramaut was infested with hoppers of all instars that were controlled during May (not mapped). Farther west a small immature swarm was seen at the beginning of May when about 120 km^2 of late instar hoppers with fledglings and mature adults were controlled. Large numbers of immature and mature adults persisted into June. Summer breeding occurred after widespread July rains in coastal Yemen and control ended in October.

111. Antecedents of the fourth sequence bred on the Tihamas of Saudi Arabia and Yemen in the winter and spring **1976/77.** There was some control in Yemen but few locusts were seen on the Tihamas between March and November 1977. Roffey starts the fourth sequence on the **Saudi and Yemen Tihamas** in October and November **1977** when only low numbers of locust were known to be present (Fig. 8b). Reports that arrived later, however, revealed that breeding had started in Yemen in November and that considerable numbers of locusts were on the Saudi Tihama as far north as Yenbo before swarms arrived in December and laid eggs near Jizan when large numbers of adults were also seen laying. Roffey was unable to decide whether the swarms came across the Red Sea from the west, came from Oman or had developed locally. In early January **1978**, swarms laid again in Jizan, entered Yemen and started to lay from Wadi Hayran (16N/42E) south wards to Hodeidah (14^{o}48N/42^{o}57E). The early January 1978 hatchings near Jizan were from unreported egg laying, and eggs from the swarm hatched in mid January in Saudi Arabia and in the Yemen. In February, the infestations over an area of about 3000 km^2 along the Jizan Tihama and an aircraft joined the ground campaign there until February 25 and in March moved to the Yemen where a similar area of infestations was recorded. Escapes, including some swarms, moved inland in March and April and bred. Infestations in May were spread widely in the interior of Saudi Arabia (Fig. 8c). Whether some locusts from the Tihamas continued eastwards to Pakistan is less likely. Roffey also considered a westward movement into Sudan from the Tihama unlikely. Breeding and control lasted in Saudi Arabia until June and in Yemen until July, when this sequence ended.

Plague prevention preparedness

112. This period revealed severe weaknesses in control preparedness. Roffey found inter-related financial, technical and organizational inadequacies at national, regional and international levels that resulted in a failure to monitor, report, forecast and control many populations. Anti-locust organizations had been scaled-down during the long post 1963 recession leaving too few trained and equipped staff to cope with the sudden increased workload that accompanies the onset of a plague upsurge as opposed to local outbreaks or short upsurges immediately followed by poor rains, which characterize other recession years. Decentralized forecasters failed to appreciate developments fully and displacements between areas of separate responsibility were overlooked.

113. These problems were exacerbated by political instability that made key swarm producing areas inaccessible to survey and control teams. The Eritrean coast from which arguably most swarms reached the highland breeding area in June-July 1978 was one instance. The southern part of this coast was also, according to Roffey, the probable origin of spring swarms that moved through the Railway Area of Ethiopia to Somalia and on to India and Pakistan between June and July 1978. Survey and control was restricted during a period of gregarization in northwestern Somalia from November 1977 until March 1978 and control could not be mounted from Boroma or Hargeisa during the eastern displacement of swarms in June 1978 that Roffey presumed reached India and Pakistan. The interior of the Yemen, an area that had never been open for regular monitoring and control, was probably the source of a major upsurge sequence. The eastern Ogaden in Ethiopia contained uncontrolled breeding in autumn 1978 and unusually the progeny did not move farther south but emigrated to the Railway Area where they were successfully controlled. Poor monitoring of the frontier zone between India and Pakistan which led to undetected breeding and swarm formation in summer 1978 could be added to the above list of areas where political or organizational factors hindered the success of a campaign

114. Roffey records that the above factors prevented adequate control being mounted until populations were fully gregarious. Consequently, he was unable to confirm or refute Bennett's finding that early

campaigns do not end upsurge sequences. He did confirm, however, that chemical control was effective against the later fully gregarious populations and undoubtedly helped end the upsurge. Before these campaigns could occur, emergency assistance had to be mobilized to provide adequate control supplies and to train inexperienced technicians in anti-locust control techniques. The timeliness of assistance was not discussed by Bennett or by Roffey. It was considered in later FAO reviews that are covered in Chapter 4.

Recession populations 1980-1984

Data sources
115. No analysis of Desert Locust events in the Central Region exists for this period. Accounts of infestations appeared in FAO's Locust Newsletters 39 to 50 (FAO, 1981a, 1982a, 1983, 1984a, 1985a, 1986a) and at DLCC sessions 24-28 held from 1980 to 1986 (FAO, 1980b, 1981b, 1982b, 1984b, 1986b). Castel (1982) described the onset of an upsurge in the Western Region in 1980 but not its continuation in 1981 and its end in early 1982, which are described in the Locust Newsletters and DLCC reports listed above. This short upsurge in the Western Region and the short upsurges in the Eastern Region are not described here as they did spread into the Central Region.

Outbreak and upsurge populations
116. The previous upsurge and short plague ended in the Eastern Region at the end of 1978 and in the Central Region in spring 1979. Summer rains in the interior of the Sudan were generally below average in **1979** and no breeding was reported. The heavy rains, which fell in late October on the Red Sea coasts of southeastern Egypt and the Sudan probably extended into northern Eritrea. Scattered locusts bred, numbers began to increase and gregarizing infestations were located along the coast of Sudan and into southeastern Egypt as well as inland along the Wadi Oko. Hopper band control started in the Sudan in February **1980**. In March, inhabitants reported notable infestations in northern Eritrea near the Sudanese border. In Egypt, close to the Sudan border, scattered breeding occurred in March and April over an area of 16 km^2 and hopper groups were treated between 24 April and 19 May. Immature swarms were initially reported from Wadi Diib (21N/36E) in the Sudan in late April. Then, between 2 and 10 May, three immature swarms, varying between 10 and 16 km^2, moved into Egypt and were controlled. Survivors were controlled in June and reports of locusts ceased in this northern sector.

117. The Saudi Tihama did not receive heavy rains until December **1979** and January **1980** and low numbers of locusts were reported there and on the northern Yemeni Tihama between October and December 1979. More rains fell in January and February, habitats became favourable and low-density breeding started. In May, ground teams found and controlled a 200 km^2 area of dense breeding containing hoppers of all instars and fledglings near El Wajh (26^{o}14N/36^{o}28E) on the northern Tihama.

118. In Yemen, heavy late spring rains fell in April and May 1980 in and to the east of Beihan (14^{o}48N/45^{o}44E) and Lodar (13^{o}53N/45^{o}52E) areas and some wadis flooded in May but no locusts were seen until 17 June, when an immature swarm of unknown origin was seen flying northeastwards near Al Hadd (14^{o}49N/46^{o}59E). During the summer, only isolated locusts were seen in Yemen and despite moderate to good summer rainfall in the interior of the Sudan in June and July 1980, only isolated hoppers and adults were reported from a few sites.

119. Adult numbers had started to increase from September in the Sudan and October in Egypt when breeding began By early November 1980[8]., breeding conditions were very favourable in the Tokar Delta and became so in southeastern Egypt following heavy rain and flooded wadis in November[9].. In the Tokar Delta, groups of hoppers and fledglings were baited and dusted in November and by December 180 km^2 was infested with bands. An 8 km^2 area of bands was found in the north in December indicating that eggs were laid in November. In January **1981**, more infestations that were widespread were found in the north and a small immature swarm formed. Ground control started and a 295 km^2 area was sprayed from the air but immature swarms of 6, 12 and 8 km^2 were seen on 9 and 22 February and again on 1 March respectively. Control continued through March and into April in northern Sudan. In Egypt, no locusts were found in February or in March.

120. The Saudi Tihama was favourable for breeding following rains in October and early November 1980 when locusts arrived. The locusts matured but numbers were low. More rain fell in November,

[8] FAO Desert Locust Bulletin no. 26
[9] FAO Desert Locust Bulletin no. 27

December 1980 and January **1981** but no sizable infestations were found until 25 February when there were three reports of a mature 2.5 km^2 swarm near Umm Lejj that split up and laid eggs within a 900 km^2 area. Hatching started on March 19 and about 5000 groups had been controlled by April. In May, an additional infestation was found nearby and sprayed and in June, another was treated in the interior at Shamli (26°48N/40°14E).

121. In summer 1981, adults were seen along the Atbara River in May but subsequently no summer breeding was recorded. Neither was summer breeding reported in Yemen or in northern Somalia where scattered locusts were seen in July.

122. In autumn and winter 1981/82 infestations in Sudan were confined to Tokar and close to the Eritrean border. Ground control began against groups of egg-laying adults in October 1981 and baiting and dusting continued against increasing numbers of hoppers and adults until March **1982**. Numbers declined in April and no locusts were reported from the third decade. In Egypt, following rain in October 1981, large numbers of scattered adults were located in Wadi Di'ib in November. Low numbers of hoppers and adults were present until February 1982 after which only a few adults were reported. Locust numbers remained low on the Tihamas of Saudi Arabia and Yemen throughout the 1981/82 winter and spring breeding season.

123. In Arabia, heavy rain and flooding occurred in February 1982 in the Asir and in eastern Arabia, widespread and heavy rain (totals exceeded 100mm) fell in the United Arab Emirates and northern Oman in February and March. Heavy rains also fell in northwestern Somalia and adjacent areas of Djibouti and Ethiopia as well as in southwestern Arabia in late March and early April. Significant but partially recorded locust developments followed from June until November in Arabia whereas in Africa, few locusts were found after late instar hoppers and fledglings mixed with other species of locusts and grasshoppers were sprayed in Djibouti in late May.

124. Low density populations began breeding east of Aden in January 1982 and 25 ha were dusted with BHC in March. From April densities increased, and in May, extensive surveys found populations over a much wider area and groups near Shuqra (13°21N/45°42E) were dusted and sprayed until 12 June. Then on 4 June, a swarm of undetermined origin was reported flying over Shuqra on strong southerly winds. A ground team tracking the swarm, found one near Shabwa (15°22N/47°05E) that split in two before departing.

125. In August, teams found and sprayed several infestations where egg laying must have started in July during extensive surveys near Nisab between Shuqra and Shabwah. Additional surveys were made in September after mature adult groups were seen moving southwest towards Nisab from Shabwah. Teams found several groups of breeding adults within an area of 600 km^2 near Nisab and spraying ended in early October. Other reports suggested that breeding had extended much farther north into the Empty Quarter as on 21 August groups of mature adults reached Sana'a on easterly winds and a small mature swarm was seen flying southeastwards at Najran in Saudi Arabia. This impression was strengthened when swarms were reported in Yemen at or near Marib on 21, 23 and 25 October and at Al Bayda (13°58N/45°43E) on 31 October. In addition, hoppers and groups of adults were located on 6 November on the edge of the Empty Quarter in Saudi Arabia in the Abu Shaddad (18°30N/46°50E) and an immature swarm was seen at Najran. Swarms and egg-laying were reported, but not confirmed, 150 km south of Sulaiyil (20°27N/45°35E). In Eastern Arabia up to June, surveys in the Emirates and Oman found solely isolated adults and only isolated adults. Thereafter, the groups of mature adults that arrived in the Emirates on 20 October, were controlled. On 20 October, low numbers of adults also appeared in Oman at Muscat, and in late October, travellers reported a small swarm at Sohar (24°48N/56°06E).

126. Meanwhile in Africa, summer rains were below average in 1982 and there were no reports of summer breeding. Winter and spring rains in 1982/83 were poor around the Red Sea and Gulf of Aden. Scattered adults reached Tokar in October and groups bred in Tokar and on both sides of the Eritrean border from November. Low numbers were also present on the Saudi and Yemeni Tihamas and small-scale control occurred in all four countries in February **1983** and in Yemen again in March against renewed hatching. Rain exceeding 200 mm fell in the United Arab Emirates in February 1983 but only low density adults were reported until May when an immature swarm was seen and split into groups at four locations between 22 May and 1 June. Swarm remnants and at one of the sites late instar hoppers and fledglings were reported in May and June and 1100 ha were sprayed.

127. Summer breeding was reported in the Sudan near Musmar where groups of hoppers and immature adults were controlled in August. In Arabia, high-density breeding adults were baited in June after

which, several areas of bands and fledglings were controlled in the area near Ahwar up to 9 July. In late June and at intervals in July, a swarm or groups of adults, were seen flying in the Hadhramaut, no breeding was reported.

128. Rains were poor around the Red Sea and Gulf of Aden during winter and spring 1983-84 and for the first time since 1970, there was no control at Tokar in Sudan. In fact, from November 1983 to October 1985, there were no reports of gregarious Desert Locusts in the Desert Locust area. In May 1984, just 1 km^2 of scattered hoppers and fledglings were treated in Yemen. The populations in 1985 form part of the next upsurge and are described below.

The plague upsurge and decline, 1985-1989

129. *Above average rains in summer 1985 after two dry years initiated massive grasshopper outbreaks and as the season ended, Desert Locust outbreaks began in the Western and Central Regions. Those in the Western Region dispersed during the winter but gregarious breeding was controlled around the Red Sea throughout winter and spring and inland in Saudi Arabia from March 1986. Swarms escaped and moved to summer breeding areas in Yemen and Oman and adults may have augmented a successfully controlled summer outbreak in Indo-Pakistan.*

130. *In Africa, during summer 1986, grasshopper campaigns again took precedence over locust monitoring until September when band and swarm control started in the Sudan and Mauritania and gregarizing populations were found in Niger and Mali. No notable gregarious winter or spring breeding followed in West Africa, whereas adults and swarms escaped control, emigrated to breed on the Red Sea coasts of Sudan, Eritrea and Saudi Arabia throughout the winter-spring season and in the interior of Arabia from the spring. The upsurge increased when excellent early and main season rains allowed two generations to breed from Niger to Eritrea (Fig. 9c & d).*

131. *From Late October, most swarms migrated to the Western Region diminishing the upsurge in the Central Region. Winter and spring breeding was confined to coastal Sudan and Egypt and was controlled successfully by early April 1988 (Fig. 9d & e). Then swarms moved across northern Egypt from the west (Figs 9e, f) and mature swarms (from the west or from the Red Sea coast) bred in northern Saudi Arabia requiring control from mid April until June.*

132. *The probability of a plague developing increased when unusually heavy and widespread rain fell in late September 1987 in northern Mauritania and in Western Sahara where many swarms bred in the winter rather than moving farther north where low temperatures preclude breeding until spring. Only a small proportion of winter infestations were controlled and the new swarms bred again locally as well as in Morocco, northern Algeria, Tunisia and western Libya during the spring 1988 (Fig. 9e). Bands were controlled from March. Spring rains ended later than normal so that breeding and swarm emigration continued until August. Swarms that migrated southward in March reached Mali in the east and the Cape Verde Islands in the west. Some moved from Mauritania through Senegal as far south as Guinea Bissau. There was no breeding in the Gambia, Guinea and Burkina Faso and the swarms may have moved north with the ITCZ to join later waves of swarms from Northwestern Africa which spread and eastwards through Mali in April and Burkina Faso and Niger in May, reaching Chad and western Sudan in late May. Widespread gregarious breeding started in June (Fig. 9f) and spread to Eritrea and Yemen when they were invaded in late July. Campaigns failed to stop first generation swarms forming in September. Some bred again locally and bands remained widespread from September into November and were still present in December in the Cape Verde Islands, Senegal, the Gambia in the West and close to the Nile in the Sudan, suggesting there were three summer generations in some areas.*

133. *In the Central Region, intensive campaigns occurred when many swarms from summer breeding reached the Red Sea coast of the Sudan Eritrea, Djibouti, Egypt, Saudi Arabia and Yemen from mid September to November **1988** and bred. At the end of November, swarms invaded northern Egypt from northwest Africa and adults reached the Lebanon, Syria and Turkey. In December, control was mounted against swarms spreading eastwards to Jordan, northern Saudi Arabia and the Kuwait-Iraq border and the groups that reached Qatar, the United Arab Emirates, Bahrain and southwestern Iran. Control and the plague ended in Kuwait in January, in Egypt and Yemen in February, in Saudi Arabia at the end of March and in the Sudan in early April 1989.*

Data source

134. Pedgley (1989) outlined the weather that initiated and sustained this upsurge and short plague. FAO provided accounts for four DLCC Meetings during this period (FAO, 1986b, 1988, 1989, 1990).

Skaf (1990) described the course of this upsurge and plague. Gruys (1994) briefly described locust developments before outlining factors that constrained and others that might improve plague prevention. These last two authors did not cite their data sources but their texts indicate that they used the DLCC working papers. Figs 9a-h were adapted from those by Gruys (1994)

Upsurge populations

135. Population increases began following above average rains from Mauritania across the Sahel and the Sudan to Eritrea and northern Ethiopia during the summer of **1985**. As is often the case, the first gregarious infestations were recorded in the autumn, after one or two generations had bred successfully (Fig. 9a). In the **Western Region,** bands were controlled in southwestern Mauritania. Some swarms formed but they dispersed during December and gregarious locusts were not seen again until autumn 1986 (Fig. 9b). In the **Central Region,** spring breeding continued into the summer on the Red Sea coast of Eritrea where low density hoppers and fledglings were controlled in August and September **1985**. The extent of summer breeding in the interior of the Sudan was undoubtedly incompletely recorded as in October, considerable numbers of adults began to reach both sides of the Red Sea (Fig. 9a). By early December, gregarious breeding had begun in Saudi Arabia between Lith and Qunfidah. Control was hampered by difficult terrain and locusts gradually moved as far north as Umm Lajj (25°03N/37°17E) in December and January. From February **1986,** laying swarms were reported from Rabigh (22°48N/39°02E) to Umm Lajj. Air and ground control against this breeding, which affected about 2500 km^2, lasted until June. From March, populations moved into the interior and although all reported infestations were controlled, later events suggest that infestations were considerably under-reported or that escapes occurred.

136. On the **western Red Sea coast,** winter breeding began in the Sudan in November 1985 and in early January **1986** hoppers of all instars were being reported. At this time, two mature swarms appeared between Port Sudan and Tokar within Khor Gwob. These swarms of Migratory Locusts mixed with Desert Locusts were reported as coming from the interior suggesting that two generations had bred there on the summer rains. (Fig. 9a). In February, swarms were reported north of Port Sudan and in southeastern Egypt. Control continued against hopper bands until April in the Sudan and May in Egypt. There was less information from Eritrea where satellite imagery suggested that habitats were favourable for breeding throughout the spring to the northwest of Massawa (15°37N/39°28E). Unconfirmed reports of adults in February and March plus a late report suggested that hoppers and adults were seen for 60 km around Mersa Teclai (17°45N/38°40E) in January. The next reports were in June when breeding was reported over large areas of the coast. The ground and aerial surveys that began in July are recorded below.

137. In **Arabia**, two swarms moved southwards across the Yemen highlands in early June (Fig. 9b) and a swarm was seen in Yemen in August 1986. Summer breeding was recorded on the southern coastal plains near Ahwar (13°25N/46°45E) and mature adults were found both in Wadi Hadhramaut and farther east in some northward draining wadis. Control was mounted against these populations and against *congregans* adults found in the Wahiba Sands of Oman during July. Chandra, Sinha and Singh (1988) concluded that some locusts from Arabia reached summer breeding areas in the **Eastern Region** (not mapped)**.** They argued that the population rise observed in July 1986 was too great to have originated solely within their region. Control of subsequent breeding in the Eastern Region was successful and only small numbers survived to emigrate westwards in the autumn.

138. In summer 1986, attention in **Africa** was focused on controlling grasshoppers so that initially Desert Locust breeding was incompletely reported. In the **Central Region**, a swarm reached Musmar (18°06N/35°40E) in the Sudan in late June and groups of mature adults were found nearby in late July. In Eritrea and northern Ethiopia serious locust and grasshopper populations were reported in July and a medium density swarm was seen on the coast in early July and unconfirmed reports continued into early August when hoppers were sprayed on the coast. Subsequently, no substantial populations were found by ground and helicopter surveys of the coast and interior. Nevertheless, in late August, fifth instar bands began to enter the Sudan east of Kassala (15°24N/36°30E) and subsequently, bands of all instars were found over 30 km^2 and controlled. No other breeding was recorded in the interior of the Sudan until September after which late instar bands and swarms were found in a broad belt extending from east of the Nile to northern Darfur. Aerial and ground control began against these infestations and continued against second-generation breeding but it was insufficient to stop swarms forming in November and December and moving eastwards to the Red Sea coasts of Sudan, Eritrea and Saudi Arabia. In the **Western Region**, mixed populations of gregarized and partly gregarized individuals

were found in Niger and Mali in September and October 1986 and in October in Mauritania. These locusts were probably local populations augmented by individuals from the Sudan but it is possible that they arose solely from unrecorded local breeding earlier in the summer. These populations were controlled and it seems that too few survived to give rise to notable winter or spring breeding.

139. Winter and spring breeding did occur in the **Central Region** around the Red Sea and control lasted until mid January **1987** in Saudi Arabia and until late April in the Sudan. In contrast, breeding continued until July in Eritrea and gave rise to swarms that moved westwards to invade the interior of the Sudan from late May and the highlands of Eritrea and northern Ethiopia between May and July (Fig. 9c). Heavy rains in late May and early June 1987 were followed by widespread and unusually early summer breeding in the **Western and Central** Regions from Niger to Eritrea (Fig. 9c & d). By August, new swarms formed and began to lay eggs. Despite ground and aerial control against hoppers sufficient fledged to form numerous swarms. Some moved to the coast of the Sudan north of Port Sudan and to adjacent parts of southeastern Egypt at the end of October and in early November (Fig. 9d). By late November, hoppers were being controlled in northern Sudan. Rains fell giving rise to favourable breeding conditions in December. By early January **1988,** late instar hoppers and fledglings were present and swarm laying was seen then and in early February. Small-scale gregarious breeding and control continued until March in the Sudan. The bands and immature swarms reported in southeastern Egypt in March were controlled in early April (Fig. 9e).

Populations reach plague levels in the Western Region

140. In **1987**, most summer swarms moved northwest and westwards from Sudan and Chad in October and shifted the focus of the upsurge from the Central to the **Western Region** (Fig. 9d)**.** These immigrant swarms augmented by those from small upsurges in Niger and northeastern Mali invaded northern Mauritania, Western Sahara, Algeria and Morocco south of the Atlas Mountains. Heavy rains had already fallen in Mauritania and Western Sahara in September and breeding began immediately in these areas as well as in northeastern Mali and central Mauritania. This winter breeding became unusually widespread following further rains in November and December (Pedgley, 1989). Hopper bands were present in Morocco and adjacent parts of Algeria from December 1987. Control was mounted in all of these areas and a particularly intensive ground and aerial campaign took place in Morocco but, FAO (1988) suggests that the area treated (500 000 ha) was only a small part of the area infested. In January **1988**, new generation swarms formed in Mauritania and Western Sahara. Some stayed and bred whilst others moved to Northwest Africa (Fig. 9e). Hoppers were only partially controlled in Mauritania and Western Sahara and second generation swarms formed from mid March. Some moved on the prevailing northeasterly winds across Mauritania to invade summer breeding areas in southern Mauritania, Senegal and the Cape Verde Islands by the end of March (Fig. 9e), an event associated with swarms emigrating from this source after winter breeding.

141. Other swarms from Mauritania and Western Sahara moved during spells of warmer southwesterly winds to northwest Africa where hopper development was slower so that first generation fledging did not start until mid February 1988 and continued in March. These displacements resulted in swarms spreading eastwards across Morocco and northern Algeria with some reaching Tunisia and western Libya in early March (Fig. 9e). Swarms reached western Egypt in the **Central Region** in late March and eastern Egypt in late April to early May and again in late May (Figs 9e, f). Northern Saudi Arabia reported mature swarms from mid April and treated bands and swarms were treated June. Pedgley (1989) suggests that the locusts reached the Central Region on winds behind cold fronts although both he and FAO allow that the Arabian swarms may have arrived from Red Sea infestations described in the previous section.

142. Widespread rains allowed the swarms in northwest Africa to mature and lay across the area before they were controlled. A new generation of hoppers appeared from late March 1988. Breeding was later in the east with hoppers not present in Libya until April and May. Fledging started throughout the area in early May. Swarms emigrated south to the summer breeding area from May but spring breeding continued in Northwest Africa into June and July and the area was not finally free from swarms until August (Figs. 9f, g).

143. Meanwhile in West Africa swarms that emigrated in March, whilst the ITCZ was still south of the summer breeding area, moved through Mauritania and Senegal .and the Cape Verde Islands where they started to breed. Swarms reached the Gambia in April and Guinea and Burkina Faso by early May 1988. Other swarms from Northwestern Africa spread southwards and eastwards through Mali in April and Burkina Faso and Niger in May. Chad and western Sudan were reached in late May (Fig. 9f).

Eritrea and Yemen were invaded in late July.

144. Summer rains were widespread and abundant in both the **Western and Central Regions** from July 1988. Swarms matured rapidly and laid eggs that gave rise to bands from July in the west and from August in the east. Despite moderate to large-scale campaigns, first generation swarms formed in September. Those remaining in the summer breeding area matured rapidly and bands remained widespread throughout September and October into November and were still present in December in the Cape Verde Islands, Senegal, the Gambia in the West and close to the Nile in the Sudan, suggesting that a third generation occurred in some areas.

The decline

145. Many swarms invaded winter and spring breeding areas of the **Western and Central Regions** from September to December **1988** (Fig. 9g). The winter and early spring of 1988/89 was exceptionally dry, in contrast to the previous year, and for the first time since summer 1985, breeding conditions ceased to be favourable for supporting population increases. Breeding was light, control was effective and many swarms were lost over the Atlantic. As a result the decline started.

146. In the **Western Region,** swarms migrated northwards across Algeria in mid September and reached Morocco in early October 1988. Large-scale aerial and ground campaigns began and continued as further waves of swarms arrived from the south throughout the autumn so that none was left to breed by early February in Algeria and by early March **1989** in Morocco. Small-scale breeding and control occurred in northern Mauritania, northwestern Niger, northeastern Mali and southern Algeria. Control continued in northern Mali and Niger until January 1989 and restarted in March when bands were controlled in Tamesna, Niger. In April, control against late instar bands and fledglings continued in Niger and began in the Tilemsi Valley, Mali. The campaign in Mali ended in early May.

147. Many swarms were blown out over the Atlantic on several occasions between September and December **1988** Fig. 9g)**.** Some reached the Cape Verde Islands where they bred in mid October. Others from northwest Africa, reached southwest England at the end of October and Desert Locusts were recorded reaching the Caribbean Islands and South America for the first time (Ritchie and Pedgley, 1989; Stemshorn, 1988; Richardson and Nemeth, 1991; Rosenberg and Burt, 1999). An unknown but probably significant percentage of the summer generations perished in these Atlantic crossings.

148. As the ITCZ retreated, a southern circuit migration began taking swarms southwestwards into Senegal in late September 1988 and the Gambia and Guinea Bissau by mid October (not mapped). These swarms began to breed in Senegal and the Gambia and hopper bands were reported until early January **1989.** Control against this breeding and further incursions of immature swarms from the north ended in February (Fig. 9h). Southern circuit swarms were reported farther south in Guinea and Guinea Bissau in February and March 1989. As the ITCZ moved northwards in May, swarms migrated across Guinea and southern Mali into southwestern Niger where in June, they scattered apparently without breeding (Fig. 9h). The report confirming swarms in the Cameroon in February as Desert Locusts (Bulletin 127) was not located amongst those archived at FAO (Fig. 9h). If genuine, it is the most southerly record for the area. Similar reports in the 1930s were numerous but generally rejected during contemporaneous and later studies (Uvarov, 1933 a, b; Waloff, 1966, 1976) because other species were numerous in these latitudes and species identifications were poor in the 1930s.

149. In the **Central Region**, control campaigns started as summer swarms reached the winter and spring breeding areas (Fig. 9h). Swarms laid eggs on the Red Sea coast of the Sudan from mid September 1988 and reached Eritrea, Djibouti, Egypt and Saudi Arabia during October and started to breed. In late October and November, swarms and breeding were also reported from the Yemen. Intensive control continued against this breeding and against swarm invasions of additional areas. In late October and early November, several swarms invaded the Kuwait-Iraq border and groups reached Qatar, Bahrain and southwestern Iran. An extensive movement on southwest winds at the end of November took swarms across southeastern Algeria and Libya into northern Egypt with locusts reaching the Lebanon, Syria and Turkey (Pedgley, 1989). In December, swarms spread eastwards again and control took place in northern Saudi Arabia, Jordan, Qatar and the United Arab Emirates. Control in some areas continued into 1989, ending in Kuwait in January, in Egypt and Yemen in February, in Saudi Arabia at the end of March and in the Sudan in early April.

Desert Locust recession populations 1990-1992 and upsurge 1992-1994

150. *Western and Central Region populations were low from 1990 to the autumn of 1992 with small outbreaks in the Sudan and in Oman in spring 1990 and in southern Algeria in autumn 1991. Spring 1990 breeding in Pakistan gave rise to groups and swarms some of which reached the summer breeding areas where heavy rain fell. Two generations of breeding were controlled during the summer and although a few small swarms formed only scattered locusts were present by December 1990 and populations in the Eastern Region remained low throughout 1991 and 1992.*

151. *In November 1992, hopper groups, bands and laying swarms were seen on the Red Sea coasts of Eritrea and southern Sudan, and egg-laying swarms were seen in Saudi Arabia. A typical upsurge had begun. Most of the locusts had probably originated from breeding on heavy and prolonged summer rains in the Sudan possibly augmented by adults from northern Somalia and the Railway Area of Ethiopia. The upsurge continued to develop in the Central Region during the winter and spring and then spread to summer breeding areas in the Eastern and Western Regions in 1993. The lack of regular monitoring and timely reporting of infestations, in part caused by shortages of resources but also to several armed conflicts, hindered monitoring. As a result, FAO found it difficult to gauge the severity of the upsurge and so failed to give adequate warning of the spread beyond the Central Region. Large-scale control followed and, by October 1993, no swarming populations remained in the Eastern and Central Regions. The upsurge continued in the Western Region where summer swarms spread both northwards and southwards to breed during the winter and early spring. No gregarious progeny reached summer breeding areas in the Western Region and the upsurge ended in May 1994.*

Data sources

152. FAO Desert Locust Bulletins 137-170 (January 1990 to October 1992) record recession populations in the Desert Locust area with a short upsurge in spring and summer 1990 in the Eastern Region not described here in detail. Magor used locust data from the FAO Desert Locust Bulletins 161 to 171 (January 1992 to November 1992) and rainfall totals in affected countries locust reports archived at the FAO to infer population developments before November 1992 (Appendix 3). The feasibility of postulated migrations was checked against daily 1200 h UTC windfields at 10 m above ground level and approximately 1500 m above sea level from charts supplied by Meteo-France and archived by the FAO Locust and Other Migratory Pests Group. Two DLCC Reports (FAO, 1993, 1995) and FAO Desert Locust Bulletins 172 to 191 (December 1992 to July 1994) describe the course of the upsurge. An FAO map (Fig. 10) was adapted to illustrate the development of this upsurge (FAO, 1994c).

Pre-upsurge population growth

153. The years 1990 to autumn 1992 recorded generally low population levels in all three Regions. Exceptions were an outbreak in Oman in spring **1990**, which was contemporaneous with an upsurge in the Eastern Region during which swarms formed in Pakistani spring breeding areas. Subsequently, heavy monsoon rains supported two generations of breeding. These were controlled and the upsurge had ended by December 1990. Finally, there was a small outbreak in southern Algeria in autumn **1991** after which reported populations were small until November **1992** when the first reports of an upsurge population came from Red Sea coastal areas in Eritrea, the Sudan and Saudi Arabia in the **Central Region**. Survey teams recorded groups and bands at coastal sites, from just north of Massawa to south of Port Sudan. In Eritrea, hopper groups and bands were third to fifth instar in the first half of the month. From 19-21 November, teams reported late instar hoppers and 120 km^2 of thin density laying swarms. In the Sudan, teams recorded bands of all instars and fledglings as well as six sightings of small (1-5 km^2), maturing and laying swarms. Clearly unreported egg laying had occurred on the coasts of Eritrea and the Sudan during October. In contrast, Saudi teams reported no hoppers in mid November when they found three, small (2 km^2) swarms laying near Jeddah (FAO Bulletin 171). Earlier stages of this upsurge were poorly recorded. The first indication that population increases had occurred during summer breeding reached FAO in November; namely reports, including some of control against second generation groups laying eggs in the interior of the Sudan. This study suggests that the major population increases recorded in November were not attributable solely to breeding on the Red Sea coasts as initially suggested (FAO, 1995; Showler, 1995) but arose mainly during summer breeding in the interior of the Sudan and possibly western Eritrea. In addition, these immigrants may have been augmented by populations from northern Somalia and the Railway area of Ethiopia (Appendix 3).

154. The 1992 summer rains started early in the interior of the Sudan and potentially could have supported three generations. Rain also fell on the Red Sea coastal plains of Sudan during July and

August, which although unusual, is a feature of many upsurge years. Estimates derived from development period model suggest that the October and November infestations were laid at intervals from mid September to mid October. Additionally, if local, they would have been the progeny of a parent generation laid from mid July to mid August. This earlier generation will be considered as the first generation (F_0) of the upsurge, although locusts may have already bred on earlier summer rains in parts of the Sudanese interior. Breeding continued in the eastern interior of Sudan but this study assumes that many of the progeny emigrated to the coast in October and November where they augmented small local populations. Widespread egg laying followed and some swarms crossed the Red Sea to lay on the central Saudi Tihama. Control began in the Sudan and Eritrea and initially the efficacy of the available pesticide was low and throughout the upsurge, security concerns limited control near this international frontier. Swarm laying continued in December and infestations extended throughout the southern Saudi Tihama into Yemen. The report of a swarm in eastern Yemen (17N/49E) on 24 December 1992 remained unconfirmed but may have indicated successful summer breeding in the Hadhramaut. In Eritrea, scattered hoppers, fledglings and immature adults were seen in December suggesting many adults derived from bands laid up to October had already emigrated. Infestations were found in southeastern Egypt in December possibly indicating an invasion by the new generation (F_1) moving northwards along the coast or emigrating from the Sudanese interior. Despite ground and aerial control of bands and fledglings on both the eastern and western Red Sea coasts in January substantial fledging (F_2) occurred in February. A serious extension of the infested area followed in March, which took swarms to the northern Tihama of Saudi Arabia and into the interior.

155. Meanwhile populations around the Gulf of Aden had been increasing in the autumn on the coasts of southern Yemen and northern Somalia. Gregarization and control began in Yemen in January **1993.** Subsequently, reports suggested only small infestations remained in Yemen and that bands possibly of *Locusta* were in Somalia. In late April and early May, swarmlets were seen in Somalia flying west towards the Ethiopian border and several swarmlets of *Locusta* mixed with Desert Locusts were seen in Ethiopia close to the Somali and Djibouti borders. Later reports from this area were reported or assumed to be *Locusta.*

156. Spring rains were plentiful in **1993** as a succession of depressions affected the Red Sea coasts and Arabian interior. Falls continued into May in Arabia keeping conditions suitable for breeding on the coasts and in the interior of Saudi Arabia and Yemen. On the western Red Sea coast, infestations in the Sudan and Eritrea but not in Egypt seemed to be coming under control by April. In Egypt, ground control continued against bands and young swarms (F_3) in April and May. In Eritrea, however, low numbers of hoppers were still present until mid May and in June ground control began against groups and bands of a new generation (F_4). Infestations were more serious in Arabia and an extensive aerial and ground campaign was mounted on the Saudi Tihama where infestations were brought under control by May. Only solitary locusts were reported on the Yemen Tihama in March and April but on the Gulf coast gregarizing populations were being controlled in April, as were bands and fledglings in early May. Farther north, however, an immature swarm was seen near Taiz (13°33N/44°03E) and Ibb (13°58N/44°12E) on 2 May. Mature swarms were seen over Sana'a (15°21N/44°12E) and others laid eggs in early May which hatched and formed bands over a wide area in valleys leading from the mountains near Beihan (14°48N/45°44E), Nuqub (14°59N/45°37E) and Nisab (14°31N/46°30E) as well as near Sada'a (16°57N/43°46E) in the north of Yemen. The extent of undetected breeding and importance of swarm escapes in the interior of Arabia was becoming apparent and would lead to invasions of the Eastern and Western Regions.

Inter-regional spread from Arabia from June 1993

157. Emigration from spring breeding areas in Arabia started in June **1993**. This invasion took immature swarms through southeastern Egypt and into the Sudan. The swarms matured as they moved westwards and breeding and control began in Kordofan in mid-June. The emigration continued westwards into the Western Region reaching Chad and Niger by the end of June. In Arabia, mainly late instar bands were present in three extensive areas in Yemen: a) between Marib (15°33N/45°21E), Wadi Beyhan (14N/45E), and Shabwah, b) in the northern Highlands between Wadi Al Jawf (16N/45E) and the Khabb Oasis (16°43N/45°44E), and c) similar breeding was probably present in Wadi Najran as immature swarms were seen on Saudi side of the border. Swarms formed and many moved into the highland valleys (17N/43E). Other immature swarms were reported east of the Asir Mountains in Saudi Arabia but it is uncertain if these were part of a southward emigration from farther north or if they were locally produced. Saudi control teams moved from the coast to the interior but control did not start in Yemen until July.

158. In Saudi Arabia, substantial air and ground control continued until July 15 against immature swarms in the southern Asir, near Najran (17°30N/44°10E) and southwest of Dawasir (20N/44E). Fledging continued in the Yemen where swarms formed and emigrated eastwards from early July. Emigration and ground and air control caused infestations to decline and control ended in late July but by then emigrants had reached India and Pakistan in the Eastern Region. Spring swarm emigration in 1993 was on a far greater scale than predicted. In Africa during July, mature swarms were widespread and hatching began in the Sudan. Some swarms continued to move into the Western Region across still dry habitats north of the ITCZ from Chad through Niger and Mali into southern Mauritania where rains had fallen and breeding began.

The decline in the Eastern and Central Regions

159. The first sign of eastward emigration from Arabia was swarms reaching Salalah in Oman in early July **1993**. They then moved northeast along the coast and concentrated near Sur where a ground and air campaign followed. Swarms and swarmlets also invaded the summer breeding areas of the **Eastern Region** in early July. Breeding started and large-scale control campaigns followed in India and Pakistan. Despite control, the first generation started to fledge in August and immature swarms formed and matured. Egg laying occurred and second generation hatching which began in late September continued into October. By late October, it became evident that control measures in the region, had been highly successful and only scattered immature adults emigrated westwards into Iran in November.

160. In the **Central Region**, fledging occurred on the Red Sea coast in the Sudan and Eritrea in July and swarms continued to emigrate and reach the summer breeding areas farther west. Ground control continued in July against these swarms and the early hopper bands. In August, the first generation began to fledge and additional laying and hatching occurred. Aerial spraying began in September as the main summer generation began to fledge. Control against late instar bands and small immature swarms in Kordofan in early October brought the summer breeding campaign to an end. An unconfirmed report stated that swarmlets reached the Red Sea coast at the end of September. Subsequently, only small-scale winter breeding occurred on the Eritrean and Sudanese coasts and the upsurge had ended in the Central Region.

161. Reports of gregarious summer breeding in the **Western Region** in 1993 were confined to a relatively small area of southern Mauritania. In other countries breeding conditions were not good and only scattered breeding occurred in northern Mali and Niger and in parts of Chad. In Mauritania, ground control teams operated against first generation infestations. The bands began to fledge in late August and the new swarms were maturing by mid September. The scale of new swarms was unexpectedly large suggesting undetected breeding. These swarms emigrated from early October extending breeding and the control campaign southward into Senegal and northward through western Mauritania into Western Sahara at the end of the month. A new generation of hopper bands appeared from October extending the area of substantial aerial and ground control in Mauritania and initiating ground control against the hoppers in Senegal. Swarms began to form again in southern Mauritania in November and led to a northward spread of swarms to Zouerate (22°44N/12°21W) and the southern parts of Western Sahara.

162. Late summer swarms also moved in November and December southwards to the Senegal Valley and into northern Senegal where bands were fledging and swarms were forming Ground and aerial control continued in Mauritania and in Senegal ground control of bands and immature swarms occurred in November and aerial control started in December as some immature swarms spread southwards. In January **1994,** control continued against numerous immature swarms in the Senegal valley and farther south in Senegal around Thiès (14°49N/16°52W) and Kaolack (14°09N/16°08W). By the end of February, control was ending in these southern areas and no locusts were seen in Senegal in March. Some swarms had moved south in February through the Gambia into Guinea Bissau. By mid March, only swarmlets remained and adults and swarmlets had spread into Guinea Conakry where small-scale control was mounted. The Cape Verde Islands had first reported the arrival of a few adults in December and in February 1994 a small infestation of late instar hoppers and fledglings was controlled.

The decline in the Western Region

163. Meanwhile, infestations were also continuing to spread in northern Mauritania and FAO launched an appeal for donor assistance to continue the campaigns in the Western Region (FAO Bulletin 184). During December **1993**, bands in northern Mauritania continued to fledge into swarms and move northwards. Laying and hatching, that started in late November, continued to the west and southwest of

Zouerate and scattered adults were seen from there to Bir Moghrein (25^{o}10N/11^{o}35W). In January **1994,** substantial air and ground control campaigns continued in Mauritania against immature swarms along the coast from the Senegal River to the Western Sahara border and against bands between Akjoujt (19^{o}44N/14^{o}20W) and Zouerate. Groups and small swarms were also present in the south of Western Sahara in January and as temperatures rose in February, they migrated northwards to reach southern Morocco (28N/10W) and adjacent areas of Algeria. In March, infestations declined along the Mauritanian coast and only residual populations were left farther north. In February, however, a northward movement of groups and low density swarms took locusts into southern Morocco and Algeria. Control campaigns against adults and an increasing area of bands lasted from late February until early June in Morocco and until late June in Algeria. Young adults and swarmlets appeared from May in Morocco, Algeria and northern Mauritania and began a southward displacement towards the summer breeding area.

164. In southern Algeria, *transiens* hopper populations were treated from 20 March to 30 April 1994 west of Tamanrasset (22^{o}50N/05^{o}58E) and a small, dense swarm was seen farther northeast (23N/05E) on 29 May. Elsewhere, a swarm and scattered adults reached southern Mauritania in late May and early June and scattered adults, some of which were yellow (mature), were widespread in June and July suggesting that the swarm had dispersed. In late June, swarms were reported in Mali near the Mauritanian border (15N/10W) but only scattered adults were seen farther east (14N/07W and 15N/01W) also suggesting that swarms were dispersing. As the ITCZ began to move northwards, the adults, seen in Guinea Conakry in April and early May, moved into southwestern Mali and reached Sirakoro (12^{o}40N/09^{o}10W) on 7 June. They passed through several towns (13N/07W) on 11 and 12 June to reach Segou District (13N/06W) on 16 June and Mopti District (14N/03W) on 16 June. At the end of the month, swarms were seen much farther east in Niger in the Tahoua (14N/04.E and /06E) and Zinder (13N/08E) Districts. By July, the swarms had scattered over a wide area ending the upsurge.

Desert Locust upsurges, 1994-1998

Data sources

165. In this account, Central Region populations are traced from summer breeding 1994 using three DLCC Reports FAO, 1995, 1997, 1999c) and concurrent Bulletins. A contemporaneous upsurge in the Western Region is included because swarms from this region invaded the Central Region in summer 1995. The upsurge in the Eastern Region that arose after heavy spring rains in 1997 and ended that summer is not covered here.

Early stages of the initial upsurges in Western and Central Region, 1994

166. Populations were sparse in the Central Region during the first half of 1994 when the 1992-1994 upsurge was ending in the Western Region. Summer rains were heavy in the Sahel throughout the season. From August, favourable breeding conditions also existed in the Sudan and extended unusually far north into the Nubian Desert where rains had flooded wadis. From October **1994,** it became clear that locusts were gregarizing. In the **Western Region**, swarms from undetected breeding in northern Mali and Niger invaded southern Algeria where they were controlled. Other swarms moved from southern towards northern Mauritania and bred on early winter rains. New swarms formed at the end of the year. Egg laying occurred in January **1995** and bands were controlled in northern Mauritania from February to April. Swarms and adults moved northeastwards from Mauritania and bred in southern Morocco and Algeria from February and by March, some had reached Tunisia and Libya. Bands were controlled in western and central Algeria from early March to June, in Morocco from mid April to June, in Libya during April and in Tunisia in May. Moderate numbers of swarms formed and moved to the summer breeding areas in May and June. In southeastern Mauritania, adults arrived in late April and swarms from early May. In June, these swarm invasions reached northern Senegal. Other swarms moved through northern Mali and Niger in June and continued eastwards into Chad and the Central Region.

167. Meanwhile a contemporaneous upsurge had started in **Central Region** when swarms formed in the interior of the Sudan in October and November **1994.** Some swarms continued breeding and control lasted until December. Successive waves of summer swarms and adults emigrated towards winter breeding areas on the Red Sea coast but the appearance of swarms in Egypt in February 1995 suggests that late summer breeding may have continued after December in the Nubian Desert. In the winter breeding areas, scattered adults started to breed in the Wadi Oko area and were present in southeastern Egypt in late October but the swarm reported northwest of Port Sudan remained unconfirmed.

Elsewhere, scattered mature adults reached Tokar and laid eggs in mid November and scattered laying occurred in northern Eritrea in the first half of December. Most of the western Red Sea coast was dry until rains fell in late November and December. Vegetation on the Saudi Tihama was reported to be green. The first confirmed reports of laying swarms occurred in late November and early December on the central and northern Saudi Tihamas and from mid December until mid January **1995** in the Sudan between Suakin and Tokar. The heaviest spring breeding was in Saudi Arabia, where large numbers of second generation bands were produced from February. Control against swarms and bands continued until April. Swarms moved into the interior of Arabia in late March and early April and probably dispersed as no further sightings occurred. On the western Red Sea coast, control against scattered hoppers and adults in the Sudan and Eritrea started in December and continued in Eritrea into March and in Sudan until the end of April. In the Sudan, hopper groups were controlled in January and bands occurred in February but by March, hopper groups, bands and fledglings were confined to the Wadi Diib area. Further northwest, swarms, probably from late summer breeding in northern Chad and Sudan, laid eggs at intervals on both sides of the Sudanese-Egyptian border from the Nile to the Red Sea coast in February giving rise to small bands from March. Small-scale breeding and control continued in Egypt until July.

Immigration re-establishes the Central Region upsurge in summer 1995

168. The **Central Region** upsurge would have ended in the spring 1995 but scattered mature adults arrived in western Sudan, probably from northwest Africa in June, followed by small swarms in July **1995**. Egg laying occurred and these swarms probably continued eastwards through the Sudan into western Eritrea where laying took place in late July. It is possible, however, that the swarms affecting eastern Sudan and Eritrea came from southern Egypt. Moderate to heavy rains fell in July throughout the summer breeding area and along the Yemen and Saudi Tihamas. The latter area also received rain in August and summer breeding was heavy. In addition, unusually widespread rain, caused by an Indian Ocean storm, fell in Oman, United Arab Emirates, eastern Saudi Arabia and the Yemen.

169. Gregarious summer breeding was heaviest in Mauritania, the adjacent parts of northern Senegal and in eastern Sudan and western Eritrea. In these areas, bands that escaped control began to fledge in September. Control continued in eastern Sudan until November. A small area of bands was treated in northern Oman in early September. Scattered breeding occurred in the Sahel and in northern Mali and in the west of Niger and occurred on a small-scale on the Red Sea coast of Eritrea, as well as on the Saudi Tihama.

170. In the **Western Region,** swarms from summer breeding moved to coastal and adjacent areas of Mauritania from late September **1995** and groups of mature adults reached Western Sahara in mid October. Laying occurred in all of these areas giving rise to small dense bands from late September or October until December. Swarms formed in southern Mauritania from October and in Western Sahara from December. Control ended in the most southerly of these infestations by early January. Spring breeding extended northwards in February **1996** and was occurring in Algeria by the middle of the month. Hatching started in northern Mauritania and Western Sahara by the end of February. Bands were controlled in these areas during March and in Algeria from the end of March. New swarms formed in April and began to move south. In late April, either the swarms moving through Algeria or local populations must have laid in central and southern Algeria as bands were found in May. These populations were augmented from mid May to late June by mature groups that laid in Algeria and in western Libya. Control was then mounted against bands scattered over a wide area of central and southern Algeria and a smaller area within western Libya. New swarms formed in Algeria from the second half of June into July.

171. In the **Central Region**, swarms from summer breeding in the Sudan and Eritrea arrived along the western Red Sea coast in late September **1995** when it was still dry and most crossed the Red Sea to Saudi Arabia and the Yemen in early October. Laying which started early in November was on a very limited scale in the Sudan. Additional swarms reached Saudi Arabia in December and laid giving rise to bands that were controlled on the Saudi Tihama in January and February **1996**. Scattered adults resulting from later, limited spring breeding near Qunfidah on the Saudi Tihama were treated by ground teams in May and June. Hoppers and immature adults on the Batinah Coast of northern Oman began to gregarize as vegetation dried out in May and ground and aerial teams treated 4000 ha. This left only low numbers of locusts present in the Region at the end of spring breeding 1996.

The decline in the Western Region, 1996

172. Emigration from **northwest Africa** occurred from late April to the end of August **1996** but on a much smaller scale than in 1995. There was no confirmation of immigration into Chad but a swarm was seen close its border with Sudan in the Central Region in mid July. In May 1996 swarms from Northwest Africa moved south through Mauritania, Senegal, western Mali and Burkina Faso. It was dry in these areas and the locusts probably did not breed. Gregarious summer breeding did start in May in northern Mali and Niger. The second generation from September also affected southeastern Algeria. From late July to late August, swarms reached southern Mauritania and the resulting gregarious breeding was concentrated in the southwest. Despite control, some swarms formed in Mauritania and moved towards winter and spring breeding areas in Mauritania and northwest Africa from early October, their number suggesting that much summer breeding had remained undetected. Second generation breeding occurred in and to the north of the summer breeding areas. Swarms escaping control formed in Mauritania in November and moved to southern Morocco. An intense control campaign began against these immature swarms. In January **1997**, the survivors were dispersing and by February, only scattered adults remained. Elsewhere only scattered locusts survived after November and the Western Region upsurge ended.

Cyclone initiates new upsurge in the Central Region, 1996-1997

173. Although a mature swarm was seen in the Sudan near the Chad border in mid July, summer breeding was on a very limited scale in **1996**. Ground teams treated only 120 ha of hoppers and adults close to the Nile Valley in northern Sudan in July and only scattered adults emigrated in the autumn. In June, however, a cyclone brought widespread rain to Oman and Yemen that initiated an upsurge. Immediately after the cyclone, two generations of locusts bred in Yemen on the southern coast and in the interior. By July, hoppers and fledglings were gregarizing and forming bands and groups in Lahej Governorate. Ground control operations started in September and October when second generation hoppers were gregarious and adult groups were forming throughout the infested area. Control against immature adults ended in early November. Over 17 000 ha were treated in Yemen between July and early November 1996.

174. Heavy rains that fell over the northern coasts of the Red Sea in November **1996** provided good habitats for winter breeding. Only scattered locusts reached the Red Sea coasts of Sudan and Eritrea in November and small scale winter breeding followed. In February **1997,** Sudanese teams saw swarms breeding and controlled 600 ha of breeding adults and hoppers in March. Populations remained at very low levels in Eritrea throughout the winter and spring and there was no control. In Arabia, no winter or spring breeding was reported from the Yemen. In Saudi Arabia, however, locusts arrived from summer breeding in the interior of Yemen and possibly from Sudan from December 1996. The initial numbers of mature adults were low and locusts extended from Qunfidah to Jeddah along the coast and foothills. Similar low density populations were found east of the mountains near Taif (21°15N/40°21E). Rain fell along the Saudi Tihama in January when the coast was green from Lith to Yanbo (24.°07N/38°04E) and small-scale breeding and fledging was reported. Ground control began in February against grouping adults that were laying eggs between Lith and Rabigh. Swarms were first seen at the end of February and they continued to lay in March when more rain fell on the Tihama. Hatching and bands formed over a large area between Jeddah and Umm Lajj and began to fledge at the end of April. They were treated by 30 ground teams and 2 aircraft in March and by 40 ground teams and three aircraft in April. In May, infestations extended 900 km along the coast from Lith northwestwards to Duba (27°19N/35°46E). Most had fledged but late instar bands were still present in the north. The large-scale Saudi winter and spring campaign ended in June having treated nearly 340 000 ha.

175. In Arabia, locusts moved southwards into the summer breeding area of Yemen from June where small-scale breeding by low density populations persisted until November 1997 but no control was necessary. Neither was control required in Egypt around Lake Nasser and in wadis in the southeastern desert close to the Sudanese border where low density populations were present in most months between July 1996 and September 1997 and where small-scale breeding was seen in March and July. Heavier summer infestations occurred elsewhere in the Central Region. Three immature swarms, probably from Saudi Arabia, were seen on the Sudanese coastal plains in mid May 1997 and apparently dispersed into the Red Sea Hills. At the end of the month, an unconfirmed report of an immature swarm came from the Baiyuda Desert west of Atbara (17°42N/34°00E). In June and July, swarm reports came from Wadi Malik in northern Kordofan and near Geneina (13°27N/22°30E) in northern Darfur. Breeding conditions were good in large parts of these provinces. In addition, non-swarming populations

were widespread throughout the summer breeding area. Control against hoppers began in August and the first swarms appeared between Derudeb (17°31N/36°07E) and Kassala in early September. Nearly 7800 ha were treated during summer breeding in the interior of Sudan. Some Desert Locusts had remained on the Eritrean coast during the summer and 400 ha were treated in August.

176. Heavy rain fell on both sides of the Red Sea in October and November 1997 ensuring good breeding conditions along both Red Sea coasts as far north as Sinai. Rains also fell in the interior of Saudi Arabia and on the Gulf coast of Yemen and northern Somalia. Only low density locust populations were reported on the Red Sea coasts of Saudi Arabia and Yemen until swarms arrived in January **1998.** In contrast, on the western Red Sea coast, swarms arrived and bred in Sudan in late October and reached northern Eritrea in early November. In Sudan, aerial spraying began in November mainly against breeding swarms but also against hopper bands found from Tokar to Port Sudan. In northern Eritrea, bands mixed with African Migratory Locusts formed by the end of November and control started against patches of hoppers and fledglings on the coastal central plains near Wakiro (15°40N/39°15E). Band control continued in both countries in December and in Sudan fledglings formed swarms from the middle of the month. Some of these swarms emigrated in January across the Red Sea to the coast of Saudi Arabia and probably neighbouring parts of Yemen. Others went north into Egypt where teams treated about 50 000 ha of swarms in January and February before they matured.

177. Breeding continued in Sudan and Eritrea in January **1998** with teams controlling hopper bands and mature swarms in Sudan and hopper bands and laying groups in Eritrea. Control continued on a declining scale into February in both countries and extended into March in Eritrea. During the winter and spring campaigns, nearly 53 000 ha were sprayed from the ground and air in Sudan and more than 18 000 ha were treated in Eritrea. The arrival of swarms in Saudi Arabia and the Yemen from across the Red Sea in January and February 1998 gave rise to heavy spring breeding. Saudi Arabia mounted large-scale campaigns from January to the end of April 1998 against bands from Jizan to Rabigh, which were heaviest between Qunfidah and Al Lith. On the Yemen Tihama, infested areas were between Bajil (14°58N/43°14E) and Midi (16°19N/42°48E). Fledging and further swarm laying occurred in March, producing hopper bands near the Saudi-Yemeni border in April and a few swarms in May. Both campaigns continued into May. Saudi teams treated about 280 000 ha and the Yemenis about 18 000 ha.

178. Meanwhile, on the Gulf Coast, scattered locusts were seen in north-western Somalia during October and November 1997. As a result of good rains, hopper bands and a few small swarms developed in northwestern Somalia in February and March **1998** and bands and fledglings were also seen in Djibouti. Mature swarms were present in northern Somalia in April when about 1300 ha were treated from the air. Two swarms and some adult locusts, probably from Somalia, reached adjacent parts of Ethiopia and nearly 2500 ha were sprayed from the air in March and April.

The decline in the Central Region, 1998

179. By late June 1998, there were no reports of swarms from any of the countries in the Central Region, suggesting that the upsurge had ended. However, good rains fell in Yemen in August and in the interior of the Sudan in August and September. Bands formed in the Yemen in September where about 100 ha were treated. By October, it was apparent that undetected breeding had occurred in the Sudan when swarms laid eggs along the Atbara River and in the Baiyuda Desert. The resulting bands fledged in December when further small-scale laying took place. By the end of January **1999,** most bands were late instars and fledging had begun. Control which had started in the Sudan in October ended in mid February with ground and aerial teams treating just over 50 000 ha. Despite swarm formation after summer breeding in the Sudan and Yemen only scattered locusts moved to the Red Sea coasts in late 1998. The rains failed and no population increases followed bringing this sequence of upsurges to an end.

PRELIMINARY CONCLUSIONS AND DISCUSSION

180. This chapter contains no new analysis. Instead, it brings together previous findings about the development of upsurges and the decline of plagues between 1920 and 1999. Plagues before 1970 and the late stages of their preceding upsurges were studied in more detail than recent ones and the papers received peer review. Consequently, statements on the role of control and environmental factors in initiating and ending more recent upsurges (Table 3) must be viewed with caution until they are confirmed by rigorous studies and peer reviews. A plausible view is that from the 1960s, plagues could

be prevented, providing that aerial spraying of swarms and bands was applied at rates commensurate with the sizes of populations and breeding conditions ceased to be optimal. This chapter highlights topics worthy of further study, which include:

- testing the validity of Bennett's findings on the types of population and their spatial extent during upsurges;
- evaluating the role of control and weather in preventing upsurges becoming plagues;
- improving the prediction of upsurges by quantifying the rain and vegetation that initiate them;
- investigating alternative tactics of control during upsurges;
- examining the associated financial and environmental costs of each control tactic
- examining how soon after an upsurge starts, teams need national, regional and international funds for different types of plague prevention and how soon after an appeal, the assistance is purchased and delivered to campaign managers.

181. Authors select analytical techniques according to the purpose of their study, the reliability of data and the time available to them. This in turn, affects the reliability with which they are able to interpret locust developments. Roffey (1982) warned that he could not link infestations to their source(s) and destination(s) with confidence as he lacked data on concurrent winds and weather systems with which to establish downwind migration trajectories. Instead, he sought the most plausible connection(s) among displacements known to link the areas concerned. In fact, except for extremely well documented events, authors cannot model migration trajectories because downwind displacements of emigrants from source to destination can only be recreated reliably when infestations in all probable sources are described and dated in detail. Unfortunately, authors often fail to present evidence supporting their conclusions on sources and destinations of migrating locusts, which leaves readers unable to judge the plausibility of their interpretations. An added difficulty, in recession and early upsurge studies, is that migration parameters and trajectories between seasonal breeding areas are reasonably well established for day flying swarms (Rainey, 1963a) but not for non-swarming adults that fly at night. Seasonal displacements by the latter are accepted as being similar in direction but shorter than swarm migrations (Pedgley, 1981a; FAO, 2003b) and this assumption accounts plausibly for recorded changes in seasonal distributions (Rao, 1960; Bennett, 1974, 1976).

Table 3. Asynchrony and suggested causes of plague declines

Region	Western		Central North		Central South		Eastern	
Plagues	Year	Cause(s)	Year	Cause(s)	Year	Cause(s)	Year	Cause(s)
1926-34	1934	Unspecified	1933	Unspecified	1932	Unspecified	1933	Drought, cold
1940-48	1948	Drought	1947	Drought	1947	Drought	1946	Migration[1]
1949-63	1961	Migration, control	1962	Emigration[3]	1963	Control[2]	1963	Control[2]. drought
1967-69	1969	Control	1969	Control	1969	Migration, control	1968	Drought
1977-79		Unaffected	1978/79	Drought, control	1979	Control	1978	Migration, control
1986-89	1988/89	Migration, drought, control	1989	Unaffected		Unaffected		Unaffected

NOTES
Migration[1]: in this table, migration is flights ending in unfavourable habitats
Emigration[3]: in this table, emigration is flights taking a population to another region
Control[2]: assumed to include reduced survival and breeding success due to sub-lethal doses of dieldrin

182. Waloff (1966) used the fact that locusts move between complementary seasonal breeding zones during recessions to estimate the number of generations separating the swarming populations found during recessions from their potential gregarious progenitors. She found only one case (Oman, 1949), before the four major plagues between 1920 and 1964, in which the initial transient to swarming locusts might have included gregarious locusts from the previous plague. This led her to conclude that plagues were not formed from swarming populations persisting into recessions. She also recorded that plagues take one or more years to develop and to decline.

183. Routine monitoring of recession populations started after Waloff's study period and so she had too few records on the early stages of upsurges to examine population growth and gregarization from the initiating rains. Instead, she estimated the number of generations occurring from the initial outbreaks to the onset of the four major plagues that started between 1920 and 1964. She had evidence for between

two and three generations in her partly documented cases and four in the better documented case that involved Oman and the Central and Eastern Regions between 1949 and 1950. In this latter example, the initial outbreak of large scattered populations, swarmlets and swarms appeared in February and March 1949. They emigrated and augmented upsurge sequences already in progress in southwest Arabia and in the Eastern Region. Significant swarming populations were produced that summer in Indo-Pakistan but multiplication and gregarization continued in both Regions for a further three generations during spring and summer 1950 before the plague became fully established and spread to Africa. In total, this process had taken almost two years.

184. Waloff whilst evaluating the potential pre-gregarious genealogies during recessions noted that each circuit had one breeding season (Table 4 shown in italics) which failed to occur every year. Good rains in these seasons appear to occur as an upsurge develops and the absence of breeding during these seasons seems to coincide with the end of upsurges. These impressions should be rigorously tested. Waloff's text shows, however, that poor rains in other seasons also cause breeding to fail during plague declines.

Table 4. Seasonal pattern of breeding in recessions (after Waloff, 1966)

Western Region			**Central Region**		**Eastern Region**
S. circuit (swarms)	**N. Circuit** (swarms)	**N. Circuit** (not swarms)	**North of 12°N**	**South of 12°N**	
Summer?	Summer	Summer	Summer	*Summer*	Summer
		Autumn/winter	*Autumn/winter*	Short rains (Winter)	*Autumn/winter*
	Spring	Spring	Spring	Long rains (Spring)	Spring

NOTES
? = Breeding not clearly demonstrated until 2005. *Season* = breeding does not occur every year

185. Waloff concluded her 1966 study by considering its implications for predicting and preventing plagues. This led her and others to advocate that teams monitor seasonal breeding areas identified in earlier aerial reconnaissance as having green vegetation. Countries began to monitor the potential recession area breeding zones in the 1960s and reports of recession populations became more regular but were still an incomplete record of their distribution. These new recession surveys enabled authors to examine environmental factors associated with the early stages of upsurges. Bennett's study (1974, 1975, 1976) was the first to benefit from the better information on the scale and types of population present as upsurges begin and continue to develop. Her results suggest a pattern of development that has implications for tactics within the early warning and control strategy. Tactics in turn are affected by the available choice of control techniques. Bennett highlighted the paradox that the early generations that contained fewer locusts were found scattered within geographically larger areas and presented infinitely worse spray targets than the very much more numerous but fully gregarious later generations. Control was ineffective in stopping that upsurge until applied on a scale commensurate with the size and extent of sub-populations, which in her study mainly coincided with aerial spraying gregarious populations.

186. Since 1964, the three upsurges that became plagues ended at Waloff's 'plague upsurge and spread' stage which she associated with populations gregarizing and switching to daytime migration as cohesive swarms. This enables the more mobile swarms to breed where rainfall is more reliable so that multiplication to assure the continuity of a plague is more likely occur. Bennett's finding that the infested area falls when populations become entirely gregarious has neither been confirmed nor modified by subsequent studies. Neither have studies refuted her view that controlling the gregarizing portions of earlier populations leaves enough survivors to continue an upsurge providing that the rains and consequently breeding do not fail. Roffey (1982) was unable to consider these points because control teams had become too few and poorly equipped by 1977 to find and treat the rapidly increasing infestations characteristic of early upsurges. As a result, many early infestations were either missed or were detected late and inadequately treated. In addition, political insecurity and floods made key breeding areas inaccessible as the upsurge began. More importantly, he was unable to analyse upsurge developments and operational effectiveness because teams no longer made adequate monitoring and control records and campaign reports. Roffey could confirm that fully gregarious populations were quickly eliminated once external emergency assistance arrived and adequate control was mounted in 1978. It is vital that good records are made so that Bennett's findings with their potential impact on the inability of early upsurge campaigns to end the plague cycle immediately are validated or refuted. Pertinent to this issue is that the strategy depends on the availability and disbursement of external funding for the major campaigns and so inherently contains the inbuilt delays and uncertainties

observed by Roffey.

187. Two characteristics have been associated with upsurge initiating rains. One is that the frequency of rain and the duration of the rainy season allow two or three generations of locusts to breed which increases the logistical burdens faced by campaign managers. As the upsurge starts, outbreaks occur simultaneously in many localities within each affected region. Many scattered adults, groups and some swarms emigrate after each generation fledges but some stay to breed so that breeding areas remain active for much longer than normal. Consequently, breeding is not only widespread in one season but occurs simultaneously instead of sequentially in the successive complementary breeding areas. In addition, there are more infestations requiring treatment, than in non-upsurge years, in each of the areas concerned. During upsurges in the Central Region, late summer breeding in the Sudan and interior of Arabia tend to overlap with the onset of winter breeding on the Red Sea coasts. Winter and spring breeding are more extensive than in other years and summer breeding may occur around the Red Sea as well as inland. The second factor, suggested by Waloff (1976) is that winter-spring rainfall is above normal for more than one season. Large amplitude waves in the northern hemisphere tropospheric westerlies cause a sequence of depressions to bring rains to the northern winter and spring Desert Locust breeding areas (Winstanley, 1973a, b) and did so during the development the 1966-68 upsurge (Bennett, 1976). This does not negate the importance of cyclones in generating upsurge sequences but indicates that they are not the sole cause as implied in some studies (Ashall, 1985, Roy, 1985) as other systems bring rain to complementary breeding areas.

188. In general, above average rains in Desert Locust spring breeding areas are negatively correlated with monsoon rains in the summer breeding areas (Winstanley 1973a, b) but this correlation accounts for only a third of the variance. Winstanley (1973b) noted periods (e.g. from 1905-1910, in the late 1940s, the late 1950s and early 1960s) when both seasons were positively correlated as might be required during an upsurge. Values for rains before and during most upsurges exist in the literature and archives but no review has established if the current qualitative statements can be replaced with quantitative parameters. Associations between variations in seasonal rainfall values and links with global circulation patterns and forcing mechanisms between hemispheres are better understood now than when discussed for the Desert Locust area by Lamb (1979) and Winstanley (1973a, b). As a result, seasonal rainfall predictions have improved and might now prove useful in locust forecasting.

189. Competing hypotheses on plague origins arose in the 1960s from attempts to analyse fragmentary recession data and use the results to forecast outbreaks and upsurges and to plan control to prevent plagues. As more data accumulated, it became evident that the two hypotheses were not mutually exclusive providing that evidence was considered in its spatial and temporal context. Rainey and Betts (1979) postulated that there were always ‘important’ populations, many not yet gregarious, meriting control moving within the recession area from which the next plague upsurge would develop. In this context, they considered gregarization zones as favoured halting places for potentially 'dangerous' populations rather than independent starting places for future trouble. Waloff (1966) and with others (Hemming et al., 1979) doubted the assertion that gregarization follows only a temporary dissociation of 'important' populations and that when dissociated these locusts and not other non-swarming locusts survive as the larger and more 'important' populations. Instead, they regarded locating areas, which after rains fall, support concentration and multiplication among low-density populations, which might over a number of seasons, lead to gregarization, outbreaks and finally an upsurge. These authors stressed that rains often fail to support continued population growth in the complementary breeding areas so that continuity in high-density recession populations rarely lasts over two or three generations needed for a plague upsurge to develop.

190. Experience of an additional 30 years in which periods with none or very few swarming populations were interspersed with upsurges, makes it easy to suggest that much of the dispute on plague origins would have been easier to follow and resolve if Rainey and Betts had looked at the populations in space and time and had subdivided regional population sightings into four subdivisions:

- those occurring in years of deep recession characterized by local outbreaks;
- those in upsurge years with good rains in all seasons;
- those upsurge years with poor rains in one or more seasons and finally;
- those in upsurge and plague years.

191. These subdivisions would have revealed that during upsurges breeding is on much wider scale than in other recession years and that in such periods gregarization continues for several successive seasons. In addition, that it is easier to maintain links between populations during an upsurge. In fact,

Bennett (1976) provided evidence confirming some links in 1966-1969 upsurge postulated by Rainey and Betts (1979). Clarifying and resolving this earlier disagreement does not imply that sufficient is yet known about the underlying systems and rainfall that promote widespread favourable breeding conditions and locust population growth leading to an upsurge and possible plague.

192. In 1941 and 1950, the warnings and appeals for funds to mount plague prevention campaigns were issued as the plagues reached their onset and spread stage. Money for the proposed prevention campaigns were not forthcoming and full plagues followed. Since then, warnings and appeals have been issued during upsurges that were successfully eliminated as the plague was beginning. Despite published descriptions to the contrary, no recent upsurge developed into a fully established plague. They reached Waloff's plague upsurge and spread stage, then declined without continuing the growth that precedes peak plague years and so were small in comparison with earlier ones. This arguably indicates successful plague prevention but proponents of outbreak or upsurge prevention perceive an upsurge as a failure of the strategy. It is important to establish the relative roles played by control, weather and migration to unsuitable habitats in the three recent declines described (1968/69, 1978/79 and 1988/89) as well as that in progress in early 2005 so that the control strategy can be evaluated objectively. Issues relating to preparedness to prevent plagues are discussed further in Chapters 4 and 6.

3. EVALUATING THE DESERT LOCUST THREAT

J I Magor and J Pender

BRIEF OVERVIEW

1. The risk of Desert Locust attack is linked to the population increases and decreases that accompany the onset, spread and decline of upsurges and plagues and their geographical extent and duration. The risk is assumed to vary with periodic changes in the weather and related variation in habitat suitability. To date, no one has described the factors underlying the risk of attack adequately and so it cannot be modelled satisfactorily. Instead, forecasts and the frequency of infestation are used as indicators of the threat posed by desert locusts against which control measures are being mounted. Maps and graphs of the frequency of Desert Locust incidence influenced the development of control strategies.

Early Warning System

2. The Early Warning System is based on 75 years' collaboration, in which national locust units report locust activity to a central Desert Locust Information Service (DLIS) and in return receive a monthly Bulletin and forecast outlining the current threat. Warnings sent between forecasts indicate a locally increased threat just to recipient countries. Alerts signifying a significant threat to many countries are distributed to all interested organizations. Key features of the system follow.

- DLIS and national units need adequate staffing, resources, training and rapid access to reserve funds to absorb the sudden increase in workload as an upsurge starts in order to maintain the flow of information without it deteriorating in quality and frequency;
- National campaign managers require ground survey teams to locate a large fraction of the population and to send them high quality reports and require DLIS to provide reliable forecasts in order to plan and initiate appropriate control measures.
- Until 1963, forecasters focused on predicting when and where swarms would invade breeding areas for managers who ran plague suppression campaigns in most years.
- After 1964, the task changed to predicting rare plague prevention campaigns, which occur at approximately 10-year intervals.
- Institutional memories weaken over time and forecasts tailored to the needs of users concerned solely during emergency upsurge campaigns may improve their impact
- A centralized forecasting service is more likely to be effective than a decentralized one.
- The quality of locust forecasts depends critically on the quality and timeliness of the locust, habitat and weather information received by DLIS.
- Locust activity varies with weather and so locust predictions reflect the accuracy of weather forecasts for the period under consideration.
- Consequently, short-term locust forecasts (< 1week) are more reliable than medium- (<2months) and long-term ones (2-12months).
- GIS introduced from 1996 provide improved analytical tools and ability to integrate datasets but forecasts continue to be limited by the quality of locust and weather data;
- Locust forecasters require staff to train as reserve forecasters and to prepare well-documented, peer-reviewed analogues from recent upsurges for use in forecasting;
- Improved weather and vegetation products used in forecasting need field validation.
- Improving knowledge of early upsurge populations is hampered by their inter-season mobility, rarity and varying location, which is inimical to project funding, tied to specific countries and timeframes.
- A valid method for testing the accuracy of the probability assigned to predicted locust events would improve forecast evaluations.

Tools for assessing locust risk

3. Compiling maps depicting the frequency distribution of bands and of swarms was a first attempt to quantify differences in the relative importance and risk of Desert Locusts throughout the distribution area for periods longer than those covered by forecasts. The maps, which provide a proxy for true risk, influenced the development of control strategies. They were used with the quantity of vulnerable crops and ability to pay to calculate Member State contributions to FAO Trust Funds, and with additional information on cropping systems to assess the potential economic impact of the Desert Locust. Their characteristics and limitations are summarized below.

- Maps of monthly, quarterly and annual frequency of Desert Locust incidence exist for bands and swarms from 1938 to 1958, to1963 and to 1975.
- Monthly incidence of any reported adult and hopper infestation were prepared for 1964-1985 excluding 1968 to represent threat during recessions as opposed to earlier periods representing a threat when plagues predominated.
- The 1964-85 maps illustrate the restricted geographical distribution of locusts in recessions and short plagues but as a swarms or bands are given as much weight as reports of single adults, interpreting them is problematic. Additionally, they are not comparable to maps for earlier periods assumed to represent threats during plagues.
- Increasing the period for estimating locust risk reflects variation in climate and control success rather than providing a more realistic measure of risk. Control success and climate variability were major factors in the marked reduction in plague intensity and duration after 1964.
- Histograms, tables and graphs are alternate ways of illustrating variation in Desert Locust attacks.

- The degree square (1^{o}latitude x 1^{o} longitude) was selected as the unit to estimate risk as the area was sufficiently large to offset under- and over-reporting whilst indicating genuine differences of frequency.
- A georeferenced dataset (1930-1999), with a spatial resolution of a degree square and a temporal resolution of a calendar month, is nearing completion and will enable GIS users to map changes in monthly locust distribution and allow solutions to be sought some limitations listed below.
- The dataset reflects distribution modified by control campaigns of varying degrees of success.
- Smaller areas are valid only if monitoring is equally frequent in these smaller units.
- Frequency of incidence maps mask the intensity of attack and changes in distribution in years with few outbreaks and as an upsurge develops and spreads.
- Preliminary estimates and values of traded crops vulnerable to loss were attempted in the 1990s (FAO 1998). These simulations omitted grazing and subsistence crops at risk during plague prevention campaigns. Methods are being sought that will establish the socio-economic impact of Desert Locusts. An agreed methodology is awaited (FAO, 2006).
- Estimating the value of crops saved from attack by inferring downwind damage prevented in a specific season not yet attempted for Desert Locusts but demonstrated the cost effectiveness of preventive control halting populations just short of a major cropping area for the Australian Plague Locust (Wright, 1986).

INTRODUCTION

1. Desert Locusts attack and damage crops and pasture intermittently. The realization that phase transformation for some species of locusts occurred within restricted outbreak areas (Uvarov, 1921) and preceded plagues suggested a feasible control strategy. The strategy entailed monitoring outbreak areas and controlling any gregarizing locusts detected to prevent swarms forming and escaping into the surrounding invasion area to initiate a plague. A two-pronged search to locate outbreak area(s) began in 1929. Entomologists began field investigations and countries agreed to complete and send a questionnaire regularly to a central unit for mapping and analysis. The questionnaire was the forerunner of today's locust reporting forms and was structured to obtain details on the timing, habitat and weather associated with current and past locust events. Questions required observers to record when and where they had seen each stage in the life cycle: immigration, egg-laying, hatching, hoppers and finally, emigration and the phase of the locusts involved (Uvarov, 1930).

2. Mapping and analyzing past and present desert locust sightings in the 1930s revealed that swarms migrate between widely separated breeding areas, and that breeding coincides with seasonal rains falling (Uvarov, 1933a, b). Entomologists, working at the same time, observed that locusts surviving control lost the gregarious appearance and behaviour of those seen during outbreaks. They characterized gregarization habitats and began to determine their geographical locations (Hussein, 1938; Johnston, 1926a, b; Rao, 1937b). They also established that solitarious adults as well as swarms migrate between seasonal breeding areas (Rao, 1937a, 1942). These complementary studies provided sufficient knowledge of the pest's biology and population dynamics for medium-term forecasting to begin in 1943 (Uvarov, 1951). The Anti-Locust Research Centre (ALRC) issued the first plague alert in 1941 and from August 1943, provided monthly forecasts predicting developments during the following six weeks to guide control campaigns. Later studies also showed that the control strategy proposed for preventing plagues was inappropriate for Desert Locust. Instead, teams would have to monitor the series of widely separated, complementary seasonal gregarization areas that were being identified in many countries (Fig. 3).

3. The number of countries providing regular reports increased markedly during the 1940-1948 plague and, from about 1943, acceptably comparable data were available on swarms and hopper bands, but not on non-swarming populations, for the whole invasion area. Subsequently, the long-term frequency distribution and the potential risk posed by swarms and bands was estimated and presented as maps, histograms and tables. These diagrams illustrate marked differences in seasonal distribution and show how infested areas expand and contract both seasonally and between plagues and recessions. These products were used to help develop control strategies (FAO, 1956; Waloff, 1959 in FAO 1959b) and in making seasonal and annual predictions. The need for joint investigations by entomologists and meteorologists was stressed from the 1930s and forecasters began to use daily weather maps to improve the short-term prediction of migration after Rainey (1951, 1963a) had characterized the downwind displacement of swarms, established its adaptive significance and association with rain and specific weather systems. Non-gregarious populations were not monitored and reported regularly until the 1960s when their importance in the initiation of plagues was established (Waloff, 1966) and longer recessions made plague prevention a feasible strategy.

4. The first evaluation of the economic importance of the Desert and other locust species (Uvarov and

Bowman, 1937) used affected country statistics for 1925-1934 on crop and livestock losses, expenditure on locust control, famine relief costs and revenue losses from tax remissions in badly affected areas. This topic was revisited in the 1950s when countries assessed crop losses for 1949-1957 (FAO, 1958). Subsequently, the potential economic impact of Desert Locusts was estimated using the frequency of immature swarms and statistics on crops grown in the Desert Locust area (Bullen 1966, 1969) and later from cost benefit analyses (Herok and Krall, 1995). The re-examination of economic and policy issues in the 1990s, (Joffe, 1995, FAO, 1998) suggested that severe risk to livelihoods and food security on a macro-economic scale were rare so that expenditure on control appeared to be uneconomic. The study also revealed the importance of evaluating the socio-economic impact of locusts and their control and of investigating the impact of damage to grazing and subsistence farming. To date, validated methodologies for such studies do not exist (FAO, 1998, FAO, 2006 annex IV no.11) and developing them is an important outstanding task.

5. The risk of Desert Locust attack is linked to the population increases and decreases that accompany the onset, spread and decline of upsurges and plagues and their geographical extent and duration. The risk is assumed to vary with periodic changes in the weather and relayed changes in habitat suitability. To date, no one has described and defined the factors underlying the risk of attack adequately so it cannot be modelled satisfactorily. Instead, forecasts and the frequency of infestation are used as indicators of the threat posed by desert locusts against which control measures are being mounted. Pedgley and Betts, (1981) and Cressman (in FAO, 2001c) have described the process of forecasting. The quantity, precision and geographical location of locust data has varied over the past 75 years and affects the spatial and temporal precision of products that can be produced. These changes are described in this chapter so that users can understand the limitations of the products from which control policies were developed and can improve and adapt them for their own needs as better data and knowledge become available.

THE DESERT LOCUST EARLY WARNING SYSTEM

Desert Locust Information Service

6. Collaboration between locust-affected countries and a central Desert Locust Information Service[1] (DLIS) form the basis of the Early Warning System. Countries have collected an agreed set of data on current infestations, habitats and weather since the 1930s, which DLIS has mapped, analysed and archived. Forecasters integrate knowledge of Desert Locust biology and population dynamics to predict interactions between current locust infestations, habitats and weather. The data they use needs to encompass the pest's migration range, the geographical scale of the control strategy and the tactics and control capacity being used. For the Desert Locust, this involves routinely receiving information from the whole invasion area and more especially from the sparsely inhabited recession area where plagues begin. Consequently, with the exception of a short period from 1973 to 1978 (see chapter 2, paras 81 and 97), DLIS has been a centralized locust information and forecasting service first in London and from August 1978 at FAO, Rome.

7. From 1860 to 1963, plagues were present in roughly four out of five years but from 1964, the proportion of plague years fell to about one in six (Fig 2). As a result, the control strategy also changed from suppressing plagues to preventing them. As a result, the emphasis in DLIS changed from mainly collecting information for interpreting and predicting swarm migration and breeding to requiring information to predict habitats supporting population growth, which unless checked would lead to an upsurge and plague.

DLIS Bulletins, Forecasts, Warnings and Alerts

8. DLIS began to issue monthly **Bulletins** on the locust situation with a forecast of potential developments for the following 1-2 months in 1943. The first series of Bulletins (August 1943-November 1948) was issued to guide the first plague suppression campaigns that were internationally coordinated and the series ended once the plague had declined. The next series began in January 1950 as a new plague began. Subsequently, Bulletins and forecasts have continued throughout recessions to support the plague prevention strategy. Currently, the monthly Bulletins and the FAO Locust Watch web site keep locust authorities, donors and other interested organizations regularly informed about the level of threat from Desert Locusts in the medium-term.

[1] Then at ALRC, London, now at FAO, Rome

9. **Forecasts** are made to alert managers to the time, location and severity of predicted infestations. The campaign manager's task is to assess the importance of predicted events and then to decide which actions are appropriate and the consequences of inaction. DLIS provide three types of Desert Locust forecast: long-term (2-12 months ahead), for helping officials allocate budgets to regional and national organizations, medium-term (1-2 months ahead) and short-term (1-2 days ahead), to guide those responsible for seasonal and ultimately daily deployment of survey and control teams (Table 1). Medium-term forecasts are issued regularly with the Bulletin to keep national, regional and international locust organizations and suppliers aware of likely developments. Short-term predictions are sent to warn countries of a specific event that has occurred or been assessed as imminent. Longer-term prognoses are prepared for DLCC Sessions, for donor meetings and for planning campaigns during emergencies. During upsurges, the monthly Bulletins are updated and distributed every two weeks but the new information seldom alters the previous medium-term forecast. Long-term forecasts provide sufficient time for preparations but their reliability is low. Medium to short-term predictions, although likely to be more reliable, provide too little time to prepare internationally assisted campaigns. Why reliability varies, opportunities to improve forecasts and mechanisms to overcome limitations are discussed below. Bulletins are supplemented by Warnings when the reliability of an event in a country increases markedly and by Alerts when the threat of a plague developing is clearly identified. Press releases usually complement warnings and alerts and provide additional background to the threat.

Table 1. Decisions supported by long- medium- and short-term forecasts (after Pedgley and Betts, 1981)

Type and duration	Reliability	Decisions	Users
Long-term Forecasts Next 1-2 seasons (next 2-12 months)	Low	Budgetary bids for staff and material	Affected governments Locust organizations Donors, Manufacturers of: pesticide application machinery
Medium-term Forecasts Next 1-2 generations, (next 1-2 months)	Medium	Deploying survey and control teams	Campaign managers Pesticide suppliers Farmers and pastoralists
Short-term Forecasts Current generation (next 1-2 days)	High	Finding and killing targets Warning of imminent invasion/migration	Local control teams Farmers and pastoralists

10. **Warnings** update forecasts in spec77ific country(ies) and have a limited distribution. They warn managers that an event significant to them has occurred or is likely to occur shortly. A frequent cause is predicted rains being unusually heavy or widespread, so that the rain-affected areas require more extensive monitoring than normal to gauge the risk of subsequent outbreaks or the onset of an upsurge. Other warnings prepare countries for swarm invasions when the weather system likely to transport locusts is nearby. **Alerts** are reserved for serious threats to one or more regions and are circulated to all interested institutions. Until 1967, they were issued as a plague started. Subsequently, recession populations were monitored regularly to support plague prevention and forecasters were able to issue alerts earlier in the plague development cycle[2]. These Alerts warn that an upsurge has started and could develop into a plague should suitable rains fall and control be inadequate. Alerts normally indicate when and where heavy rains have to fall to sustain upsurge and plague development and may be downgraded should rains not continue to fall in the same and in complementary breeding areas[3]. Additional Alerts are made should the locust situation deteriorate markedly and may be associated with appeals for external funding to maintain adequate control. Desert Locust Bulletins and the Locust Watch web site are the sources of earlier warnings of potential threat given provided when rains fall that are likely to lead to gregarization. Using the normal means of communication minimises the number of unnecessary alerts. Alerts follow when field data clearly reveals a wide geographical spread of gregarizing population(s) typical of previous upsurges. Press releases associated with an alert explains the nature of upsurges, plagues and the damage they may inflict and actions in progress to overcome the problem.

11. Locust forecasting is highly dependent on and at times limited by, the quality of locust reports and the fraction of the population that is located by survey teams. In addition, it is also highly dependent on the accuracy of weather forecasts since locust numbers are highly responsive to rainfall, which is

[2] The timing of Alerts is summarized in the overview and the dates appear in the text to chapter 2,
[3] Complementary breeding areas are zones where either winter, spring, or summer rain falls, that are connected by migration circuits

extremely variable especially in recession habitats. In addition, the speed and direction of winds and the duration of adult locust migratory flights determine destination(s) reached by locusts leaving a breeding area. Locust forecasters cannot improve weather forecasting but they need to be aware of improvements in meteorology that could improve locust forecasts. At present, for example, weather forecasts are reliable for a week to ten days ahead although forecasts for longer periods including those for seasonal rains are becoming more reliable for some locust areas and may prove sufficiently accurate to be used with confidence in future forecasts of upsurge probability.

12. Another limitation affecting the confidence attached to forecasts and alerts is that forecasters' qualitative judgements that the quantity, frequency and geographical extent of plague inducing rains distinguish them from those that cause localised outbreaks has yet to be confirmed and the associated rainfall and vegetation parameters quantified. Satellite derived rainfall estimates and vegetation cover provides an increasing potential for studies to define weather and vegetation parameters associated with population changes observed during routine surveys. It is important that such studies, using satellite-derived estimates, cover a representative number of upsurge sequences.

Acquisition and limitations of available locust, weather and habitat data

13. DLIS forecasters request affected countries to provide an internationally agreed set of locust, weather and habitat data each month. They obtain additional rainfall records and estimates from meteorological services and satellite derived estimates of vegetation greenness from remote sensing centres. Some countries collect additional locust, weather and habitat information for use at their National Headquarters. Until the 1960s, plagues were present somewhere in most years and reports of bands and swarms predominated. Although procedures for monitoring non-gregarious populations were developed during the 1934-1938 recession, they were not used routinely, to assist plague prevention, until the 1960s. Swarms and bands can be monitored from aircraft in most habitats. As a result, in the late 1950s, DLS switched from ground surveys, which were expensive in personnel, vehicles and field maintenance and too slow to monitor whole plague breeding zones, to systematic aerial survey that adequately identified areas requiring control (Joyce, 1979). Similar, though less well-documented changes occurred in other regions (Rainey et al., 1979) and were the subject of operational research by the Desert Locust Project (FAO, 1968; Roffey, 1965).

14. DLS found that a ground survey team could monitor about 15km^2 a day. In contrast, a pilot and observer could search 4000-5000 km^2 daily of the potential breeding area on the Somali Peninsula, which was divided into 10 minute squares (each roughly 400 km^2) to ensure systematic searching. During these plague years, bands of all instars were readily seen by aerial survey as they basked in open ground from about 30 minutes after sunrise until marching began some 2-3 hours later. Rainey (1963b) recorded that swarms were located in all but 5 per cent of 298 aircraft and helicopter flights over known infested areas and noted that visibility varied with locust behaviour. Swarms were least visible from the air when basking beneath bushes and when in rugged terrain where the plane had to fly higher than normal, clouds often-obscured visibility and parts of the valleys were hidden from view. As a result, swarms sometimes remained undetected in sparsely inhabited and mountainous areas. As a result, swarms sometimes remained undetected in sparsely inhabited and mountainous areas (Rainey, 1963b; Rainey and Betts, 1979).

15. Such complete coverage of populations is not achieved during recessions. Low density non-gregarious populations cannot be monitored from aircraft[4] and are difficult to monitor by ground teams. Popov (1968) inferred that even careful observers fail to notice them until multiplication causes numbers to rise considerably and they have started to gregarize. Rainfall and the vegetation it produces, play a key role in determining locust distribution. Areas of green vegetation may be delimited by aerial survey or satellite imagery but ground teams are needed to locate the well-camouflaged and easily overlooked locusts within the relatively large areas of vegetation and to demarcate the boundaries of areas containing sufficient locusts to warrant control. Ground teams, see groups and small patches of locusts only within 10's of metres of a survey vehicle and bands perhaps 100 metres away (Symmons, 1997). Foot transects, the survey technique most often used to monitor non-gregarious populations, are based on a method pioneered by Rao (1960) during the 1934-1938 recession. His method and variants of it were widely promoted during training courses in the 1960s but his method of estimating population density within an ecological zone is no longer followed. Rao was seeking a rough value that would provided a common basis for comparing the effects of environmental changes between years and alert control managers to significant seasonal changes in the location, behaviour and activities of non-

[4] Helicopters flying about 5 m above the ground can flush adults but must land to estimate numbers and to find hoppers

gregarious locusts. His staff could provide sufficient transect counts from series of intensive and extensive surveys for this purpose and he developed a formula to estimate adult densities from counts made within transects of known width and length. His teams counted hoppers within areas of about measuring about 10 m^2. To counteract the effects of variation between individual adult surveys, he used average densities estimated for the ecological units he had identified within a seasonal breeding area. The total area surveyed was then estimated by summing the area of individual surveys, whether or not locusts were found. Next, he summed the number of locusts counted and then estimated the average population density. After eight year's data collection, he found that densities <10 000/$mile^2$ (4000/km^2) represented unimportant population fluctuations. In contrast, densities above that limit, especially over a wide area could be significant and lead to breeding concentrated within restricted habitats. Rao noted that an outbreak might occur should subsequent densities reach around 1 x10^6/$mile^2$ (400 000/km^2). He considered that swarm formation required additional concentration to 20-100 x 10^6/ $mile^2$ (8-40 x 10^6/km^2).

16. Recession survey procedures since the 1960s are similar, but not identical, in all countries as are the calculations that convert locust transect counts to densities (Duranton *et al*., 1987; Duranton and Lecoq, 1990; FAO, 2001b). Density values are cited, as if valid, for areas as large as a hectare or a square kilometre, which may be misleading for three reasons. First, because in some instances the habitat is smaller than the unit of area cited and secondly, because delimiting the boundaries of an infestation within a suitable habitat is an unsolved problem (Symmons, 1997). Thirdly, Stower (1962b) demonstrated the variability of transect counts over short distances within an infested area and, in addition, warned that foot transects consistently produce population estimates some 25-50% lower than those made by more accurate methods. Nevertheless foot transects, supplemented by vehicle transects, remain the method of choice for locust monitoring because they are relatively simple and quick to do and so allow teams to sample more widely within seasonal breeding areas than is possible using more accurate census methods.

17. Spatial and temporal gaps in locust information are inherent in an affordable and sustainable recession monitoring system. Teams partially offset data gaps by collecting information from nomads and travellers but the accuracy of this supplementary information is uncertain unless later verified by a survey team. Such supplementary sightings are more plentiful during plagues than in recessions because locusts at low densities are easily overlooked. Survey teams themselves may fail to survey areas not only because they lack resources (e.g. funds or vehicles) but also because they cannot enter areas that are politically insecure, that contain landmines or where access routes are flooded. The logistical difficulty of collecting information in remote areas may also reduce sampling to below optimal frequency. Most survey teams are mobile and have sufficient time and resources to sample only part of a seasonal breeding area even when reduced to the parts where rain has fallen and where breeding may be in progress. Finally, teams sometimes fail to record and transmit all relevant information. Observations of non-swarming populations cannot be adequately assessed and integrated if they are sent to forecasters without geographical coordinates, survey routes and a description of habitat quality or a local assessment of the population present based on these factors. Another problem for distant analysts is that non-gregarious locust behaviour and density are heterogeneous within an infested area. This makes the variability observed within a sampling site difficult to describe and record unambiguously on forms.

18. In reality, scarce funds mean that the number of locust teams maintained throughout a recession rapidly become too few to monitor the much greater area of favourable habitats that characterize the early stages of an upsurge. Regrettably, lapses in adequate monitoring and reporting continue to occur as upsurges begin which in turn reduces the reliability of forecasts during such periods. Insufficient monitoring may last for many months if new and additional survey teams require training or their recruitment depends on external funding. Forecasts are based on assessments of the current situation. Consequently, these lapses and associated gaps in locust information may obscure the seriousness of the situation and delay the mobilization of emergency funding.

19. Two other factors may affect analyses of current and historical locust records. Firstly, locust species may be wrongly identified in areas and periods where other locusts and grasshoppers were numerous. Secondly, there are inherent risks if locust organizations provide data summaries to DLIS rather than detailed reports. For example, analysts estimating fledging dates for campaign planning or forecasting will get a significantly different answer if a summary report misleadingly states that first to fifth instar bands were seen from 2 to 30 May when, in fact, hatching occurred only at the beginning and fledging solely at the end of the period. Computer and satellite communication links now provide

instantaneous and reliable data transmission and programmes allow the direct import of electronically exported survey data from an affected country into the forecaster's GIS at DLIS in Rome. Survey reports need to be quality checked locally before transmission and be augmented by summaries and assessments based on local knowledge. Even so, they can now easily arrive in time for inclusion in Bulletins and mid-month updates during upsurges.

Understanding and testing forecast reliability

20. Forecasters use different information, which have varying levels of reliability when preparing long-, medium- and short-term forecasts (Table 2), which in turn influences the reliability of locust predictions. **Long and medium locust forecasts** have to be based on monthly climate statistics and on predictions by meteorological services of the likely variation of rainfall and temperature from long term averages. In addition, forecasters rely on the frequencies of reported locust incidence in an area and on case studies. However, both frequencies of locust incidence and case studies form an incomplete record of how and why locust numbers and spatial distribution changed. Inevitably, the accuracy of such forecasts is low, both spatially and in terms of population size. An initial long- or medium-term forecast, based on past analogues and the weather likely to occur during the forecast, cannot narrow down the areas to be infested. Warnings that are more precise may be possible a few days ahead, when weather forecasts can reliably predict temperatures and windfields able to transport swarms downwind from reported locations. By then, other areas may no longer be threatened because the population has been killed in its source area or been displaced in a non-threatening direction. Long-term forecasts should, therefore, clearly state for decision makers the dates when each worst-case scenario envisaged will be confirmed or downgraded according to intervening developments. Medium-term forecasts should indicate the weather systems associated with predicted movements so that recipients and their local weather forecasters know which weather systems may result in increased locust activity.

Table 2. Types of information used in long-, medium, and short-term forecasts

Information on event	**Forecast lead-in time**		
	long	**medium**	**short**
Frequency of incidence maps	☐		
Probability of change from recession to plague & decline	☐		
Past monthly distribution maps	☐	☐	
Case studies and dates of emigration and immigration	☐	☐	
Temperature, rainfall, seasonal wind statistics	☐	☐	
Rainfall and temperature predictions for following season	☐		
Rainfall and temperature predictions for next two months	☐	☐	
Current month’s hopper and adult distribution	☐	☐	
Active emigration areas (inferred and reported)		☐	☐
Current month’s weather charts		☐	☐
Recent habitat assessments		☐	☐
Five to ten day weather forecasts			☐
Today’s weather chart			☐

21. Locust forecasts are based on the probability of analogous past situations recurring and these events having a known, or more correctly a plausibly perceived, frequency of occurrence. The probabilities of three aspects of an event are predicted: of it occurring (or not occurring), of its severity (scale) and its geographical location. Qualitative terms indicate whether each of these probabilities is high, medium or low. Probabilities will change during the forecast period if events such as control eliminating an infestation, migration altering distribution, or the weather on which a prediction is based, occur. Forecasters may issue short-term forecasts, often called warnings (see para. 10) when a change in a forecast probability is imminent. It is equally important that recipients use recent information on the migration and control of locusts in their area and use local weather forecasts to adapt and update predictions when issuing national Desert Locust bulletins.

22. In commenting on forecasting reliability, it should be noted that no valid measure of this factor exists. Forecasters give three reasons for testing the accuracy of their predictions.

- To reveal factors that cause incorrect predictions if unreported, if not considered, or if overlooked (Betts, 1976, Pedgley and Betts, 1981)
- To increase the understanding of events (Betts, 1976).
- To guide recipients on the reliability of the service provided (Betts, 1976).

23. Evaluating the accuracy, timeliness and utility of forecasts is difficult. No satisfactory method of testing forecast accuracy has been developed to date. Symmons (1972) stressed a fundamental problem relating to the probabilistic nature of Desert Locust forecasts and Pedgley and Betts (1981) noted the two other sources of difficulty that are listed below.

- Testing probabilistic forecasts.
- Deciding how to treat predictions for which only a part of the predicted event (severity of infestation, geographical location or timing) occurred as forecast.
- Finding evidence to test predictions given that populations are incompletely reported.

24. Locust forecasts are probabilistic and so it is the probability assigned to events that should be evaluated. Each defined prediction can be classified as occurring or not occurring. The correctness of the probability assigned (say three out of ten occasions) can then be ascertained, in principle, from a run of similar events over a sufficiently long period. It follows that a single predicted locust event should not be assessed in isolation and that different events should not be pooled. A complication exists because both the weather that drives the locust's prevalence itself varies with time and campaigns are mounted against gregarious locust populations. This means that the probability of an event may alter when the climate changes and or control occurs. To use and test probabilistic forecasts the terms for severity of infestation, geographical area involved and probability terms must be defined in advance and be known and understood by users. Forecasters always used terms denoting differing degrees of probability but they defined them explicitly and in advance in only four of the 50 years for which they prepared forecasts. The geographical units used in forecasts were defined and mapped but not evaluated for the same four years (October 1970 to May 1973) a period too short for testing the assigned probabilities.

25. Previously, Betts (1976 and in ALRC 1966) tested what she called the reliability of the forecasting service by determining how often locusts appeared as predicted when an event was forecast as having high, medium or low probability. She counted as correct, forecast events that occurred and as wrong, those that did not. She pooled all events in the same probability class and derived the percentage of 'correct' forecasts (Table 3). She tested the 63 forecasts issued between August 1960 and October 1965, which contained 1280 predictions. She divided her results into three periods here shortened to 'plague, decline and recession'. Betts categorized the first short period as one of widespread swarm activity but with the Western Region in recession at its end. The second period saw the withdrawal of the plague from the Central and finally the Eastern Region. The third period was the first long recession for which forecasts were issued.

Table 3. Verification of the reliability of Desert Locust forecasts (after Betts, 1976)

Forecast periods examined		Predictions of probability			
Situation	**Date issued (number)**	**High** % correct (No.)	**Medium** % correct (No.)	**Low** % correct (No.)	**Total** % correct No.)
Plague	8/1960- 3/1961 (8)	85 (110)	45 (73)	12 (26)	62 (209)
Decline	4/1961- 7/1963 (28)	88 (300)	62 (167)	34 (116)	70 (583)
Recession	8/1963-10/1965 (27)	74 (104)	48 (142)	42 (242)	51 (488)
Total	8/1960-10/1965 (63)	85 (514)	54 (382)	40 (384)	64 (1280)

26. The number of high and medium probability events forecast, adjusted for the periods having differing durations, fell and those of low probability rose between the plague and recession periods. During the recession, the percentage of low probability events that occurred rose sharply indicating a less reliable service. Rainey (1989a) citing the original version of Bett's report (ALRC, 1966) stressed the importance to campaign managers of knowing the proportion of the three classes of prediction that occur. By ignoring the pooling events in this evaluation, Rainey and Betts are likely to have concealed differences in 'success rate' achieved for specific events or areas from recipients. Furthermore, a forecasters' test for correctness may not coincide with a user's view of a forecast's utility. The geographical units used in forecasts are large and an occurrence just reaching the edge of an area was counted as 'correct' during evaluation, whereas, a user may take a less positive view.

27. Rainey (1989a) also drew attention to the greater success in predicting changes in spatial distribution than in predicting changes in number. This finding is of notable significance because since

the 1970s, forecasters have needed to predict increases in numbers from recession to upsurge and the decrease from upsurge or plague to recession populations. Bett's report (ALRC 1966) concluded that changes in numbers were difficult to forecast because of the consistent and acute shortage of information on the scale of infestations arising from the practical difficulties of securing useful quantitative information in the field and in evaluating the impact of control. These problems still exist.

Improving forecasts, problems and research opportunities

Targeting recipients

28. Clearly, forecasts have dubious value unless they influence user decisions and can be used effectively only if recipients have an appreciation of forecasting procedures and limitations. Desert Locust forecasters have always concentrated on predicting where and when infestations will occur and to a lesser extent, the severity of attack. They have paid less attention to understanding the specific requirements of a range of potential users (finance officers, donors, agrochemical manufacturers and retailers, plant protection officers, farmers and pastoralists) despite there being a growing awareness that unless forecasts are written and evaluated with the users' requirements in mind, they will fail to influence decision making . Consequently, there is a need for more comprehensive information on decision-making in locust control than appears in locust literature. Reactions to forecasts are recorded mainly through institutional structures, such as formal committees, advisory groups and conferences (Uvarov, 1951; Lean 1965). Experience suggests a need for discussion with recipients to determine how well they understand the forecasts and how well forecasts, warnings and alerts influence their decisions. A summary and forecast tailored to the objectives of key groups of decision makers rather than to all users, could well increase their impact and improve decision making.

29. All recipients want timely forecasts and, as Desert Locusts are highly mobile, a trade-off exists between the delay caused by sending data to a distant central office for analysis and the resultant improved prediction of long-distance invasions. A working party in 1972, when solely brief telegrams arrived quickly, placed a higher value on rapid exchange of information between regional centres and forecasts written “without any qualifying terms”, than on receiving an assessment for the whole area, with a medium-term probabilistic forecast from a central office. This review took place during a recession, when economically damaging populations were not moving between regions, and the recommendation to discontinue centrally issued forecasts was implemented (FAO, 1972b). The decision was rescinded during the 1977-1979 upsurge (FAO, 1978) after regional forecasters had failed to predict inter-regional swarm movements because their forecasts were based on information from a single region. When an FAO Working Party (FAO, 1972b), whose members were all users of the forecasts recommended that probabilistic forecasts from a single centre should be discontinued, they ignored two fundamental features of the forecasting method, that forecasts need to be based on information from all infested areas and that the method used is inherently probabilistic. If such apparent misunderstandings still exist, they should be remedied, since forecasts can only be used effectively if forecasting procedures and limitations are fully appreciated by users.

Integrating and modelling locust, weather, and habitat data in GIS

30. The concept of ‘important’ recession populations arose to identify which non-swarming populations have the potential to initiate upsurges (FAO, 1967a[5]; Rainey and Betts, 1979). Populations selected (chapter 2, para 48) were essentially those that were gregarious or which might gregarize after breeding. Rainey and Betts (1979) drew plausible but hypothetical links between these ‘important’ recession populations based on well established swarm migrations and contended that linking major populations was a better method of forecasting than predicting phase change. Undoubtedly some of the putative links between the 1963 and 1967 had taken place (see chapter 2, para 191) and forecasters and analysts continue to deduce such connections but also seek to predict the onset of gregarization among ‘unimportant’ populations when habitats are suitable for population increases.

31. Locust forecasting is not an exact science and keeping track of inferred populations is an important task in a system necessarily based on incomplete data. Populations in some areas can remain unrecorded for many months and forecasters have to infer the potential of such populations to multiply and change phase in areas if suitable rains fall. The use of Geographical Information Systems (GIS) offer new opportunities for tracking observed and inferred populations over space and time in relation

[5] The ‘potentially important’ category contained only two populations. One was an unconfirmed swarm; the other, groups and recently fledged isolated desert locusts and other acridids seen at light for at least 11 nights (Rainey and Betts 1979).

to concurrent changes in weather and vegetation. Consequently, the GIS system (SWARMS)[6] at FAO was designed to allow users to access and compare separate sources of past and present information on locusts, their habitat, the weather and climate. This information includes observed and inferred locust populations, measured and satellite derived estimates of the distribution and quantity of rainfall and vegetation for assessing habitat quality.

32. Forecasters can already generate, store and display the development of likely but unreported populations in a breeding area by using egg and hopper development models (Reus and Symmons, 1992). Gauging the size, impact and movements of such populations will remain an art, acquired from experience, unless reliable population dynamics models are developed and validated. Such developments await field studies that establish the population dynamics of the early stages of plagues well enough for realistic models to be constructed. In the meantime, forecasters continue to work within the limitations imposed by current knowledge, hypotheses, communications and budgets. Forecasters are conscious of the imperfections in the data and knowledge of the pest that impede data interpretation and their integration in models.

33. Determining the movements of recession populations is another essential part of establishing their population dynamics because adults migrate between complementary seasonal areas. Trajectory models simulate the windborne displacement of swarms well only for accurately dated and timed locust reports because windfields change over space and time. Sufficient is known about swarm migration parameters to use the FAO7 wind trajectory model. Forward or back trajectories for non-swarming adults will be unreliable, until field and laboratory studies provide reasonable estimates of what initiates emigration from breeding sites, how long non-swarming individuals fly in a night, the number of nights they migrate and what causes migration to end. This set of facts will be extremely difficult to determine for low-density populations.

Validating new survey techniques and remote sensing imagery

34. Assessing population size from survey data remains subjective. Local managers and information officers need to deduce if populations similar to those sampled in described habitats exist in comparable habitats shown on satellite imagery. Woldewahid (2003) and colleagues suggest that determining, mapping and then regular sampling of preferred habitats would simplify and reduce the area to be surveyed. This would be the case only if, as they suggest, geostatistical methods can be used to infer locust densities in unsampled, preferred habitats. They pioneered this method on the Red Sea coast of the Sudan when population levels were at their lowest levels and their work needs to be repeated both in other gregarization areas and during an upsurge to see if relationships described for very low density populations continue to hold. In addition, whether local monitoring teams would be able to cope with the sampling involved during early upsurge periods before additional resources are available for reinforcement remains questionable..

35. Remote sensing specialists began to identify habitat suitability classes in key gregarization areas in Mali, (Cherlet and Di Gregorio, 1991) and Eritrea. New and more sensitive methods of identifying the vegetation are now available (see chapter 5) but need critical calibration in recession areas to establish if these new remote sensing products can be used with confidence to guide survey teams to areas of suitable habitat with a relatively high probability of locust activity.

Plague dynamics and climate variability

36. The vast, sparsely inhabited recession area and the seasonal mobility of the Desert Locust, present major problems for establishing the population dynamics of this species. Popov (1968) and Roffey and Popov (1968) suggested two reasons why the early stages of outbreaks are seldom recorded and, by extension, why population studies have proved so difficult. First, solitarious hoppers are easily overlooked even by careful observers, because they are usually concealed in the vegetation. Secondly, the change from this cryptic, sedentary behaviour, to easily observed spontaneous marching occurs rapidly and so can easily be missed between surveys. The 1985-1989 plague upsurge was no exception. The first heavy rains fell in the summer of 1985. They gave rise to a few, very localised outbreaks as expected. A year later in September and October 1986, surveys across the Sahel found very few locusts despite habitats being recorded as highly suitable for breeding throughout the summer. As a result, no special warnings were issued. Surveys a few weeks later, found that locusts had gregarized and swarms appeared. This suggests that the current survey technique fails to reveal the extent of population

[6] **S**chistocerca **WAR**ning and **M**anagement **S**ystem

[7] Developed by Meteoconsult, Wageningen, the Netherlands

increase and the numbers of locusts present and likely to concentrate and gregarize as the vegetation dries. If reports suggesting few locusts is a feature common to this initial stage in all recent upsurges, then locust units with the forecasters need to investigate whether a survey technique closer to that described by Rao (1942), which is summarized in paragraph 15, might better indicate the increased numbers present and so improve prediction of upsurges.

37. Lamb (1979) noted that the recession starting in 1960 coincided with a sudden reversion in the global wind systems to a regime, which prevailed before 1890, a previous period ending with a long recession (Waloff, 1976). Rainey much later (1989b) emphasized the potential importance of the change in weather patterns in the 1960s. He supported the view that control had contributed to curtailing upsurges as it had to ending the 1950-1963 plague (Rainey, Betts and Lumley, 1979). He speculated, however, that the change in global weather patterns that started about 1960 was associated with a more restricted north-south movement of the Inter-tropical Convergence Zone (ITCZ), which in turn had affected Desert Locust migration. Accordingly, he selected three locust distributions to test this hypothesis. The distributions chosen and the countries potentially threatened by invasion from these sources were:

- Somalia, Ethiopia September–December 1978 threatening Kenya, Tanzania and Uganda;
- Arabia, April-May 1979 threatening countries to the north;
- Mauritania and Mali, October-November 1980 threatening Morocco.

38. The case-studies selected by Rainey would indicate why on three occasions an invasion typical of a plague failed to occur not whether the specified change in global circulation had in turn altered Desert Locust migration patterns. Roffey (1982) included the first two and Castel (1982) the third season in their studies of these upsurges and concluded that the swarms either were no longer present to invade the countries that Rainey indicated (Roffey) or were too small and liable to disperse (Castel). Nevertheless, whether the weather was more likely to initiate and maintain plagues before than after 1960 needs testing to evaluate the role of control in preventing them. Rainey also expected a sudden reversion to pre-1960 wind patterns sometime in the future and urged the locust community to continue monitoring and making retrospective studies of the overall locust situation in order to update guidance for the long-term control policy.

39. Winstanley (1973a, b) looking at climatic trends in the Desert Locust area concluded that seasonal winter and spring rainfall totals expressed as a percentage of the long term mean fell from the 1950s to 1960 after which the trend reversed. During the 20th century, he identified similar low seasonal values occurring around 1900, 1920 and 1930. He also found that the winter-spring rainfall pattern was negatively correlated with summer rains in the Desert Locust area. High summer totals were associated with strong zonal circulation in the mid-tropospheric circumpolar westerlies because this circulation pattern allowed the ITCZ to move farther north than normal. In contrast, a weak zonal circulation suppressed the northward extent of the ITCZ and associated summer rainfall but brought rain bearing depressions farther south during the winter and spring. Fluctuations of varying periods were evident and, Winstanley found that although the correlation between winter-spring and summer rainfall in individual years was statistically highly significant, it accounted for only about a third of the variance. His data revealed periods from 1905-1910, in the late 1940s, the late 1950s and early 1960s when both rains were positively correlated. At times, regardless of trends, the 5-year means of both season's rains were above and at others were both were below normal, which might lead to locust population numbers rising and falling respectively. No studies have been undertaken to examine these findings of Winstanley.

ASSESSING THE RISK OF DESERT LOCUST ATTACK

Frequency of infestation as a proxy for true risk

40. This section discusses methods selected to estimate the frequency of locust attack and the limitations of available datasets. Datasets transferred to spreadsheets offer quick ways of displaying desert locust distribution and frequency of incidence in GIS that should provide an improved appreciation of desert locust risk for managers and policy makers. Studies of the frequency of bands and swarms began in the 1950s when fifteen years of reliable and uniform reporting was available for analysis (Waloff, 1960). Earlier records, were too sporadic for comparisons between areas to be valid.. Maps and graphs of the frequency of desert locust incidence were influential in the development of

control strategies (FAO, 1956; Waloff, 1959 in FAO 1959b and were used in the calculation of Member State contributions to FAO Regional Trust Funds, the other factors being the quantity of vulnerable crops and ability to pay. Similar rules governed the calculation of contributions to the Inter-Governmental Control Organization, DLCO.EA. Frequency maps with additional information on cropping systems have been used to assess the potential economic impact of Desert Locusts (Bullen, 1966, 1969; FAO, 1998; Herok and Krall, 1995).

Frequency of incidence maps

41. Compiling maps depicting the frequency distribution of bands and of swarms was a first attempt to quantify differences in the relative importance and risk of Desert Locusts throughout its distribution area for periods longer than covered by forecasts. Quantitative (chloropleth) mapping was not feasible because data on swarms or bands is not collected in pre-defined spatial units. In addition, the results would change rapidly because locusts are mobile. Attempts to draw lines of equal incidence (isopleths) around reported band and swarms also failed as gaps between isolines were often not boundaries between areas with different frequencies of infestation but ones that had not been surveyed as frequently. An acceptable solution was reached when Rainey suggested using the **degree square** (1 degree of latitude x 1 degree of longitude)[8] as a convenient, basic spatial unit for comparing desert locust incidence (Waloff, 1960). Locust frequency was calculated as the number of years with locusts out of the total number of years in a selected period. This technique had two advantages over previous approaches. Fewer data had to be extracted to estimate of areas of equal incidence. In addition, degree squares were felt to be sufficiently large (approximately 10 000 km^2) for most inaccuracies of reporting and mapping infestation positions to fall within the correct square whilst revealing genuine differences of frequency that exist over a few hundred kilometres. It was decided to base frequency of incidence solely on the presence or absence of locusts within an area during each month in order to counteract the relatively frequent reporting of locusts in well populated areas and their under-reporting elsewhere. Consequently, the intensity of attack is not taken into account. Another point to consider is that infestations are distributed neither uniformly nor randomly within a degree square. Locust distribution is most varied where changes in soil and vegetation or relief occur. Consequently, correlations between habitat and locust incidence are not demonstrable at this spatial resolution.

Table 4. Published frequency of incidence maps

Period	Content	Source
a. 1938-1953	annual incidence of swarms and of bands	FAO, 1956
b. 1939-1958	monthly incidence of swarms and of bands	Waloff, 1960
c. 1939-1963	monthly incidence of swarms and of bands quarterly incidence of bands	Steedman, 1990 Rainey, 1965
d. 1939-1975	monthly incidence of swarms monthly incidence of bands	Pedgley, 1981b; Steedman, 1990
e. 1964-1985 less 1968	monthly incidence of swarming and other adults monthly incidence of bands and other hoppers	Steedman, 1990

42. Five sets of maps showing the frequency of Desert Locust incidence have been published (Table 4) with the characteristics as outlined below. All used the degree square method but none includes years after 1985. Maps of monthly, quarterly and annual frequency of Desert Locust incidence were prepared from archived maps of bands and swarms between 1938 and 1975 and some were published. Four of the sets (Table 4 a-d) vary only in the number of years used in their compilation. Regular surveys for non-swarming populations began towards the end of the 1950s and became routine throughout the Desert Locust area in the 1960s when recession and not plague years predominated. FAO compiled a fifth set of frequency maps for 1964-1985 (Table 4 e) to represent the locust threat during recessions and changed the compilation method in two ways. The plague year 1968 was omitted but not 1978 also arguably a plague year and any reported infestation was counted no matter how few locusts were seen. Thus a count could represent swarms or bands seen or just a single adult. Whilst these maps illustrate the more restricted geographical distribution in these years, they are not strictly comparable with maps for earlier periods.

43. Campaign managers have used smaller spatial and temporal units when looking at the distribution of Desert Locusts in relatively well-documented areas. Joyce (1962b) sampled hopper band infestations

[8] Degree squares differ in area by some 30% between the equator and 43°N the northern most limit of infestation during the initial study period, 1938-1953.

in 20-minute squares [roughly 1000 km^2] over 10 day periods for the seven-year period from 1950 to 1958 to establish the distribution of high frequency breeding areas in Eastern Africa. More recently, Ould Babah, (2003) used 30 minute squares (roughly 2500 km^2) to study Desert Locust distribution in Mauritania.

Histograms, graphs and frequency tables

44. In 1962, the DLCC Technical Advisory Committee sought more information on the relative liability of countries to locust attack than that presented in 1956 to the Panel of Experts on Long Term Policy of Desert Locust Control. Accordingly, information from large-scale distribution maps was extracted on to matrices to show the months when hopper bands and swarms were present by country. Lean (1960) and Waloff and Connors (1964) show data by country for 1949-1959 and 1937-1963 respectively. Close examination of these diagrams reveals that some country boundaries and names had changed; an issue inherent with long runs of data in the Desert Locust area. Lean's matrix indicates that he included some reports that were unconfirmed or of doubtful species omitted by Waloff and Connors. Authors summed data from the tabulations, displayed them within country boundaries on maps as totals and stacked columnar histograms of the monthly frequency of bands and swarms (Waloff and Connors, 1964) and as graphs (Lean, 1960; Waloff, 1976; Waloff and Connors, 1964).

45. Waloff (1976) analysed the annual presence of swarms from 1860 to 1972 for 62 territories some of which were entire countries and others were parts of one or more countries, each representing a seasonal breeding area. From these data, she identified eight plagues. The first seven lasted from seven to twenty-two years whereas the eighth occurred solely in 1968. The duration of the intervening recessions in the four Desert Locust regions also differed. Statistical analysis revealed no evidence of periodicity between the onsets of successive plagues. The frequency distribution of recession durations suggested that they were ended by a chance occurrence of the factors initiating plagues which, unless ended by swarm invasions, was linked to above average rainfall in the winter-spring rainfall zone in the recession area. Fifty per cent of regional recessions lasted less than two years suggesting that populations were frequently at a level from which they could rapidly build up to plague levels. Waloff's annual swarm matrix and her estimate of the total number of territories that were probably infested (1860-1925) before the reporting system was established exists as a regularly updated spreadsheet at FAO.

Limitations of frequencies as a risk assessment tool

46. The degree square method of assessing the frequency of incidence of desert locust bands and swarms was developed as a guide to frequency of attack and for considering the tactics of plague suppression. The method enabled the vast amount of available mapped data to be presented in a way that clearly indicated the relative frequency of locust infestations between areas. The maps require careful interpretation as the probability of infestations being reported varies between areas and over time. A risk also exists that areas surveyed frequently are recorded as areas of high locust incidence and failing to realise the importance of less frequently visited ones especially where smaller sampling is biased to areas close to roads and units smaller than a degree square are used.

47. All published frequency of incidence products are based on records of the presence or absence of locusts in a pre-defined area in each calendar month for a period of years. They provide a useful but grossly oversimplified global picture for campaign managers. Locust datasets will never indicate the full extent of the locust threat because they are based on populations that are being controlled which according to Uvarov (1951) limited the extent of plague invasions. The current control strategy, aimed at preventing swarms from reaching plague levels and so invading major cropping areas, exacerbates this problem. Users should also note that neither, the number of swarms or bands, their size, density, stage of development nor the time spent in the pre-defined area is reflected in the maps. In addition, the frequencies are based on archived reports, which are an incomplete record of infestations. Locusts may go unrecorded in the many remote areas or be only partially reported by survey teams whilst a few reports included in the data set may be of other species.

48. Initially it was thought that increasing the period considered would produce an improved measure of risk. Later, it was realised that variations in control success and in climate were major factors in the change in the frequency of bands and swarms with a marked change apparent from 1965. No critical studies have established the changing risk of plague initiation between the early pre-1960s wetter period and the subsequent drier period (Fig. 4). Also untested is the hypothesis (see paras 37 and 38 above) that the more restricted north-south movement of the Inter-tropical Convergence Zone associated with a

change to generally drier weather also led to an abrupt change in the extent and severity of Desert Locust migration and by extension to the frequency of infestations between the two periods. Other climatic variables potentially affecting locust numbers are set out in paragraph 39.

49. Methods of establishing global crop loss by Desert Locust as opposed to other contemporaneous factors are not well developed. Wright (1986) was able to demonstrate the value of crops saved from attack by the Australian Plague Locust by inferring the damage prevented in a season when control halted an upsurge just short of a major cropping area. Her proposal for similar field studies for the Desert Locust during an upsurge (Wright, 1988) has not been attempted. The simulated evaluations (FAO, 1998) were a first attempt to model Desert Locust plagues and related damage. Both sections of the model, simulating plague generation and predicting duration of locust infestations and their location in relation to crops would need to be improved to give reliable crop loss assessments and would also need to include grazing and less market orientated agriculture to reflect socio-economically important losses.

50. Risk will vary over time not only because both climate and control success vary but also when cropping areas are extended by irrigation or the introduction of drought resistant varieties. Two sets of maps used to represent risk during plagues (1939-1963) and risk during long recessions interspersed with upsurges (1964-1985 less 1968) were calculated differently. Consequently, they are not comparable. The former records solely bands and swarms but a count in the recession frequencies may represent one locust being seen during a traverse or in other years one or more swarms being seen. It seems probable that the range of records used in the recession frequency maps is too wide to be of practical value to campaign managers. As well as masking the intensity of attack, frequency maps hide changes in locust distribution between recession, upsurge and plague years. A georeferenced dataset, 1930-1999 with a spatial resolution of a degree square and a temporal resolution of a calendar month is nearing completion that will enable GIS users to map monthly changes in locust distribution and to use the GRID functions of a GIS to calculate incidence frequencies for different types of population and for different sets of year

4. PLAGUE PREVENTION PREPAREDNESS

J I Magor

BRIEF OVERVIEW

1. Desert Locusts at low densities permanently inhabit the recession area of all three regions. They breed where rain falls and migrate between areas with different rainfall seasons. Outbreaks occur within these populations in many years. Small outbreaks often disperse and, unless very close to crops, pose no threat to agriculture. In contrast, upsurges require heavy widespread and recurrent rainfall in a succession of seasonal breeding areas, a rare occurrence. Swarms migrate farther than scattered adults so that during an upsurge, campaigns extend, first to the edge of the recession area and then into the invasion area reached only during plagues.

Original objective

- Prevent plagues and so avoid damage in the major cropping areas of Africa, the Near East and southwest Asia

Plague prevention achievements

- No plague since 1964 developed beyond the onset phase so plague prevention in 1968-69; 1978-79, 1988-89 and 2004-05 protected major agricultural zones from invasion and damage.
- Few territories beyond the recession area were invaded during post 1964 plagues. Kenya[1], Tanzania and Uganda, and substantial parts of Northwest Africa, the Near East and the Eastern Region remained free from Desert Locusts.
- Alerts and Appeals were issued earlier in upsurges after 1964 when recession monitoring for plague prevention began.

Revised objective

- To achieve sustainable preparedness that safeguards livelihoods, health and the environment whilst minimising losses to recession area grazing and subsistence crops during upsurges.

Plague prevention preparedness

- National, regional and international organizations move from recession monitoring to upsurge campaigns without the serious delays associated with the inter-related financial, technical and organizational weaknesses observed from 1940 to 2005

Recurring limitations to preparedness

- Inter-related financial, technical and organizational weaknesses recur at national, regional and international levels so that locust early warning and control structures scaled-down during recessions have too few trained and equipped permanent and reserve staff to find, report, predict and control infestations when an upsurge starts.
- Locust Trust Fund emergency reserves, including the FAO Working Capital Fund failed to offset shortfalls in funding.
- Donors respond to appeals for international assistance but the locust situation deteriorates between appeals being made and the delivery of resources to campaign managers in the field.
- Remedial actions taken after each plague to resolve constraints are not sustained everywhere

Financing preparedness

- Preparedness is not yet sustainable without international funds
- International donors have to date provided funds for large-scale plague prevention campaigns

Current capacity building

- EMPRES Central Region Programme from 1994 has been strengthening the capabilities and capacities of the national and regional Desert Locust early warning and control teams to deliver effective and efficient plague prevention using timely and environmentally sound interventions as early as possible in the upsurge cycle.
- Locust organizations require contingency plans to provide an operational framework to improve plague prevention and to facilitate the acquisition of international assistance and to minimise institutional memory loss.
- Contingency plans should integrate lessons learned on previous occasions and be sufficiently flexible to accommodate changes between emergencies in locust distribution, in control measures and in sources and procedures to release emergency funding.

INTRODUCTION

1. FAO reviewed preparedness for preventing plagues in the 1980's following an analysis of the responses made during the 1977-1979 upsurge and short plague. The analysis identified inter-related

[1] Swarms invaded Kenya in November 2007 for the first time since November 1961

financial, technical and organizational weaknesses at national, regional and international levels. The weaknesses identified mirrored those associated with earlier and subsequent upsurges suggesting that there are inherent weaknesses in the monitoring, early warning and response systems. Roffey (1982) reported that control of the rapidly increasing populations was inadequate as this short-lived plague began whereas, later in the plague, locust populations were quickly eliminated by spraying with contact and persistent pesticides. A significant change was that between periods the locusts had become gregarious, were in accessible areas and funds had arrived which made control organizations fully operational. Roffey discusses the role of political, organizational and technical problems as the plague started but not the role delays in obtaining external funding and supplies had in limiting their solution. These delays were potentially the reason insufficient survey and control capacity was in place as the upsurge began. The reduced capacity for control early in the upsurge effectively prevented Roffey from investigating Bennett's hypothesis that early control fails to stop further developments.

2. Inadequate finance is a perennial problem reducing the preparedness of locust monitoring and control organizations and the 1977 to 1979 period was no exception. Desert Locust control has always required external funding to re-equip survey teams and to finance large-scale campaigns (Uvarov, 1951; Lean, 1965; FAO, 1970, 2006). To date, this reliance on external funding further reduces preparedness due to, the significant time lags between appeals being launched, funds being made available and resources being delivered. Past mechanisms to bridge the gap have been ineffective. Maintaining strategic reserves of pesticide and equipment was a partial solution suitable for periods with long plagues but not those containing long recessions. FAO set up Trust Funds between 1954 and 1958 to finance large plague suppression campaigns but Lean (1965) reported that national contributions to them were limited. The need to finance initial emergency actions was anticipated in plague prevention schemes (UK, 1938; FAO, 1969) and the accumulation of funds as an emergency reserve was major aspect of the UNDP (SF) Desert Locust Project. FAO (1969, 1970) reported, however, that these funds together with those accumulated from unallocated balances of FAO Regional Commissions were inadequate for dealing with an emergency. As a result, the FAO Working Capital Fund for the control of livestock diseases of $0.5 million [$2.2 million][2] was amended to include responding rapidly to Desert Locust emergencies (FAO, 1970). When required in 1978, however, its purchasing power had almost halved to $0.3 million][3]. This fund represented only a small proportion of the $12.5 million [$31.8 million][4] emergency funding provided mainly by international donors for emergency control measures between February 1978 and October 1980[5] (FAO, 1980b; Roffey, 1982).

3. As well as financial shortfalls, political instability made four key breeding areas inaccessible at the beginning of the 1977-1979 plague. Two insecure areas were the Eritrean coast and northwestern Somalia which Roffey's (1982) analysis suggests were linked by migration and played a major role in the swarm invasion of India and Pakistan in summer 1978 (Chapter 2, paras 99-100, 105,107). The third, was the interior of the then Yemen Arab Republic which at that time had never been regularly surveyed and was probably the source of one sequence of the plague upsurge. The fourth insecure area was the eastern Ogaden in Ethiopia where uncontrolled breeding occurred in autumn 1978.

4. Organizational weaknesses, which unlike political ones can be addressed by the locust community, fell into three areas. One was the decentralization of the reporting and forecasting system in 1973. Another was the lack of adequate survey and control resources. Finally, Roy (1985) suggested that the national and regional anti-locust resources in Arabia and eastern Africa were insufficiently coordinated.

5. The Desert Locust Information Service no longer operated from a single location. Instead, seven organizations shared the tasks and this proved ineffective (see chapter 2, paras, 81, 97). The decentralized information service appeared to function adequately during years with few outbreaks but its weaknesses became apparent early in the 1977-1979 upsurge. Three factors were responsible for the weaknesses. First, the five forecasting centres were insufficiently staffed to cope with the increased workload, which delayed data processing and analysis. Secondly, the content and timeliness of survey and control reports had deteriorated during the recession so that often only narrative summaries were sent to regional centres and details of locust sightings on approved forms were rare. As a result, the regional centres and FAO found it difficult to assess the situation accurately. Thirdly, the five regional centres issued their monthly summaries and forecasts on approximately the same day and without

[2] $US equivalent updated from 1969 to 2006
[3] $US equivalent updated from 1969 to 1978
[4] $US equivalent updated from 1978 to 2006
[5] Roffey did not explain why he cited funding to 1980, though it is possible that emergency funding and supplies were still arriving after the rapid end of the plague

sufficient prior inter-regional communication. Consequently, they failed to consider immigration from neighbouring areas in formulating their forecasts. Roffey also found that locust events were not being analysed in conjunction with current meteorological data, a factor, which with poor reporting hindered accurate forecasting and the appreciation of significant major developments. As a result, India and Pakistan received no advance warning of the swarm invasion from the Central Region in the summer of 1978.

6. Some factors that delayed control, such as bad weather curtailing ground and aerial survey and control measures are inevitable and outside the control of locust organizations. Other technical and organizational weaknesses in control related to how anti-locust structures were managed, financed and scaled-down during recessions. In some areas, there were too few staff and not all of them were sufficiently trained and equipped to find and control the rapidly expanding infestations during the upsurge. Consequently, some major infestations were not discovered until they were fledging or the progeny was emigrating. Roffey also cites shortages of managers experienced in organizing and conducting control campaigns, shortages of suitable survey vehicles and insufficient insecticide stocks. In addition, he noted that inexperienced pilots and engineers were adjusting spray equipment incorrectly and that pilots no longer knew, nor were given, the correct spraying instructions for different targets and environments. Roffey also found little evidence that adequate records of control measures were kept thereby preventing the analysis of operational effectiveness and the ability to determine control impact.

7. Remedial actions to resolve these issues were undertaken from 1978 onwards. A centralized Information Unit was established at FAO, Rome in mid-1978 (FAO, 1978). Funds were raised by FAO from international donors to recruit experienced staff and provide equipment for the emergency. A number of proposed improvements were discussed and agreed by the DLCC in May 1979 as part of a comprehensive longer-term plan to strengthen all aspects of locust control (FAO, 1979). As a first step, FAO decided to ascertain the minimum number of staff, and quantities of pesticides, equipment and finance needed at regional and national levels to be constantly available for plague prevention.

8. The reviews of control potential and capabilities for plague prevention in the Central Region were a part of this process (Ashall, 1985; FAO, 1985b; Roy, 1985). The results of these reviews are incorporated below in assessing preparedness in 1985 and as a base line for evaluating current preparedness. Despite these actions, no significant improvements in preparedness were evident in 1985 when the drought broke and initially grasshoppers then the African Migratory, Red, Brown, Tree and Desert Locusts threatened to reach plague proportions in Africa. Remedial actions recommended after the 1986-1989 plague (Gruys, 1994) are also outlined so that managers can evaluate progress in their achievement towards improved preparedness.

DEFINING PREPAREDNESS AND SHORTCOMINGS IN 1985

9. Roy (1985) and Ashall (1985) left no doubt that the Central Region had major weaknesses to overcome and that external funds were needed to reach the minimum level of preparedness required to prevent plagues. Consultants reviewing their reports urged FAO to seek international support to equip teams adequately (FAO, 1985b). The estimated cost of replacing and buying new equipment and pesticide to make national teams and DLCO.EA operational was $1.8 million [$2.9 million.[6]] The consultant reports also urged national governments to allocate autonomous budgets for locust survey and control operations and noted that, particularly in Yemen, operational funds were required to ensure that surveys took place. They also recommended that FAO use Trust Funds primarily for training and strengthening national survey and control teams.

The control strategy 1985, facts and assumptions

10. What strategy and tactics did Ashall and Roy recommend, what facts did they use and what assumptions did they make? Popov (in Roy, 1985) delimited potential recession breeding grounds in the Central and Eastern Regions and outlined their ecology. He prepared quarterly frequency of infestation maps (1964-1977) from maps compiled by Roffey and used them to denote important breeding areas and potential seasonal movements of populations between them. Popov does not describe how the maps were constructed. The size of shaded units on the maps indicates that the spatial resolution was 30 minutes square (30 km by 50 km). Popov also had access to FAO's monthly degree square frequency of incidence maps for hoppers and adults for the period 1964-1984 excluding the plague year 1968, which

[6] $US equivalent updated from 1985 to 2005

were included in Roy's report. Ashall extracted control data from 1963 to 1982 from the DLCC reports as a guide to quantities of insecticides likely to be needed. He also identified two periods (late 1967 and early 1978) when reported infestations made it obvious that a plague could develop. He discounted a third period of considerable control (1972-1974) which lacked the necessary sequences of heavy rain in complementary breeding areas to have produced a plague.

11. Roy used three plague upsurges (1948-1949, 1966-1967, 1977-1978) to outline the survey and control measures required to prevent plagues. He considered that all three started in Oman. Whilst undoubtedly Oman was not the sole source of these plagues (see chapter 2), he was correct to emphasize the importance of monitoring this area when it receives rainfall. Roy envisaged an early warning system in which locust habitats suitable for breeding would be identified using satellite imagery to detect green vegetation, a response to rainfall. He anticipated problems in transmitting satellite derived information to locust units in time to direct surveys but not in producing functionally reliable imagery. In reality, affordable satellite imagery and derived products that detect sparse vegetation in locust habitats were not to become available for another 20 years (see chapter 5).

12. Ashall (1985) called the control strategy operating in 1985, “upsurge prevention” and described it as monitoring populations in seasonal breeding areas and undertaking preventive control when populations start to gregarize (Fig. 5). He used control measures in the period 1963-1982 as a guide for estimating the control resources required for plague prevention. He noted that about 55% of populations controlled were not fully gregarious but failed to cite the proportion that occurred during plague upsurges. This period contained no plagues that reached Waloff’s fully established plague status. Ashall contrasted the 1972-1974 upsurges that lacked widespread rains in successive complementary breeding areas with the periods 1966-1968 and 1977-1978, when rains continued until increases in the resultant upsurge populations warranted emergency plague alerts. He noted problems associated with achieving upsurge prevention. Firstly, operations being delayed because areas are remote, are sometimes inaccessible and because locusts gregarize rapidly (Ashall, 1985, para. 35). Secondly, he drew attention to arguments by MacCuaig (1970) and Bennett (1974, 1976) that led him to recommend upsurge elimination as the tactic to achieve plague prevention (Ashall, 1985, p. 58, recommendation 3).

13. MacCuaig (1970) recorded that spraying dense control targets such as swarms and bands maximises kill per unit of pesticide. He also postulated that early intervention against gregarious infestations would result in a smaller numbers of locusts being present as an upsurge developed into a plague. He used plausible data on population growth to deduce that a greater reduction in plague population size would arise should gregarious populations be controlled from early rather than from later in an upsurge. Bennett (1976) reviewing locust events from 1966-1969 widened this concept. She postulated that the weather initiating plague upsurges might differ essentially from that which produces purely local outbreaks. The rationale was that the repeated sequences of widespread rains on which upsurges depend are themselves associated with global weather patterns that are not present in years characterized by local outbreaks. Until upsurge-generating rains could be predicted reliably, she suggested delaying control, but not crop protection, beyond initial gregarization until a clear plague threat existed in order to avoid treatments unnecessary in the context of plague prevention. Bennett (1976) accepted that a delay in implementing control measures would enable locust numbers to increase substantially but deduced that they would form dense control targets within a far smaller gross infested area, as happened in 1968 (see chapter 2, paras 76, 77 and Fig. 6b). Ashall noted that the threat of a plague became evident in the first four months of 1968. He also postulated that a similar point exists during every plague upsurge and that control from this point offers maximum return for resource and effort expended. assumed

14. Ashall agreed with Bennett that early, partly gregarized populations would be too geographically extensive to spray on environmental grounds if not solely for the high cost involved. Such populations are also extremely difficult if not impossible to find and to demarcate as suitable targets (Symmons, 1992; van Huis, 1994c, p. 95-96). Ashall assumed that bands and swarms might occupy an area up to 1000 times smaller than a similar number of solitarious locusts. His reasoning was that the commonly cited swarm density is 50 million/km^2, whereas, that which typifies large solitarious populations is only 50 000 locusts/km2. In Bennett’s study (see Chapter 2, paras 76-80), control mounted against the gregarious portions of early upsurge populations left sufficient non-gregarious survivors to continue the upsurge in all but one case. On this single occasion, 4000 km^2 was blanket sprayed to eliminate an entire population of about 150 million locusts that Bennett estimated would have formed swarms totalling at most 3 km^2. The insecticide used, however, was about half the quantity needed to eliminate

swarms totalling 400 km^2 in the main upsurge sequence of the plague. This conclusion has not, however, been tested with data from subsequent upsurges.

Proposal to refine the plague prevention strategy

15. FAO brought a group of consultants together to consider the reports by Roy (1985) and by Ashall (1985). The group rejected Ashall's recommendation to change the plague prevention strategy from upsurge prevention to upsurge elimination (Fig. 5). The group stated (FAO, 1985b section 3.4) that upsurges were frequently stopped when controlled in time. However, they did not specific instances where the upsurge prevention strategy had been successful. Consequently, it is not possible to ascertain if they incorrectly assumed success due to control, when in fact, habitats ceased to be capable of supporting population increases or a combination of these factors. The chief objections to adopting upsurge elimination were first, the complexity of recession populations that makes developments unpredictable and; secondly, delaying control of important concentrations involved a risk, owing to the high reproductive potential of recession populations that the larger populations produced might migrate to inaccessible areas.

Table 1. A guide to controlling recession populations (after FAO, 1985b)

Locust population type		**Gregarious Swarms & bands**		**Non-gregarious High density**		**Medium density**		**Low density**	
Location	Breeding	Large	Small	Large	Small	Large	Small	Large	Small
In or near crops		**Control**	**Control**	**Control**	Monitor	Monitor	Ignore	Monitor	Ignore
No crops	Likely	**Control**	**Control**	**Control**	Monitor	Monitor	Ignore	Monitor	Ignore
	Unlikely	**Control**	**Control**	Monitor	Ignore	Monitor	Ignore	Monitor	Ignore
Remote areas	Likely	**Control**	**Con /**Mon	Monitor	Ignore	Monitor	Ignore	Monitor	Ignore
	Unlikely	**Control**	**Con /**Mon	Monitor	Ignore	Standby	Ignore	Ignore	Ignore
Inaccessible		Standby		Standby		Standby		Standby	

16. The FAO consultants concluded that the upsurge prevention strategy could be considerably refined in view of increased knowledge of recessions. However, some of the assumptions on which they based this decision were false. For example, satellite imagery was not able to identify upsurge generating rains and locust habitats reliably thereby eliminating the need for surveys in habitats unsuitable for breeding. The consultants had managed Central Region locust control campaigns and the guide to initiating locust control during recessions (Table 1) in the report (FAO, 1985b) may reflect practices in use against 'important' populations (see chapter 2, para. 48). The table is difficult to interpret, as the group defined none of the qualitative terms, most of which had, and still have, no fully established quantitative parameters. An agreed range of areas defining the use of 'large' and 'small' for individual swarms and bands existed then but were amended subsequently (Table 2).

Table 2. Changes in swarm and hopper band size categories

Categories	**Hopper band area**		**Swarm area**	
	Pedgley, 1981	FAO, 1994a, 2001b	Pedgley, 1981	FAO, 1994a, 2001b
Very small		1-25 m^2		<1 km^2
Small	25-2500 m^2	25-2500 m^2	<1 km^2	1-10 km^2
Medium	0.25-8 ha	0.25-10 ha	1-100 km^2	10-100 km^2
Large	8-30 ha	10-50 ha	>100 km^2	100-500 km^2
Very large	>30 ha	>50 ha		>500 km^2

Table 3. Densities and areas for use with the FAO Guide above (after Duranton and Lecoq, 1990)

Locust stage	**High density**	**Medium density**	**Low Density**
Hopper instars 1-3	10-100/m^2	2.5-10/m^2	< 2.5 /m^2
Hopper instars 4-5	1-10/m^2	0.25-1/m^2	< 0.25/m^2
Adults	1000-10 000/ha	250-1000/ha	< 250/ha

NOTE: large area = > 50 ha; small area = < 50 ha

17. Approximate ranges exist for the size and density of non-swarming populations that are likely to be 'grouped, scattered or isolated'. Unfortunately, the guide to controlling recession populations does not indicate whether 'high, medium and low densities' represent ranges within which locusts are,

respectively, ‘grouped, scattered and isolated’. In addition, the density at which locusts gregarize varies between habitats and with vegetation cover (FAO, 2003b). Consequently, for specific habitats, density ranges are likely to vary with the changes in vegetation cover that occur between years. It seems likely, therefore, that as well as decisions varying between countries, only teams already familiar with the practice of control in their country could use this table. Duranton and Lecoq, (1990) much later suggested indicative quantitative values for population parameters when they adapted this table for use in the Sahel (Table 3).

Table 4. Sizes of regional swarm populations (after FAO, 2003b)

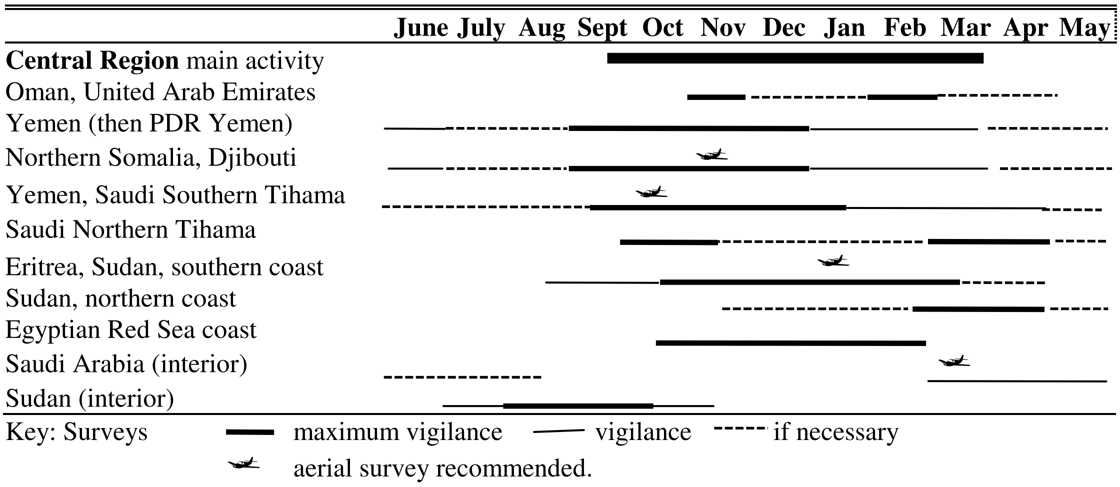
Classification	Population numbers (10^6)	Swarm area (km^2)
Small	1 000	>10
Medium	10 000	>100
Large	100 000	>1 000

18. Roffey (1965) suggested a threefold classification for regional population parameters (Table 4) based on estimates from campaigns in the Horn of Africa during the 1950-1963 plague when DLS estimated swarm numbers and areas using aircraft and recorded the number and size of destroyed bands. These data multiplied by plausible densities for swarms and for bands provided estimates of locust numbers and other parameters used to evaluate their campaigns (Joyce, 1979). No similar campaign data exist for other regions or during recession and upsurge periods. Roffey’s ‘small population’ may be similar to swarm population sizes reached during plague upsurges and there would be three or four medium or large populations present simultaneously in the distribution area during a major plague where swarm area indicates the estimated total aggregate area of all swarms in a “region”.

Required control resources

19. Ashall (1985) discussed the resources needed to prevent plagues with each Central Region country and with DLCO.EA. He recorded the organization and structure of DLCO.EA and national locust units in 1983 as well as their survey and control capacity. Using his knowledge of the size and accessibility of recession breeding areas, particularly those where gregarization occurs, Ashall established the number of ground teams needed to affect plague prevention monitoring and control. He noted that regional aerial spraying resources were concentrated in Saudi Arabia and DLCO.EA. Roy (1985) provided a calendar for ground and aerial monitoring of seasonal breeding areas, which also indicated the degree of vigilance required as a season progressed. After a consultancy, FAO (1985b) amended the calendar (Table 5) without recording the reasons and agreed the proposed number of ground teams and control resources to be available permanently (Table 6).

Table 5. Calendar for surveys in the Central Region during recessions (after FAO, 1985b)



20. Ashall and FAO recognized that national units could not keep the control capacity to prevent plagues on standby for long periods. Instead, they recommended that permanent anti-locust teams should mount the initial campaigns of a plague upsurge. Ashall recommended upsurge elimination in his paper. This tactic, he suggested, would give managers about eight months to mobilize an emergency

Table 6. Survey and control resources needed for early upsurge campaigns (after FAO, 1985b)

Countries	**Staff at 1982**		**Team**	**Vehicles Light**			**Load Carriers**			**ENS**	**ULV**	**Radios**			**Dieldrin 20% (tonnes)**			**Fenit'n 96% (tonnes)**			**TOTAL**
	tech'l	general	need	need	have	want	need	have	want	have	want	need	have	want	need	have	want	need	have	want	**COST**
Sudan	15	70	6	12	6	6	8	0	8	20	30	9	25	0	40	24	16	20	22	0	
Ethiopia	?	?	4	8	0	8	4	0	4	14	20	7	0	7	20	21	0	20	5	15	
Djibouti	?	?	2	4	2	2	2	0	2	3	10	3	0	3	2	2	0	2	2	0	
Somalia	?	?	4	8	1	7	4	0	4	20	20	6	0	6	10	0	10	0	0	0	
Yemen PDR	3	16	4	8	10	0	4	1	3	22	20	7	16	0	10	38	1	10	5	5	
Yemen AR	6	5	4	8	7	1	4	0	4	30	20	6	16	0	10	38	1	10	5	5	
Oman	12	160	3	6	6	0	3	0	3	4	15	4	0	4	10	1	9	5	0	5	
UAE	4	15	3	6	19	0	3	0	3	15	15	4	5	0	10	20	0	5	0	5	
Saudi Arabia	10	119	16	32	120	0	16	15	1	80	80	0*	0	0	80	150	0	20	22	0	
Egypt	80	190	3	6	50	0	3	0	3	3	15	5	19	0	5	3	2	5	0	5	
DLCO.EA	71	213	10	20	123	0	10	52	0	100	50	14	?	0	50	76	0	50	98	0	
Total needs						24				0	295			20			37			40	
Unit costs $						9000					500			4000			3500			6700	
Need $'ooo						216					147			80			129			268	**1811**

NOTES**:**

Staff in post: Roy and Ashall used data supplied to DLCC that are not limited to the mobile survey and control teams

Ground team:

Personnel: 1 technical Officer, 1 technical assistant, 3 drivers, 2 labourers, (Ashall, 1985) plus

Equipment: 1 ENS, 5 x ULV motorised knapsack sprayers, pesticide; 1 mobile radio, 3 camping sets; scientific and safety equipment (listed in Ashall, 1985)

Vehicles: 2 x 4 wheel drive; at least one load carrier; spares

* Saudi Arabia: uses telephones to transmit survey data not radios

Abbreviations

ENS = exhaust nozzle sprayer

Feni'n = fenitrothion

Tech'l = technical

ULV = ultra low volume

supply of vehicles, insecticides and application equipment from local, regional and international sources before the upsurge elimination campaigns began. He argued the feasibility for this two-phase tactic as the first in a sequence of rainfall cues indicating that a plague upsurge might follow[7]. Suitable rains did continue to fall and control started in the Central Region in November 1977.

21. Ashall's mobilization period was to start once it was apparent that a plague could develop which, in the instance he examined, was December 1977. In March 1978, FAO issued he first plague warning and appeal for funds and released money from the Working Capital Fund. Ashall noted that from November 1977 until June 1978 control teams applied about one third of the lethal doses of insecticide that they applied during the entire upsurge and plague[8]. The pre-June 1978 campaigns were, however, in part small because resources for larger ones were not available and in part, because some infested areas were not accessible (Roffey, 1982). In 1978, there were only two to three months for resources to arrive between the March appeal and June, the end of the 8-month warning period. Ashall did not suggest that additional national or regional teams might undertake control before international assistance arrived. Nor did he examine the time between launching an international appeal for emergency assistance and the deployment of the resulting assistance in a control campaign and the effect this had on timely plague prevention. In this instance, however, the post July campaigns and poor rains ended the plague during 1979 (Roffey, 1982). Had rains provided excellent breeding conditions, a less favourable outcome might have followed.

22. Timings in the 1968 plague were more protracted if the initial rains are accepted as falling in summer 1965 and similar if one starts with winter 1966 rains. There was control against gregarizing populations in autumn 1965 but no clear evidence of inter-regional population movements or displacements linking complementary areas that characterize upsurges. Good rains fell during spring and summer breeding 1966 so that populations continued to increase and gregarize whilst attention was focused on grasshopper outbreaks in the Sahel. Successful Desert Locust breeding continued throughout 1967 and, at the end of December, FAO issued a warning that a plague could follow good spring breeding. This was some five months after control began against 1966 upsurge populations. Ashall concluded that the first four months of 1968, was the period when the threat of a plague first became evident. Spring rains and breeding were good and a second warning was issued in May 1968 as the fully gregarious progeny emigrated. Campaigns began to eliminate the plague after 1968 summer breeding. Bennett suggests, however, that hopper infestations in the Sudan some two or three months earlier had warranted a large-scale aerial campaign but she did not consider whether its absence was related to delays between the international appeal and the arrival of funds to contract aerial spraying units.

23. Surprisingly, Ashall assumed that dieldrin 20% and BHC dust would be used in future campaigns even though countries had been turning to environmentally safer chemicals in the previous 20 years and at least one, Saudi Arabia, had ceased to buy persistent pesticides (Ashall, 1985, para. 57, 67). The consultants (FAO, 1985b p.24) recommended that plant protection services and regional organizations should persuade countries to waive any ban on the use of the persistent chemical dieldrin as barriers against hopper bands outside crop areas to reduce campaign workloads to manageable proportions. Dieldrin was only being used in India as the 1986-1989 upsurge was about to begin. This suggests that the estimated control resources recommended (Table 6) based on dieldrin and BHC would have been inadequate to operate a plague prevention strategy using contact pesticides. the estimated control resources recommended (Table 6) based on dieldrin and BHC would have been inadequate to operate a plague prevention strategy using contact pesticides.

PREPAREDNESS ACTION PLAN, 1985

24. FAO (1985b) recognized that plague upsurges would continue to occur owing to combinations of favourable weather and inaccessible breeding areas and recommended operational research and training to improve survey and control operations. No comment was made on Roy's proposal that a technical coordinator be appointed to improve coordination between the Arabian and African sections of theta improve survey and control operations. No comment was made on Roy's proposal that a technical coordinator be appointed to improve coordination between the Arabian and African sections of the

[7] Roffey traced other 1977-1979 upsurge sequences back to heavy winter rains in 1976/77.

[8] Ashall expressed the quantity of insecticide used as the number of billion (10^9) doses applied, a figure related to the theoretical killing power of an insecticide and not to the number of locusts present or killed. His calculation omits the very large summer 1978 campaign in the Eastern Region that eliminated one section of the upsurge sequence and used twice as many lethal doses in a single season than were applied from 1977-1979 in the Central Region (Roffey, 1982).

Central Region. Roy (1985), considering operational weaknesses, emphasized that a lack of trained operators led to as much as tenfold overdosing of locusts, thereby wasting money and creating avoidable environmental pollution. He noted two contributory factors. One was the difficulty of retaining trained control specialists because field operation posts lacked career prospects. The other was that not only did field staff lack survey and control manuals but that no reference materials on these topics could be found at national headquarters.

25. As a result, Roy recommended that staff be trained and regularly retrained and assumed that a by-product would be improved documentation. Continuing operational research was recommended to find replacements for dieldrin, to test new insecticide application technology and to improve the early warning system by rapid transmission of the location of infestations, continuing to use products derived from satellite imagery and by appointing locust information officers in each country. They welcomed two initiatives being planned by DLCO.EA. One was the formation of a regional spray unit that could train national technicians. The other was to prepare and host simulated control campaign exercises to train locust operations managers. The consultants recognized the importance of the second initiative and recommended that FAO provide the services of a consultant experienced in managing locust control campaigns to prepare the exercises.

26. The 1986-1989 plague upsurge was beginning by the time the consultants reported their findings to the DLCC (FAO, 1986b). As a result, locusts tested preparedness before recommended improvements could be made. The simulated control campaign exercises w the subsequent recession (Van Huis, 1994a, c) as did extensive training on ultra low volume (ULV) spraying and the preparation of the associated the Desert Locust Guidelines (FAO 2001 a-f; FAO, 2003c) and Train the Trainers Manual (FAO 2003a).

Weaknesses exposed and remedies initiated during the 1986-1989 plague

27. Following the 1986-1989 plague, Gruys (1994) reported that the preferred strategy was upsurge prevention but that a short plague had occurred because preventive actions were still handicapped by a mixture of previously identified political, organizational and technical problems. He questioned the reliability and cost-effectiveness of upsurge prevention in the absence of a suitable (barrier) technique for controlling the loose assemblages found as an upsurge starts. He reported that emergency funding was released, as in the past, to suppress plagues, which allowed remedies for the problems he identified to begin. The problems noted by Gruys were similar to those found during previous emergencies.

- Lack of security prevented campaigns: Eritrea, 1986; northern Chad and western Sudan, 1987; Western Sahara and northern Mauritania, 1988. Skaf (1990) cited political issues and the use of non-persistent pesticides for the failure of large-scale control campaigns to prevent the plague.
- Inadequate survey and control capacity also delayed control in the early stages of the upsurge. This was exacerbated in West Africa where in 1986 the scarce monitoring and control capacity was diverted to serious grasshopper infestations. As a result, local managers and the FAO early warning system lacked regular locust reports, which in turn prevented accurate predictions and timely reactions. Later, as recommended by the FAO (1985b), national units received additional control resources and additional staff joined the Desert Locust Information Service at FAO temporarily.
- FAO coordinated the vast international assistance operations through its Emergency Centre for Locust Operations (ECLO) established for the first time in 1986. ECLO was established initially to combat other species and staffed by the existing Locust Group personnel. Fortunately, they were able to call on consultants experienced in locust control to help cope with the vastly expanding workload. Nevertheless, non-locust trained consultants in some bilaterally funded control campaigns offered inappropriate insecticide application advice and provided non-ULV pesticides and equipment.
- Inadequate mechanisms for the rapid delivery of the required quantities of pesticides were offset during 1988 and 1989 by donors establishing a pesticide banks.
- Non-availability of pesticides suitable for barrier spraying certainly increased the workload and cost of hopper campaigns. Gruys notes early tests with insect growth regulators (IGRs) sprayed as barriers using funds provided during and immediately after the plague.

CURRENT PREPAREDNESS

Assessing preparedness

Measuring preparedness and success in preventing plagues is highly dependent on the tactic(s) adopted and on the qualitative terms used to describe the locust infestations as they become increasingly gregarious. No objective criteria exist to define when in the continuum, outbreaks become upsurges and when plagues begin. Figure 5, created originally to bring clarity to a group discussion on control strategies (Posamentier & Magor, 1997), obscures the difficulty analysts have in recognizing the transition from one stage to another in the recession and plague cycles. A better understanding of plague upsurges (Waloff, 1966) led to the routine monitoring of pre-plague populations and a switch in strategies from plague suppression to plague prevention. This in turn led to post 1964 alerts of incipient plagues being issued as an upsurge started rather than at the beginning of a plague as in 1941 and 1950. Post 1964 plagues declined rapidly in contrast to earlier ones and affected fewer territories (Fig. 2). A comparison of frequency of incidence maps for 1939-1963 and 1964-1985 (Steedman, 1990) show that Kenya[9], Tanzania and Uganda, and substantial parts of Northwest Africa, the Near East, Afghanistan, Pakistan and India have not been infested by Desert Locusts during upsurges between 1964 and 2005 (see also Fig.1).

28. In 1941 and 1950, appeals for funds to prevent a plague were issued as the plagues were starting (Waloff's plague upsurge and spread stage). Since then, warnings and appeals have been issued during the preceding ‘upsurge’ stage. Despite published descriptions to the contrary, no recent upsurge became a fully established plague as defined by Waloff in her 1966 historical analysis. Three reached her plague upsurge and spread phase and then declined without continuing the growth that precedes peak plague years. Arguably, Waloff and her contemporaries would have perceived this as achieving plague prevention. The sense of failure surrounding upsurge and early plague campaigns since the 1980s suggests that commentators are expecting the current strategy to deliver upsurge prevention or very early upsurge suppression rather than its elimination. In this context, it is important to compare the relative roles played by control and the weather during the four recent declines (1968/69, 1978/79 1988/89 and) and during earlier plagues.

29. FAO established the EMPRES/CR Programme in 1994 to strengthen the capabilities and capacities of the national and regional components of the Desert Locust management and early warning systems to implement effective and efficient plague prevention using timely and environmentally sound interventions as early as possible in the upsurge cycle. Whichever tactic is employed, plague prevention requires an operational national survey and control capability and procedures able to mobilize national, regional and international reinforcements rapidly. In addition, improved technologies have to be tested, adopted and incorporated into working practices. This degree of preparedness has proved elusive in the past and, as each upsurge developed, some teams required additional resources, such as replacement survey vehicles and control equipment, to be funded by international assistance. Detailed information, by country, of personnel, equipment and insecticide stocks are routinely prepared for each DLCC session but these do not necessarily equate with operational readiness.

30. Preparedness is then, an inter-related complex of national, regional and international inputs each of which depends on the operational status of existing resources and perhaps, more realistically, the ability to access reserve funds at relatively short notice. EMPRES CR records of locust budgets, staff and equipment for 2003 indicate that the Central Region would still require additional funds, extra staff and equipment in order to mount campaigns similar to those needed to eliminate plague upsurges in the past 40 years. These data neither indicate whether the financial burden of adopting new techniques and mobilizing reserves during emergencies can be absorbed within national budgets nor the timeframes in which regional or international funds would be needed. This preliminary desk review was unable to judge the source(s) of funds that led to improvements in the region but preparedness will be compromised should either national, regional or international finance be discontinued.

31. Notable improvements associated with EMPRES in the Central Region are that Oman and the interior of Yemen, surveyed sporadically before 1985, now have a locust survey and control units. The early warning system has adopted new technologies nationally and at FAO (described in Chapter 5). As a result, survey and control reports are being transmitted electronically from the field into national RAMSES GIS systems in affected countries before being transmitted in machine-readable form to FAO. It is not clear, however, if the system could cope with the increased workload, a plague upsurge

[9] Swarms invaded Kenya in November 2007 for the first time since November 1961

would bring. On the other hand, Somalia no longer has any permanent units so one can anticipate delays in early upsurge monitoring and control there and possibly in other politically sensitive and insecure areas. Such delays could preclude upsurge prevention and suppression but should not preclude upsurge elimination or extremely rapid plague suppression providing that contingency plans exist to mobilize regional and international reinforcements and funding is available to implement such plans.

Evaluating and testing campaign effectiveness

Recession populations and control tactics

32. Preventing locust plagues was easier to achieve for species that have geographically well-defined outbreak areas within which upsurges occur than for those such as the Desert, the Brown and the Australian Plague Locust. These three locust species have no well-defined outbreak areas but rather outbreak zones relatively large areas parts of which occasionally become very favourable for population increases leading to gregarization and upsurges. Preparedness to prevent plagues of such locusts becomes a balance between affordability, adopting tactics that are least likely to fail and, increasingly, minimising environmental impact. Consensus on plague prevention tactics has proven hard to achieve for the Desert Locust because it migrates seasonally and uncertainties exist about its population dynamics. In addition, parameters do not exist that describe differences between environmental triggers leading to self-regulating local outbreaks from those that initiate upsurges liable to spread between regions and cause plagues.

33. The studies reviewed in Chapter 2 strongly suggest that Desert Locusts are always present at low densities in the three regions and that within each region adult pre-maturation flights link breeding areas that receive rainfall in different seasons. Small outbreaks occur within these populations in many years, in the few sites where rainfall produces sufficient vegetation to allow populations to increase, gregarize and form aggregations or where convergent windfields cause adults to aggregate into swarmlets. These isolated outbreaks tend to disperse and, unless very close to crops, pose no threat to agriculture (Roffey et al., 1970). Consequently, Bennett (1976) and others (FAO, 1985b) suggest that teams should control such local outbreaks only if they are close to crops. National campaign managers seldom follow this tactic and, are unlikely to adopt it until they and forecasters can reliably recognize rainfall and outbreak distributions that initiate solely outbreaks from those capable of initiating upsurges, in case their outbreak is part of an early upsurge population.

34. Heavy widespread and recurrent rainfall occurring in a succession of locust seasonal breeding areas occurs relatively infrequently and may support upsurge development. During these periods, seasonal breeding areas can support more than a single generation and large population increases can occur. Sometimes, after one or two generations have bred, many approximately synchronous outbreaks occur. At other times, population increases continue in a complementary breeding area before gregarization produces many outbreaks indicating that an upsurge may be starting. Often the outbreaks are present in several countries and may occur in more than one region. The best evidence available suggests that only a small part of the population is aggregated into treatable targets at this very early stage of an upsurge (Bennett, 1974, 1976). Most of the population is scattered at relatively low density within the habitat and remains unsprayed. Later, these locusts emigrate to a complementary breeding area where, providing favourable rains fall, they breed and numbers multiply. At first, with each successive season of favourable rains, the infested area expands and a greater proportion of the population becomes gregarious. During this period, managers have to decide when to switch from ground spraying individual targets to aerial spraying of swarms and zones infested with bands. Eventually and paradoxically, although more locusts are present they infest a smaller area once they become gregarious because swarms and bands have higher densities than scattered locusts. Consequently, a smaller area has to be sprayed to control the later stages of an upsurge. Bands usually occupy only 1 to 2% and occasionally up to 5% of a band zone[10]. This led some locust managers to advocate swarm control after considering the logistics, costs and environmental side-effects of spraying the 95-98% uninfested parts of a band zone against the smaller, more discrete and defined but arguably more technically difficult, targets presented by swarm(s) produced from a band zone.

[10] Band zones arise because laying swarms split into smaller aggregations, each of which produces an eggfield within which eggs are concentrated in favourable sites. There may be many eggfields in an infested area. Consequently, after hatching, hoppers are grouped at four scales: into bands that themselves are grouped into band zones representing an egg-field, thirdly within an infested area containing a number of band zones and finally into the season's gross infested area. Between seasons and years, the number of band zones occurring within an infested area varies, as does the number of infested areas, which together total the gross infested area.

35. Swarms migrate farther than scattered adults so that following a sequence of significant seasonal rainfall events ensuring repeated breeding success and swarm formation, the upsurge and campaigns extends, first to the edge of the recession area and then beyond it into the invasion areas reached only in plague upsurges and plagues. Rainfall is generally more reliable in the invasion areas than in the recession areas, which increases the likelihood of successful breeding. When tracing the potential pre-gregarious genealogies of gregarious populations, Waloff (1966) noted that one breeding season in each regional circuit did not occur in every recession year. These were autumn and winter in the Western, North-Central and Eastern Regions and summer in the South-Central Region. Good rains in these seasons appear to occur as an upsurge develops and the absence of breeding during these seasons seems to coincide with their end although poor rains in other seasons also cause breeding to fail as a plague declines. This probable association between seasonal rainfall in Desert Locust Regions and the onset and termination of upsurges deserves rigorous testing.

Evaluating control impact

On Locusts

36. A notable change, between the period before and after the 1960s, was that routine evaluation of both control and campaign effectiveness by many, if not all, locust units had ceased by the late 1970s (Roffey, 1982). Two factors made these tasks easier in the earlier period. Swarming populations were present in most years and some control units had regional responsibilities. The development and operation of evaluation techniques in all three Regions were discussed at a meeting in 1979 as teams were trying to readjust procedures to the longer recession periods (Gunn and Rainey, 1979). Bennett (1974, 1976) was able to adapt the evaluation methods when she analysed the 1966-69 upsurge and short plague but unlike campaign managers, she was dealing with information for all populations not those within a single country. Independent estimates of area infested other than those produced by dividing pesticide(s) used by the recommended dose rate(s) would need to be re-introduced for a realistic evaluation to be undertaken.

37. Gunn (1979) and Joyce (1979) outlined the development of operationally useful quantitative methods of evaluating the impact of control in the Central Region. A key to their success, no longer available to campaign managers, was that up to the late 1960s, some managers directed research programmes to improve operational efficiency and they were responsible for the control of entire regional or sub regional locust populations. This enabled them to organize near synoptic surveys of an entire sub-population, to follow changes in its numbers and distribution over time, to attack infestations in a synchronized fashion at the most appropriate time and, on a scale matching that of the infestations present. They measured the effectiveness of campaigns by comparing the area occupied by the parent swarms, roughly estimating the hopper numbers within treated band zones and finally, measuring the area occupied by the fledging swarms at the end of the campaign. They also calculated the number of lethal doses sprayed, from which an estimate the efficiency of pesticide application could be determined. Both authors and Courshee (1965) also discussed issues around the selection of control tactics and techniques for combating different types of population and the relative costs of each tactical option. Pesticides available then, are no longer in use but the variation in population distribution and the proportion that has to be killed to keep the population at the same or lower levels remain similar.

38. Two basic features of the population reduction strategy adopted for the highly mobile Desert Locust were (i) to organize synoptic surveys to determine the distribution of a semi-autonomous, regional or sub-regional population and (ii) to synchronize control at the spatial and temporal scale indicated by the surveys. This approach was influenced by Knipling's (1972) finding for regulating crop pests that killing 90% of an insect population in 100% of the area it occupies regularly, is more effective in maintaining low-population levels than killing 100% of the insects in 99% of the area. More recently, Van Huis (1994b) considered population increases over five generations and the percentage kill needed to keep the population at its initial level. He started with 10 individuals and used a plausible range of multiplication rates (1-10) which if the “population” were not controlled would produce from 100 to 1 million individuals after breeding five times. To prevent these increases, teams would need to kill 50% of each generation if the multiplication rate was 2, rising to an 80% kill for a multiplication rate of 5 and 90% if the multiplication rate was 10, a rate associated with some upsurges (FAO, 2003b). In the latter case, should one generation remain uncontrolled, then the kill rate would need to be 95% for the remaining four generations, a hard goal to achieve.

39. Not all plague suppression campaigns up to 1964 were organized regionally. Some were always organized by individual countries and this structure became universal during the 1970s. In waging

national, plague prevention campaigns many factors remain the same and need to be considered when selecting the tactics to adopt. When should tactics change from ground spraying individual bands to aerial spraying band zones? What emphasis should be placed on band and swarm control? Methods designed for evaluating plague suppression campaigns are suited to evaluating early and late upsurge campaigns with minimal adaptation as shown by Bennett (1974, 1976) when she analysed the 1966-1969 upsurge and short plague.

On health and the environment

40. Insecticides used in locust control pose some risk to human health and, if incorrectly or misapplied, can cause unwanted side effects among non-target organisms and the environment. Much effort was expended after the 1985-1989 plague to examine these risks (FAO, 2000b) and to develop ways of minimizing them operationally. As a result, the new edition of the Desert Locust Guidelines contains a volume on protecting operators, local inhabitants and the environment (FAO, 2003c). These comprehensive guidelines address risk reduction in all its aspects from choosing control tactics and insecticides through applying best practice during campaign preparation, implementation and the post-campaign storage of pesticide stocks and the safe disposal of empty containers.

41. The monitoring of safety measures, human exposure and environmental contamination is gradually being integrated into control operations. Countries are beginning to create specialized teams to assist control units to apply pesticides correctly and to implement safety measures and environmental protection practices. These teams are being trained to work alongside control teams and monitor side effects of pesticide treatments and recognize early symptoms of insecticide intoxication, as part of a programme aimed at the general introduction of good field practice. Team members take blood samples to monitor human exposure to pesticides, measure residues in water bodies and other non-target zones, and they advise on the proper handling of empty containers and pesticide stocks.

42. Scientists are seeking to identify the least harmful locust control agents for possible use in environmentally vulnerable areas. Environmental surveys in such habitats establish the effects of different pesticides on non-target insects, including ecologically important groups such as ants and termites and the natural enemies of pests including locusts. Introducing such surveys and the adoption of best spraying practices during all campaigns are important aims of the EMPRES programmes and ultimately they will need to become standard features for locust contingency planning and control campaigns. To date maintaining sustainable and effective survey and control capacity, as well as environmental and human health monitoring has required external funding in some countries and shortfalls in funding are likely to recur when the EMPRES programme ends.

Testing preparedness

43. Testing the operational preparedness to achieve plague prevention is not as straightforward as it might seem. It is easy to assume that knowledge and data exist to make testing preparedness an easy three to four stage process. First, compile archived details of infestation locations, sizes and phases typical of locust control campaigns as plague upsurges develop to provide a plausible locust scenario. Secondly, apply work rates appropriate to the number of permanently retained control teams and their available resources including vehicles, spray equipment, operational funds and pesticide stocks to estimate the proportion of locusts that could realistically be controlled before laying or emigration. Thirdly, add reserve staff and resources for which there are agreed national or regional emergency funding and mobilization plans. Fourthly, if national and regional reserves are insufficient, decide when and how in an upsurge cycle to call for international reinforcements. Currently, the plague prevention control strategy advocates spraying solely gregarious populations or those that might gregarize after breeding. Non-gregarious locusts are not control targets and so a test is needed to estimate if they will be sufficiently numerous to continue the upsurge.

Upsurge and plague campaigns

44. Unfortunately, setting the parameters for locust infestations in typical upsurge campaigns is far from straightforward. Providing plausible estimates of the scale of upsurge populations remains uncertain and open to debate because knowledge of population dynamics is incomplete. Simulating campaigns was first mooted in 1985 to make inexperienced locust personnel aware of the practical problems faced by campaign managers and control teams (FAO, 1985b) but a plague delayed their preparation and use. During the subsequent recession, participants from affected countries, donor agencies and FAO used a suite of exercises designed to examine the resources needed to achieve successful control at different stages in plague development (Van Huis, 1994a, c). A revised, interactive

computer-based version of these exercises is now available on the FAO web site (Symmons, 2003). The exercises relate to 'outbreak, upsurge and plague' populations, which represent locust populations present at the beginning of an upsurge, when an upsurge is well developed and finally early in a plague based on locusts present during selected campaigns from the 1966-1969 emergency. They were selected as key stages in plague prevention (Fig. 5) because their elimination requires significantly different resource levels. Symmons also designed and presented a more realistic, field version of the outbreak exercise in which participants have to locate and simulate spraying 'locust concentrations' represented by pebbles placed in typical Central and Western Region habitats (FAO, 2002a; FAO, 2004a).

45. Explanatory texts accompany each exercise and suggest plausible input parameters with their degrees of reliability. The EMPRES CR seminar report (FAO, 2002a) gives a detailed account of the exercises, their purpose and on planning campaigns, as well as, participant reactions. Participants may redefine some but not all parameters to values they think are more plausible. The DLCC Technical Group (FAO, 2004a) found setting parameters for 'outbreaks' the most contentious and the group queried the density and sizes of patches and bands proposed as typical. It is probable that most users would expect outbreaks to reflect an earlier stage in an upsurge, when locusts are less gregarious, when hopper densities are lower and the proportion of scattered locusts is higher.

46. Symmons derived his 'outbreak' parameters from the progeny (small swarms, groups and scattered adults) recorded when they invaded Iran, and augmented populations in southern Yemen and Somalia in December 1967 (not 1968 as mistyped in the exercise). The source outbreak was largely unobserved and developed within Oman between late 1966 and late 1967. Travellers did notice hoppers and adults in summer and autumn 1967 and Popov (1968) and Bennett (1974) used these observations, with the distribution of rains and egg and hopper development periods to infer plausible egg laying and fledging dates in 1966 and 1967. They inferred that the emigrants resulted from three generations breeding successfully which were not surveyed or controlled as, at that time, Oman had no Locust Unit (see Chapter 1, paras 57, 58 and Chapter 2, para. 64).

47. Whether Symmons' exercise represents an early outbreak or a later stage in an upsurge is less important than the fact that it does represent the size of campaign occurring before external aid arrives. In this instance, the first plague warning was issued in December 1967 as the locusts in the simulated 'outbreak' were emigrating and a second warning was issued in May 1968 at the end of the subsequent breeding season. Resources listed in 2003 by EMPRES CR and views of the Technical Group (FAO, 2004a) suggest that the national locust teams and reserves would be able to mount successful campaigns against such 'outbreaks'. In several countries, however, external assistance from regional or international sources would be required to mount a successful control campaign even against such outbreak level populations. This suggests a significant risk exists that upsurge prevention (Fig. 5) will fail whilst regional and international aid are being organized and delivered.

48. The upsurge and plague exercises consider the stage at which spraying blocks (areas containing heavy infestation) and aerial control campaigns should replace ground spraying of individual locust concentrations. The mobility of bands in relation to their size and gregariousness is introduced as an aspect of selecting track spacing if barrier spraying is used. The resources required to undertake aerial control campaigns quickly exceed the existing control capacity of all but a few countries. This again highlights the issue of time lags between appeals for international assistance and the actual delivery of resources for the campaign.

Control resources, the regional and national context

49. The above exercises clearly establish that contingency plans are an essential tool to plan a large campaign effectively and to assist in securing the additional resources required to mount large upsurge and plague campaigns as is clearly spelled out in the EMPRES CR seminar report (FAO, 2002a). The exercises do not attempt to evaluate variations in the threat to specific countries that need to be reflected in nationally held resources and their associated contingency plans. The importance of national as opposed to regional resources for mounting campaigns has increased in the period since 1964. Ashall assumed that DLCO.EA would continue to provide considerable ground and aerial control to Member States each year. Since 1985, however, a restructured DLCO.EA no longer provides all the seasonal ground and aerial survey functions described by Ashall. Instead, National Units may also need to consider contracting commercial air spray companies.

50. No compiled data existed to develop and evaluate national preparedness exercises. Papers describe three upsurges in the Central Region (Bennett, 1974; Karrar, 1974; Roffey 1982) and the data

they contain on infestations and control campaigns were briefly assessed. Bennett archived details for 1966-1969 from which she estimated the effectiveness of seasonal campaigns. Her archived files contain data on population classes, their locations, areas infested, areas controlled and control methods. She also archived notes on discussions she held with campaign managers and listed the reports from which she had extracted data. As a result, the data she archived should enable others to determine how she estimated infested and treated areas in her study. Karrar listed solely the areas controlled and Roffey gave the areas infested where known, the quantities of pesticide used during a season and he summarized the impact on the population (Table 3 in Roffey, 1982). Problems exist in using all three studies as they include seasons when the authors inferred that infestations were present in inaccessible areas. In addition, campaign data on areas sprayed, especially before externally funded resources arrive, may be more a reflection of limited survey and control capacity available than an accurate reflection of the dimensions of known and inferred locust infestations.

51. A preliminary extraction of Bennett's data on to Excel spreadsheets enabled information to be assigned within each country to degree square resolution. A problem highlighted in transcribing her archived lists was how to transform survey data into areas infested. The spreadsheets have not been included with this report, as project time did not allow this time-consuming task to be checked and annotated for users. In addition, the representative nature of these country specific values cannot be established until those for other upsurges are available. In the meantime, managers could use the number of national teams and typical work rates to obtain a first approximation of areas that teams could survey and treat before reinforcements are needed.

Control resources, international funding

52. To date international donors have provided a substantial part of the funds needed to mount the large plague prevention campaigns but their willingness to contribute immediately, as in the past, cannot be presumed. One objective of affected countries and FAO must be to secure or replace donor finance. Otherwise, effective plague prevention strategies will fail. The role of donors has changed since the 1930s from being colonial powers with responsibility for many affected countries to being Development Agencies disbursing development and emergency funds. Funding a plague prevention strategy except during upsurges and plagues does not qualify easily as a justifiable call on either of these budgets. Locust emergencies are now rare and, between them, donors may forget the integral role assigned to their finance, originally to suppress plagues and latterly to prevent them. Consequently, they may delay or even fail to provide funding unless they are both advised and convinced in advance that affected countries are unable jointly to raise the necessary funds and that preventing or suppressing plagues is justifiable in terms of benefits and costs including environmental costs.

Contingency planning

53. Locust Organizations need mechanisms in place to facilitate the delivery of international assistance and to provide an operational framework and guidance for the locust organisation when an upsurge begins. Such contingency plans should minimise institutional memory loss and integrate lessons learned from previous occasions when funds were mobilized to equip national and regional reinforcements for upsurge campaigns, to hire international consultants and to coordinate responses. Locust contingency plans need to be sufficiently flexible to respond to changes between emergencies in external funding procedures.

54. The FAO Central Region Commission has a very small reserve fund of around $100,000, a sum completely inadequate to cover the substantial costs of significant control operations. The FAO Reserve Funds set up in earlier periods as part of International and Regional Trust Funds were similarly inadequate. This was also the case for the global Working Capital Fund operated by FAO during the 1970s, which failed to keep pace with inflation, and so lost purchasing power before an emergency arose. Since the 1940s, one aspect of contingency planning has been a centralized call for international funds when the threat of a plague becomes apparent. In pre-1960s cases, emergency funding arrived too late to prevent the plagues becoming established and lasting many years. Subsequently, monitoring recession populations led to earlier warnings and calls for international aid but time elapsing between an appeal and delivery of resources to campaign managers is not well documented. It is however a critical factor in contingency planning (FAO, 2002a). Comparable contingency actions to mobilize national and regional reserves and to approach donors bilaterally exist. They too, are poorly documented in library holdings and so are not discussed in this desk study. Improving contingency planning and evaluating control activities are, however, major objectives of the EMPRES programme.

55. In 2003, it appeared that a serious upsurge was starting in both the Central and Western Regions and FAO alerted countries to the deteriorating situation in October 2003. Why it continued in the Western but not in the Central Region is unclear. Certainly, rain was much less favourable to locusts in the Central than the Western Region in the winter of 2003/04. An analysis of events is urgently required to judge the relative roles played by control preparedness and the weather in the marked differences in regional outcomes. Calls for emergency funds for the Western Region began in February 2004 at the stage of upsurge development similar to that which Ashall (1985) indicated as the time for managers to mobilize reserve teams and funds. It remains to be seen if funds arrive and resources are delivered within the eight-month period allowed by Ashall and if control teams in the Western Region already reinforced from within that region can contain the upsurge until October 2004. It cannot be presumed that international donors will contributed as before, as the apparent slow response by donors to the initial appeal for international assistance in 2004 may indicate. It also remains to be seen if funds arrive in the timeframe envisaged by Ashall or if his assumptions need amending. It is instructive to remember that in advocating upsurge elimination, the arrival of reinforcements in time for late upsurge campaigns would have been acceptable. In contrast, in the Western Region and during the early stages of the EMPRES CR programme much emphasis was placed on controlling gregarizing populations early in an upsurge as a more effective, although unproven tactic. Any indication that this tactic has worked should be rigorously tested.

Addendum March to June 2005

56. The February appeal for pesticides and survey and spray aircraft to minimise swarm production in Mauritania during spring 2004 was issued as swarms produced on winter rains continued breeding in northern Mauritania and emigrated to breed throughout the Mahgreb in the spring. Too few donors responded to this appeal so that neither the Mauritanian teams, reinforced from within the region nor Mahgrebian teams were able to stop upsurge developments. As a result, the Sahel was invaded by swarms from June until August 2004 and each wave of swarms matured and bred soon after arriving. The first wave reached Cape Verde, Senegal and Burkina Faso an event associated with spring generation invasions from northern Mauritania and Western Sahara where swarms form earlier than farther north in the Region. Swarms migrate farther than adults during recessions and so apart from these countries and southern Mauritania, swarms also bred in the agricultural zones of Mali, Niger and Chad that are infested by gregarious populations during upsurges.

57. The main summer breeding had finished before most external funding and supplies started to arrive in the Sahel in late September 2004. The summer rains were short and winter rains did not fall in northern Mauritania in 2004. As a result, whilst some first generation swarms bred in the Sahel, many emigrated to northwest Africa through Algeria and Mauritania. Most emigrant swarms remained immature until March 2005 giving the teams in Mauritania and Northwest Africa, now fully resourced through international assistance, five to six months to control a finite number of swarms. Elsewhere, some swarms produced in the summer later moved south to Guinea and reappeared as expected when the ITCZ moved northwards and eastwards in May and June 2005 as far as the Sudan.

58. External aid arrived in the timeframe envisaged by Ashall (6 to 8 months after an appeal) for plague elimination campaigns but too late to stop large-scale production of first generation swarms during summer breeding 2004. Two factors may need amending. Ashall was predicating control by Regional organizations covering complementary areas. Deliveries need to anticipate the annual migration circuits and to be concentrated in the most affected areas but as responsibility for control now lies with each country, moving supplies freely to the most affected areas is less feasible. Secondly, Ashall's timing is not suitable for controlling gregarizing populations early in an upsurge; a tactic that the Western Region and the EMPRES CR programme contend is a more effective in preventing plagues. Unfortunately, the assertion that upsurges can be ended quicker by treatments of the initial outbreak stage of an upsurge can be field evaluated only when funds become available to all infested countries and they start control early in an upsurge.

5. THE ADOPTION OF POST 1985 TECHNOLOGIES

P. Ceccato, H M Dobson, J I Magor and J Pender

BRIEF OVERVIEW

1. Elements of the Anti-locust technology changed during and shortly after each upsurge and/or plague but the funds needed to re-equip and train teams to use the new technology was seldom available until the next upsurge or even plague had developed. An awareness that chemical pesticides may cause environmental pollution increased during the 1988-1989 plague and led to moves to develop and introduce biopesticides. At the same time, farmers were being encouraged to practice integrated pest management so that future control campaigns may need to adapt anti-locust measures to preserve these practices. After the 1988-89 short plague ended, funds became available to develop biopesticides, investigate the environmental impacts of pesticides (Locustox Project) and to use computers to manage locust, weather and habitat data used in early warning systems.

Constant factors when improving control technology

- Funding and consequently expertise diminish as plagues end.
- Control strategies need appropriate legislation.
- New control methods may demand profound changes in the organization of control and require the amendment of anti-locust legislation and practices.
- Improved techniques have to be actively promoted.
- Some research opportunities exist solely during plagues.
- A vital step in achieving preparedness is spreading improved work practices made during and after emergencies throughout the Desert Locust area.

Guidance on safe use for current and new pesticides

- Changes in control techniques arise from a need to deliver more effective control and to deliver safer control methods for operators, inhabitants, livestock and the environment.
- FAO's Pesticide Referee Group (PRG) provides guidance on pesticides effective against locusts and grasshoppers. PRG Reports on FAO's Locust Watch web site list products effective in trials against locusts and grasshoppers together with dose rates. Information on the speed and mode of action of the pesticides is included as a guide for potential users. The Group established insecticide field trial protocols and regularly assesses results of trials of candidate pesticides and their suitability in respect of volatility, mammalian toxicity, non-target impact and formulation characteristics.
- Three types of product have shown promise for adoption in Desert Locust control since 1985: insect growth regulators (IGRs), the phenyl pyrazole, fipronil and a mycopesticide based on *Metarhizium anisopliae* var. *acridum.* These products are not yet fully tested and registered for use against the Desert Locust in all affected countries.
- Safety is enhanced by purchasing suitable pesticides in appropriate quantities, storing, and using them correctly. Rotating drums in stores and using the oldest first minimises obsolete stocks and drums should be destroyed safelt after campaigns.
- A vital safety component is calibrating sprayers to emit the correct dose rates
- FAO provides guidelines on minimum requirements for locust and grasshopper sprayers that are hand-held, vehicle mounted (FAO, 2004b) as well as suitable for use on fixed-wing aircraft and helicopters . Reliable rotary atomiser that produced droplet sizes appropriate for ULV spraying with contact insecticides were available by the end of the 1990s.
- Global Positioning System (GPS) allow infestations to be precisely located, re-found, sprayed and mapped.
- Control operators and non-target fauna should be monitored regularly.

Early Warning System

- The fundamental features of the early warning system, collecting, transmitting and analysing information on locusts, weather and habitat remain unchanged but the data are now managed and displayed in bespoke geographical information systems, SWARMS at FAO and RAMSES in national locust units.
- Information Officers can also visualise, analyze and automatically download rainfall estimates derived from satellite measurements of daily and 10-days rainfall estimates and vegetation indices derived from MODIS images over which national and district administrative boundaries and locust infestations can be displayed.
- National teams need to evaluate the reliability with which the new MODIS products identify sparse green desert vegetation that provides suitable conditions for locust breeding and population increase. Survey teams are now able to store digital pictures of vegetation in a database within RAMSES so that imagery and the geolocated photographs can be displayed on screen together. These tools will help them distinguish vegetated habitats on images are favourable for locusts and should be monitored.
- eLocust, a palm top computer and GPS system enables survey officers to record and transmit their locust, weather and habitat records directly from the field to the GIS at their national headquarters.
- Almost all recession countries now manage their survey and control data in a GIS and export information to FAO's system SWARMS. More training is required for users to generate analyses of control campaigns and

peer reviewed case-studies of locust events because such research requires greater knowledge of GIS than needed to operate the bespoke routines programmed into SWARMS and RAMSES.
- Customized GIS require ongoing support and maintenance for annual commercial maintenance contracts and for developers to continue to meet system requirements as software changes and users' aspirations change.

INTRODUCTION

1. The Desert Locust's population dynamics alternate between recessions and plagues thereby making it an intermittent threat. Recessions contain periods when locust numbers are too low to threaten the livelihoods of farmers and pastoralists. As numbers and densities rise, outbreaks and upsurges develop which, unless stopped by control and/or the weather, initially threaten subsistence crops and grazing and later threaten major agricultural regions. The control strategy aims to prevent plagues arising and requires international cooperation throughout the pest's distribution area. Preventing plagues depends not only on timely applications of effective and safe control measures but also on teams collecting information on infestations and transmitting it rapidly to national control headquarters for analysis, managing campaigns and onward transmission to the FAO, where a central forecasting unit operates an early warning system. Uvarov (1951) recorded lessons to be learned on developing and introducing improved technologies that remain relevant today:

- Funding and consequently expertise diminish as plagues end.
- Control strategies need appropriate legislation.
- New control methods may demand profound changes in the organization of control and require the amendment of anti-locust legislation and practices.
- Improved techniques have to be actively promoted.
- Some research opportunities exist solely during plagues.

2. Two factors drive changes in control techniques. First, the need to deliver more effective control and secondly the need to deliver control methods that are safer for operators, inhabitants, livestock and the environment. The review in chapter 1 showed that parts of the anti-locust technology changed during and shortly after each plague but the funds needed to re-equip and train teams to use new technology were seldom available until the next plague had developed. The first coordinated campaigns intended to re-establish a recession occurred during the 1940-1948 plague and required the large-scale production and use of poisoned baits. As the next plague started in 1949, teams were organized and equipped for large-scale baiting campaigns but were not adequately equipped for the new techniques of ground and aerial spraying of liquid pesticides (Gunn, Perry *et al.*, 1948; Gunn, Graham *et al.*, 1948). FAO encouraged the adoption of these more efficient methods but their social and economic implications aroused some opposition because spraying removed an important source of employment and revenue from the vast local labour forces used in baiting campaigns (Lean, 1965). The 1949-1963 plague saw spraying widely adopted but some dusting and baiting was still used during the 1987-89 plague.

3. Techniques developed during the 1949-1963 plague were ultra low volume (ULV) spraying and its associated equipment, as well as spraying swarms from air to ground and air to air (Courshee, 1965; MacCuaig, 1963; Sayers, 1959; Symmons, 1994). ULV spraying was extremely practical for locust control and was quickly adopted particularly by countries where the need for locust control was relatively frequent. The advent of dieldrin, a persistent and cumulative pesticide led to spraying swaths or lattices onto vegetation across the likely path(s) of marching hopper bands. Spray runs (tracks) were up to five km apart. Spray drift affected part but not the whole of the inter-track area. (Courshee, 1965, 1990; Joyce, 1979)[1]. Hopper bands gradually accumulated a lethal dose of dieldrin as they crossed one or more sprayed 'barriers'. The vegetation remained poisonous for several weeks removing the need to return to spray infestations that subsequently hatched within or entered the sprayed area. This was an effective method of killing mobile hopper bands but is less effective against populations that are grouping or against small, less mobile bands characteristic of early upsurge periods. By the end of the 1966-1969 plague, non-persistent contact pesticides began to replace dieldrin to protect users and the environment but acceptance of the new, more expensive, slower and logistically more demanding control method was still being resisted by some groups before and during the 1985-1989 upsurge and plague (FAO, 1985b; Skaf, Popov and Roffey, 1990).

[1] Note, these spacing are not those now recommended for the non-cumulative pesticides accepted as suitable for 'barrier' spraying by FAO (2001d) and by the Pesticide Referee Group (FAO, 2000a).

4. An awareness that chemical pesticides may cause environmental pollution increased during the 1985-1989 plague and led to moves to develop and introduce biopesticides. At the same time, farmers were being encouraged to practice integrated pest management so that future control campaigns may need to adapt anti-locust measures to preserve these practices. After this short plague ended, funds became available to develop biopesticides, investigate the environmental impacts of pesticides (Locustox) and to use computers to manage locust, weather and habitat data used in early warning systems. The chapter reviews progress in the development and adoption of techniques developed specifically for locust control and those developed elsewhere, such as computers, satellite imagery and navigational aids, and adapted for use in locust control and early warning systems.

5. As in previous eras, both development and non-adoption of new techniques is more often limited by lack of funds and training than by unwillingness to adopt new technologies proven sufficiently robust to withstand the harsh conditions of Desert Locust campaigns.

ADVANCES IN LOCUST CONTROL SINCE 1985

Evaluating impacts on non-target organisms, human health and the environment

6. Chemical pesticides remain the main control agents when outbreaks, upsurges and plagues occur and mitigating the potential adverse effects on human health and the environment became one of the foci of applied research in the 1990s. An important outcome was the precautionary steps set out in Guidelines (FAO, 2003c) on safety and environmental precautions that should be followed when locusts are controlled. Locust control takes place in a wide variety of habitats. Best practice starts with the choosing a pesticide appropriate to specific habitats, storing and applying them correctly, monitoring the impact on human health and non-target fauna as well as evaluating the effects of control on the Desert Locust population and the safe disposal of empty containers.

7. In 1989, FAO set up a Pesticide Referee Group (PRG) to assess the effectiveness of existing and new candidate pesticides and to provide guidance on their use against locusts and grasshoppers. The PRG also established insecticide field trial protocols and on an ongoing basis assesses the results of trials of candidate pesticides along with their suitability in respect of volatility, mammalian toxicity, and non-target impact and formulation characteristics. PRG reports list products shown to be effective in trials against locusts and grasshoppers together with dose rates. Information on their speed and mode of action is included as a guide for potential users. Meeting reports are available online (e.g. FAO, 2000a). The reports do not, however, provide indications of relative costs and it is difficult to verify details such as whether application criteria for barrier spraying against Desert Locust were obtained directly from large-scale field trials against this species or were estimated by other means. The reports of the PRG Meetings and a database of trials they evaluated can be found on the FAO web site.

8. Much new information on assessing the risks of pesticides on the environment, the risks to personnel applying the pesticides and to local inhabitants were gained in the 1990s (Everts et al. 1997, 1998a, b, 2002) to the point where the training of teams to monitor such effects could begin. Everts and colleagues described the hazards of pesticides used in locust control to a wide range of terrestrial and aquatic fauna, which provided initial guidance for the selective use of pesticides in different ecosystems. Additional knowledge is required. In particular, the identification of areas of ecological sensitivity where spraying should only be undertaken using biopesticides, and the continuing task of developing, testing and adopting safer pesticides and safer application techniques and methods. The training of teams to monitor the potential side-effects of control campaigns will also be an ongoing requirement.

Pesticides

9. Since 1985, three types of product showed promise for adoption in Desert Locust control: insect growth regulators (IGRs), the phenyl pyrazole, fipronil and a mycopesticide based on *Metarhizium anisopliae* var. *acridum.* These products are not yet fully tested and registered for use against the Desert Locust in all countries. The first two are persistent but non-cumulative which could allow the return of work-efficient 'barrier' spraying should they prove environmentally acceptable. Fipronil's alleged impact on bees led France to suspend its use in 2004 pending further studies on non-target impacts (CET, 2003, France, 2004). The effects of fipronil sprayed as crosswind barriers at 750 metre intervals at 4 grams active ingredient per hectare in the wet season and as a full cover treatment at the beginning of the dry season were examined in Madagascar in 1998. At both sites, high mortality was observed in

the harvester termite, *Coarctotermes clepsydra in Madagascar,* which affected the abundance of vertebrates such as lizards as well as more specialist termite feeders. It was recommended, therefore that fipronil should not be used in full-cover spraying and that additional studies of barrier spraying be carried out (Peveling et al. 2003). Australia is undertaking a re-registration review of veterinary and agricultural products containing fipronil (Australia, 2003) to re-assess user safety and labelling regulations. Nevertheless, fipronil remains registered for locust control in Australia and is used in wide interval (barrier) treatments in rangelands and grazing areas but at a lower dose rate than was used in Madagascar. The Australian trials with a new 'parallel to wind' wind barrier technique (see para 17) provides larger unsprayed inter-barrier spaces affording greater security for non-target fauna. Imidacloprid is another product potentially usable against locusts (FAO, 2000a). In May 2004, France extended the ban on using imidacloprid as a seed treatment for maize, again for an alleged impact on bees, until the chemical is reviewed in 2006 by the European Commission under the pesticides authorization process (PAN-UK, 2003a, b). These reviews may limit the availability and acceptability of these products elsewhere until conclusions are published.

10. The mycopesticide's infectivity, which is limited to acridids, makes it promising for use in environmentally sensitive areas, where conventional chemical pesticides should not be used. However, its relatively slow mode of action and associated time taken to achieve mortality of the target locusts and grasshoppers when compared to conventional pesticides makes its use problematic close to crops. An advantage is that isolates were developed as ULV products. One isolate (IMI 330189) Green Muscle® is provisionally registered in South Africa and in the CILSS countries of West Africa (FAO 2002b). A closely related mycopesticide, developed from a different isolate (FI 985), is registered as Green Guard® (Milner, 2002) and has been used operationally against locusts in Australia since 2002. FAO (2002b) published a risk assessment concerning importing and large-scale use of mycopesticides. Medium-scale trials with *Metarhizium* to set dose rates and establish effectiveness for use against Desert Locust had to await the return of suitable targets in 2004. A further issue is whether commercial production for such an intermittent market can be guaranteed, as it was in Australia, where the need to spray using a bio-pesticide, as opposed to conventional pesticides, was imperative to preserve export markets for organically produced livestock and other agricultural products.

11. With IGRs, the mode of action disrupts chitin production during the nymphal moulting phase. The products are therefore only useful against the nymphal stages and not against the adult stage. IGRs are close to being integrated operationally into locust control campaigns. Diflubenzeron, an early example, is the most widely tested within the Desert Locust area. It has relatively low toxicity to mammals (WHO class IV), fish and birds but can have serious effects on aquatic arthropods (Lahr and Diallo, 1993). Tingle and others (1994) showed, however, that only few non-target terrestrial invertebrate groups were affected in Madagascar. It has a half-life within the Sahelian environment of around 15 days (Sissoko, 1991; Gadji, 1993) and is quickly broken down by micro-organisms on contact with the soil (Nimmo, Dewild and Verloop, 1984). Trials to test barrier spraying against marching Migratory Locust bands occurred in Madagascar in 1993 (Cooper et al., 1995). The results were promising but barrier spraying parameters require further testing against Migratory Locusts at intervals greater than 400 m and still have to be established for Desert Locusts. Barrier width and spacing is more critical than with dieldrin for two reasons. First, the insects excrete the poison quite rapidly (Coppen, 1999) and secondly, hoppers must eat a lethal dose whilst passing through a barrier, as IGRs have no contact action. The closely related IGRs teflubenzuron and triflumuron were also tested for use against locusts and grasshoppers. All three have verified dose rates for blanket spraying but a dose rate for barrier spraying with teflubenzuron is yet to be determined (FAO, 2000a).

Sprayers

12. Reliable spray application equipment for applying pesticides, especially ULV pesticides by aircraft and four wheel drive vehicles existed before 1985 and so few changes occurred. Hopes that microlight aircraft might play an important role in survey and control were not realized. Their lighter weight makes them more vulnerable to turbulent air conditions and their smaller payload gives them insufficient spraying capacity for all but the smallest of tasks. Improvements to sprayers reported here, resulted from interactions with manufacturers and FAO has provided guidelines on minimum requirements for locust and grasshopper sprayers (FAO, 2004b) to reduce the use of inappropriate equipment for locust control.

13. The gradual replacement of dieldrin from the 1970s with contact pesticides of low persistence and the greater emphasis on pesticide efficiency and on minimizing their impact on humans, livestock and

the environment necessitated changes in spraying equipment and application techniques. The main operational advantage of dieldrin barrier spraying was that large areas within which hopper bands were present could be relatively quickly delineated and sprayed and if reinfested did not need to be resprayed. These advantages were lost when less persistent pesticides were introduced because smaller blocks containing locusts needed to be demarcated and the spray applied more uniformly increasing search and control costs. A more sophisticated application tool than the Exhaust Nozzle Sprayer (ENS) was required for ground spraying, and more systematic spraying methods than those used for the very forgiving and robust barrier spraying technique.

14. Droplet size is critical parameter in ULV spraying given the low volumes of pesticide applied per hectare. Excessively large droplets containing most of the pesticide fall out quickly and those that are too small drift long distances without effect. Hand-held and aircraft-mounted sprayers, with more accurate flow control, were already available as were rotary atomisers producing much narrower droplet spectra than the ENS. A narrow droplet spectrum is more effective per unit volume of pesticide, and a rotary atomiser is the only practical way of producing such a spectrum in the field. Two main designs of rotary atomiser in use in the 1980s were spinning cages on aircraft and spinning discs on hand-held battery-powered sprayers. Aircraft mounted rotary cage devices were redesigned to improve performance and reliability. In addition, electrically and hydraulically-driven versions were developed, which are better suited to the slower and more variable airspeeds of helicopters than windmill-driven units were.

15. The 1986-1988 plague stimulated development of a vehicle mounted sprayer that overcame the shortcomings of the ENS and sprayer companies began developing a vehicle mounted sprayer with rotary atomisers. Sprayers producing droplet spectra more suitable for spraying non-persistent contact pesticides were tested during this period but had poor reliability in the field. Early efficacy results in the field were promising (Symmons et al, 1989), but reliability was poor initially due to mechanical failures, pump seal degradation and drive belt problems. As a result, the ENS remained the mainstay of ground-based ULV spraying during most of the plague and for some years after it. Mauritanian locust staff reverted to the ENS because the rotary atomiser devices broke down in 1994 (Ould Baba, personal communication.). Manufacturers solved these problems and by the end of the 1990s reliable versions were available for adoption (FAO, 1994b, 2002c) and refinements were offered as optional extras. These included positive displacement pumps to allow flow rate to be set accurately regardless of pesticide formulation characteristics, direct drive motors to solve drive belt problems, and a system to adjust droplet size in from the controls in the cab. Hand-held spinning disc sprayers were refined by introducing an aluminium handle and battery case that was more durable than the previous plastic one, and a better disc design and motor reliability.

16. The current range of sprayers meets the requirements for most locust control tasks and have been field tested (FAO, 1994b; FAO, 2002c). Hand-held spinning disc sprayers can be used for control of small hopper bands, vehicle-mounted passive drift sprayers can be used for more extensive hopper band control, and vehicle spraying work rate can be doubled by using vehicle-mounted airblast sprayers that produce roughly twice the swath width. These airblast sprayers can also be used to control small swarms roosting in bushes and low trees. Aircraft mounted sprayers can be used for full cover spraying or barrier spraying of hopper-infested areas, or for spraying settled swarms. They can potentially also be used to spray flying swarms, although few aircraft with systems to prevent locusts choking air intakes, cooling fins and windscreens are thought to be in operation today. These different types of sprayer can be used in integrated ways to tackle the range of target types and stages encountered in the field.

17. Even though IGRs and fipronil have made barrier spraying possible again, these products require more accurate application equipment than dieldrin did. Accurate doses are required in barriers, and avoidance of long range drift of very small droplets is important to retain the environmental integrity of inter-barrier zones. A potentially valuable modification to the barrier technique in which barriers are sprayed parallel rather than cross wind to provide discrete barriers about 100 metres wide with no pesticide residue in the inter-barrier spaces is being tested in Australia (McCulloch and Spurgin personnel communication).

Ancillary equipment

18. Global Positioning System (GPS) technology is used to record the location of infestations and teams have hand-held GPS for this purpose. Two GPS functions are particularly important for locust

field staff. First, GPS systems can be used to mark a target accurately i.e. capture the geographical coordinates of a target or corners of a treatment block to be passed to control teams. Although the value of this information degrades with time, particularly for very mobile swarm targets, experienced field officers are often able to track the downwind movement of locusts since the last sighting using meteorological information. Secondly, GPS can guide ground teams or aircraft to map coordinates of infestations. Recent research has examined the potential for introducing spray systems linked to GPS and to Differential GPS for improving track guidance and spray control in aircraft (FAO, 1999b) and for ground spraying (Aston, 1999). Such features are becoming standard on commercial spray planes and in some countries (e.g., Australia) are mandatory requirements.

19. More sophisticated GPS systems used in aircraft can also calculate the position of spray tracks, guide the pilot along them and record the flight path for later analysis. This technology avoids most of the need for flag marker teams on the ground, freeing up personnel to locate and demarcate other targets and freeing them from what can be a hazardous task. Large scale agriculture is increasingly making use of further refinements that record important spray parameters such as atomiser speed and flow rate. Active spray systems linked to the GPS and track guidance equipment now exist that can switch off the pump at the end of spray runs and as the aircraft flies over no-spray zones provided their coordinates have been entered previously. It can also regulate the flow rate to compensate for fluctuations in forward speed and track spacing. The problems of re-finding targets, navigating accurate spray passes, applying the correct dose and avoiding sensitive areas apply equally to vehicles, albeit on a smaller scale. It is possible that these GPS, track guidance and active spray technologies will be transferred to vehicles in the future, but at present they are still being development. GPS technology is not the answer to all spatial problems in Desert Locust control. It does not help ground teams to locate targets initially, nor to find the boundaries of moving swarms or extensive areas with heavy enough infestation to warrant control operations. Neither can it guarantee that migrating swarms will be relocated from earlier sighting positions.

CHANGES IN THE EARLY WARNING SYSTEM

20. The fundamental features of the early warning system, collecting, transmitting and analysing information on locusts, weather and habitat remain unchanged. Since 1985, however, the manual systems have become computer based and highly integrated using GIS . In addition, new remote sensing products are now being transmitted electronically to affected country locust headquarters in order to test if sparse desert vegetation can be reliably identified from such imagery and used operationally for guiding survey teams to the areas most likely to contain locusts in close to real time. Developments in remote sensing and the introduction of hand-held computers for recording field observations are reported first as they required modifications to the functions available in early warning GIS.

Satellite imagery

21. Roy (1985) anticipated problems in transmitting remote sensing products to affected countries in time to plan surveys but assumed that the FAO ARTEMIS products could identify the sparse desert vegetation among which Desert Locusts breed. This proved over-optimistic as the low Normalized Difference Vegetation Index (NDVI) values of sparse vegetation are close to those of bare soils. Consequently, the original method, based on a fixed NDVI threshold to distinguish vegetation from bare soils, produced both errors of commission where bare soil was identified as vegetation and errors of omission where vegetation was identified as bare earth. A second problem was that the spatial resolution of the original NOAA-AVHRR[2] and subsequent SPOT4-VEGETATION images (pixel size: 1.1 x 1.1 km at nadir and 1 x 1 km respectively) were too large to detect vegetation that though significant for locusts covered only a part of a pixel. In recent years, advances in imagery processing and affordable higher resolution imagery have provided at least a partial resolution of these problems. Transmission of imagery between FAO Rome and affected countries became operational in 2001 when satellite images were posted on the FAO File Transfer Protocol (FTP) server for downloading using internet connections (Ceccato, 2005).

Methodology and recent adaptations

22. NOAA/AVHRR images were replaced in 1998 by those from SPOT4-VEGETATION, which have better image positioning and are optimized for global vegetation monitoring. Two products are

[2] National Oceanic and Atmospheric Administration-Advanced very High Resolution Radiometer

produced at the Vlaamse Instelling voor Technologisch Ondersoek in Belgium and forwarded to FAO in Rome. A 10-day synthesis of daily images is produced both on single channel (Blue, Red, Near infrared and Short-wave red) and on the NDVI. At FAO, the images are cut into small windows corresponding to each recession area country and the country images are placed on an FTP server for national information officers to download. Additional processing was developed to improve the identification of sparse desert vegetation.

23. The red and near-infra red channels provide information complementary to the NDVI that distinguishes between bright soil (high reflectance in both bands) and sparse vegetation (low reflectance in the red channel) but not between dark soils and vegetation. Ceccato developed a method to offset this error by using the short-wave infrared (SWIR) channel, which is sensitive to water in soil and vegetation. The soil usually dries more quickly than vegetation leading to SWIR reflectance values that are higher for soils than for vegetation.

24. Assigning different colours to each channel provides locust information officers with an additional facility for identifying vegetation. Red is allocated to the SWIR channel, green to the near infra-red channel and blue to the red channel so that combining the three channels produces a colour composite image where vegetation appears green and bare soil has a pink tinge. These colour composite images thus eliminate the NDVI commission errors in which bare soil appears to be vegetation.

25. The omission error due to the 1 km^2 resolution of SPOT-VEGETATION is solved by using the MODIS sensor aboard the TERRA and ACQUA satellites. MODIS images at a spatial resolution of 250 m are accessible free of charge. The same compositing method is applied and images produced are made available to national Information Officers on an FTP server. MODIS images are gradually replacing those derived from SPOT-VEGETATION.

26. In 2006, the International Research Institute for Climate and Society (IRI), at the Earth Institute, Columbia University, in collaboration with DLIS, developed an interface to estimate ecological conditions and rainfall events in the Desert Locust recession area. The interface is available in the IRI Data Library[3] as an online 'clickable map', which allows Desert Locust Officers to visualise, analyze and automatically download MODIS images and rainfall estimates derived from satellite measurements into their RAMSES-GIS software. Three sets of maps display MODIS images and the most recent daily and 10-days rainfall estimates over which national and district administrative boundaries can be overlaid. These visual features can be toggled on or off and the user can zoom in to any region for greater clarity. The MODIS images at 250 m spatial resolution representing i) a colour composite, ii) the Normalized Difference Vegetation Index and iii) the Enhanced Vegetation Index (EVI) are provided every 16-days and can be downloaded automatically. Problems with downloading very large images through the Internet, especially in African countries where the connection is slow, can be avoided by downloading smaller region(s) of interest. The smaller windows drawn and selected by users are automatically converted into the data formats required. The IRI Data Library can be used remotely by information officers to compute long-term series of rainfall, NDVI and EVI and compare them with historical data (Ceccato *et al.*, 2007). The graphs created allow Desert Locust information officers to obtain contextual information that identifies where and when rainfall and vegetation conditions are above normal. The IRI interface is now used by

27. DLIS and the Desert Locust Officers now access MODIS and rainfall data from the IRI sites. The rainfall products give advanced warning that breeding sites may develop. MODIS products identify sparse green desert vegetation, which may provide suitable conditions for locust breeding and population increase. The actual presence or absence of locusts can only be determined by national teams surveying the areas identified from the imagery as potentially suitable for locusts. Survey teams are encouraged to take digital pictures of vegetation to store in a database within RAMSES so that imagery and the geolocated photographs can be displayed on screen together. In this way, local teams can develop a tool to help them assess the reliability of imagery for identifying sparsely vegetated habitats and to identify vegetated habitats on images that are known to be favourable for locusts.

eLocust

28. From the 1950s, survey data were normally transmitted by high frequency radio to national headquarters daily with consequent errors due to bad reception and transcription. In the 1990s, FAO commissioned the programming of a hand-held computer for entering and transmitting observations

[3] http://iridl.ldeo.columbia.edu/maproom/.Food_Security/.Locusts/

from the field following the successful introduction of a similar product in Australia. The initial trial system, **eLocust** ran on a Psion 5mx palmtop computer running a customized programme. Data were stored in the database, PsiDat, customized maps of countries were displayed using RealMap and the programmes, maps, descriptions and illustrations could be downloaded from the Locust Watch web site.

29. In the field, this trial system was tested operationally. Locust officers connected their GPS to the palm top computer to store the coordinates of survey sites. They then entered and stored the locust weather and habitat observations made at the site on a survey form displayed on screen. Finally, they connected the palm top computer to a Codan high frequency radio mounted in their vehicle and transmitted the stored data for the day to control headquarters via a modem powered by the cigarette lighter of their vehicle. At national headquarters, the data were received via a high frequency radio modem connected to the GIS RAMSES described below.

30. Recession area countries readily adopted this relatively low cost tool as finance and training allowed. As with all information technology, a second version **elocust2** became necessary to replace obsolete hardware. Another innovation was to transmit survey data to national headquarters by satellite link. The system is described on the FAO Locust Watch web site[4].

GIS developed to manage locust weather and habitat data

SWARMS, the FAO GIS

31. The Desert Locust early warning system was developed as a manual system based on cartographical analysis of locust, weather and habitat information collected in and by affected countries. The 1986-1989 plague initiated moves to improve the system and to review control strategies. A UNDP/FAO Scientific Advisory Committee[5] identified GIS as the most appropriate tool to aid forecasters and researchers produce and disseminate monthly Bulletins, ad hoc short-term warnings, and alerts of serious developments as well as analysing the datasets for case-study analyses. As a result, UNDP commissioned the development of the data management system and research tool, SWARMS (**S**chistocerca **WAR**ning and **M**anagement **S**ystem) to replace the manual mapping and analysis techniques developed over the previous 60 years. Five main processes had to be replicated and performed concurrently and iteratively.

- Registering and indexing new reports.
- Mapping locust weather and habitat data from survey reports.
- Analysing survey and inferred data to establish the current locust situation.
- Comparing past and present situations to select forecast analogues.
- Forecasting developments from reported and inferred infestations.

32. SWARMS was designed in close collaboration with FAO users and when it became operational in 1996 was among the most complex of contemporary GIS applications. The designers provided FAO forecasters with a management system for locust, weather and habitat data that had an ergonomic and easily mastered user interface for registering, indexing, cross referencing, mapping and storing incoming reports. The system has facilities for the rapid retrieval, display and comparison of current, historical and inferred events and can display selections of stored data on a range of background maps. It also provides facilities for calculating frequencies of infestation. The Desert Locust egg and hopper development period model (Reus and Symmons, 1992) is programmed into the system for calculating estimated dates of laying, hatching and fledging based on field reports of actual or suspected egg laying. Finally, interfaces allow the capture and display of rainfall data and remotely sensed vegetation imagery.

33. Machine readable reference datasets were supplied to replace the topographic maps, gazetteers and climatic statistics used in the manual system. An advantage of GIS is that users can overlay geo-referenced data from different sources on these background maps and on satellite imagery. Maps can be displayed at different scales saving time previously needed for the manual compilation and replotting locust data to produce overlays at the same scale as habitat maps and weather charts supplied by external agencies. A stand alone bibliography of case-studies, DLCASE was provided as a guide to

[4] http://www.fao.org/ag/locusts/en/info/info/index.html via activities and DLIS).

[5] UNDP/FAO Scientific Advisory Committee was established in 1989 to advise UNDP on the suitability for funding of research projects aimed at developing alternative strategies for Desert Locust control

sources and destinations of locusts during outbreaks, upsurges and plagues formerly dispersed in many books and reports.

34. SWARMS contains two types of locust data. The sightings dataset is the equivalent of large-scale mapping which forms the basis of the early warning system. Users build up this dataset as they input details of new survey observations recording when and where locusts were seen with other locust information on maturity, size and behaviour. Users are able add contemporary or past information to this dataset. An historical dataset at a spatial resolution of one degree square (1^{o} latitude x 1^{o} longitude) enables users to view changes in monthly locust distribution from 1930. SWARMS has been continually modified and updated for capturing, and displaying daily weather data and monthly climatic statistics.

RAMSES, the GIS for national organizations

35. SWARMS was a larger, more complex and more expensive GIS than individual countries required. FAO can access specialist computer staff for keeping the SWARMS networks operational and for installing major hardware and software upgrades of the large commercial software packages that run on the workstation but accessing such specialist services is more problematic in locust affected countries. Nevertheless, experience in developing and operating SWARMS and the advent of personal computers (PC) in Locust Units and electronic transfer of survey reports to FAO by e-mail suggested that national locust organizations would benefit from the introduction of a PC-based GIS at in which georeferenced data entered into a database could then be displayed on screen. Anticipated benefits of this affordable solution were:

- a more structured approach to data collection and management;
- enhanced facilities to map and analyse infestations to help organize and manage control campaigns;
- facilities to store, retrieve, display past locust, weather and habitat records for analysis;
- a potential to automate data exchange with FAO and other locust units.

36. RAMSES was designed to focus on data collected within a country and in version 2 has most of the functions available in SWARMS. A major difference between RAMSES and SWARMS is that data points are not displayed on a RAMSES screen as they are entered into the database, which makes input errors harder to detect. RAMSES users did not want the ability to store data inferred from development and trajectory models within their GIS and so these features were not included. They do have facilities for importing and viewing data from other countries except for information collected solely in the Western Region, which cannot be transferred into databases in the Central and Eastern Regions. Finally, RAMSES unlike SWARMS does not have the capacity to store the complete dataset of reported locust events from the whole distribution area over a large number of years.

37. RAMSES version 1 was implemented and tested from 1997 in Eritrea, Yemen, Ethiopia and Mauritania. By 2000, the faster processing times and greater storage space of PCs allowed RAMSES version 2 to have more effective data input and analysis facilities. In addition, the developers could remove limitations identified in version 1 and add new functions to handle eLocust and satellite imagery and to import existing datasets as well as Mauritania’s existing dataset, LocDat.

38. RAMSES version 2 operates on a PC running Windows 2000 or XP. It still uses ArcView 3x with the spatial analyst extension but the relational database is now Access 2000. In both versions, a redesigned database makes data retrieval and display simpler and faster. The new design has one main locust table and separate tables were created to hold meteorological, habitat (soils, vegetation) and control data. There are now separate English and French versions to accommodate the additional survey data collected in some francophone countries. These data were too numerous for a single table and so the French locust table was subdivided and the hopper data were placed in a second table. The consequential changes to the database on the programmed GIS routines were successfully implemented and users can now view daily and decadal as well as monthly selections of data. In addition, the system now displays each selection as a single layer so that users can add and subtract selected features to the screen display during analyses.

39. A revised in-put form makes manual input easier and faster. Each screen page now corresponds to one of the eight sections on the FAO recommended forms. Improvements made to the structure of rainfall tables and the routines used to process them allow users to access daily, decadal (10-day) and annual totals for rainfall stations and to export them as a flat file for processing in Excel spreadsheets

and ArcView tables. Finally, additional integrity checks, lookup tables and default values should minimise errors reaching database fields and eradicate record duplication. RAMSES version 2 also provides robust routines for the import and export of data between the English and French RAMSES systems, between RAMSES and SWARMS and for importing eLocust data into RAMSES. Data transfer between versions 1 and 2 of RAMSES was not done piecemeal as RAMSES version 2 contains routines that read data in an old database and use them to repopulate the new one. A programme reloads data after less significant changes to the database to ensure the successful transfer of all items to the modified system.

Training, maintenance and support for customized computer systems

40. Computer management of data has become an established feature of the Desert Locust early warning system. Almost all recession countries had RAMSES GIS version 2 by 2005 for managing their survey and control data and for exporting information to FAO's system SWARMS. There is less evidence of the systems being used in a more generic way to generate analyses of control campaigns and peer reviewed case-studies of locust events. Such research requires greater knowledge of GIS than needed to operate the bespoke routines programmed into SWARMS and RAMSES and which are imparted in the brief training that accompanies the instalment of systems. Another issue revealed during the 2003-2004 upsurge is that countries just outside the recession area, which are invaded as a plague begins, lack recent training in data collection, analysis and transmission and may require computer systems to manage their data and to forward it to FAO in a suitable format. These are issues to be considered and resolved before the next upsurge.

41. The bespoke software in SWARMS, RAMSES and eLocust was developed using grant funding and the systems will be used long after the fixed period of the grant(s). This could lead to potential difficulties because these customized systems are associated with rapidly developing commercial hardware and software. Manufacturers update their hardware and software at frequent intervals, which has a number of implications for customized systems. Firstly, upgrades fix faults hindering the use of a commercial product and manufacturers may be unwilling or unable to provide assistance with problems arising if new versions are not installed in customized products. Secondly, upgrades may introduce incompatibilities with other components of the customized system. This particular problem arose during the development of SWARMS and has arisen in RAMSES where users have installed upgrades of commercial software running on but not supported by the system. Thirdly, upgrades may provide functionality that could not be offered to users as part of the original project brief. In addition, database structure, GIS routines and import/export programmes are designed to facilitate interchange of an agreed set of data. Consequently, changes will need to be planned carefully to avoid potentially costly changes to database structure and GIS routines to maintain seamless interchange between systems.

42. For these reasons, customized systems require ongoing support and maintenance. To date, FAO has found cover for annual commercial maintenance contracts and for developers to continue to meet system requirements. This has enabled the development of SWARMS and RAMSES to gradually implement and test functionality required to meet the changing needs and aspirations of users. To date, less attention has been focused on training users.

43. Though future developments and training are a particular problem for the computer based early warning system past events show that they are equally important in all other aspects of locust control. Integrating progress made during and after emergencies in work practices throughout the Desert Locust area is a vital step in achieving preparedness.

6. TOWARDS SUSTAINABLE PLAGUE PREVENTION

J I Magor

BRIEF OVERVIEW

Achievements and new objectives

1. National, regional and international organizations jointly formulated and progressively adapted a plague prevention strategy to counter the Desert Locust threat, which emerges after heavy rains fall in the arid and semi-arid recession area and trigger a locust population explosion. Limiting subsequent population growth to prevent plagues has kept substantial parts of the of the surrounding invasion area free from invasions since 1964, thereby protecting major cropping areas in Africa, the Near East and Southwest Asia. Recent socio-economic studies are beginning to quantify the threat to the livelihoods of nomads and subsistence farmers during upsurges and recently developed irrigated zones in the recession area are equally vulnerable before a plague has developed.

2. Anti-locust organizations take longer than locusts to mount an attack. The current plague prevention strategy requires timely and coordinated inputs from national, regional and international sources, each of which depends on accessing reserve funds at short notice. Every two months, a new locust generation, potentially ten times larger than its parents, can emerge and invade additional areas. Accordingly, minimising delays in financing campaigns in resource poor countries is important for reducing the risk of damage to recession area grazing, subsistence crops and livelihoods. National, regional and international organizations need to re-examine how affected countries and the international community fund plague prevention.

3. Currently, the FAO EMPRES programmes provide an opportunity to re-evaluate control strategies, prepare contingency plans and update operational procedures with national, regional and international funders. EMPRES also provides an opportunity to test recently improved technologies and incorporate them into operational practices. This degree of preparedness has proved elusive in the past. Nevertheless, secure recurrent funding will be required to ensure that the strategy maintains its functionality when external programme funding ends.

Control strategy, tactics

- Inadequate early monitoring and control was a feature of all post 1964 upsurges. Not all infestations were found, control capacity needed strengthening and control tactics progressed from outbreak prevention through upsurge prevention and suppression to upsurge elimination (Fig. 5) before the incipient plague collapsed and the emergencies ended. The debate on the optimum time to start control continues.
- The current plague prevention strategy (FAO, 1985b) relies on recession area countries maintaining permanent locust units to monitor seasonal breeding areas, to locate and control gregarizing populations and to mount the initial campaigns during an upsurge. Simulations (FAO, 2004a) indicate that some national capacities, mainly ground teams, maintained throughout recessions will be unable to monitor the large areas involved as an upsurge starts or to mount large-scale control campaigns.
- The increasing proportion of locusts in spray targets (swarms and bands) as an upsurge develops suggests that plague prevention campaigns may be unsuccessful until the upsurge elimination campaigns on occasions when rains continue to promote population growth to this stage.
- FAO rejected a recommendation to adopt the upsurge elimination tactic proposed on the grounds that early, partly gregarized upsurge populations were too extensive to spray on environmental grounds and involved high financial costs (FAO, 1985b).
- The original strategic objective of plague prevention was clearly stated. An alternative and less precise term 'preventive control' has come to be variously defined as 'outbreak prevention' (Ould Babah, 1997; Showler, 1997) 'avoiding swarm invasions i.e. upsurge prevention or early upsurge suppression (Chara, 1997) which has confused constructive discussion of these strategic issues.
- Lecoq, Duranton and Rachadi (1997) recommended investigating Desert Locust population dynamics to improve strategic concepts.
- GIS provide excellent tools for analysing control campaigns, executing case studies of locust events and examining control strategy issues. Such research requires greater knowledge of GIS than needed to operate the bespoke routines programmed into SWARMS and RAMSES, which are explained in the brief training that accompanies the instalment of systems.

Safeguarding health and the environment

- Locust control that is more effective and improves safety for operators, inhabitants, livestock and the environment depends on the development and operational use of safer pesticides.
- Three types of pesticide have shown promise for adoption in Desert Locust control since 1985: insect growth regulators (IGRs), the phenyl pyrazole, fipronil and a mycopesticide based on *Metarhizium anisopliae* var. *acridum.* Their evaluation and integration into operational control practices are ongoing.
- Paradoxically, proponents of both early control and of upsurge elimination cite increased environmental safety among the advantages of their control tactic. This dichotomy needs to be clarified and resolved.
- Correct application techniques allow the application of minimum effective dose rates, thereby, minimizing adverse side effects. Training is required to ensure the universal uptake of these practices and their assimilation by national locust units. Good operational practices are important for safeguarding ecologically important non-target

groups such as pollinators and accords well with organic farming and integrated pest management (IPM) protocols.
- Campaign managers need to be accountable for using supplies prudently and for protecting the environment, habits not necessarily fostered by dependency on emergency assistance.

Sustaining the Early warning system

Rapid access to funds is needed for DLIS in Rome and national locusts units to maintain the flow of information without deterioration in quality and frequency as an upsurge starts. This implies ongoing training of reserve staff needed when an upsurge starts and workloads increase beyond the capacity of permanent staffing levels.
- Ongoing budget allocations need to be assured for annual commercial maintenance contracts and for developers to continue to improve and update the computer-based early warning systems, SWARMS in Rome and eLocust2 plus RAMSES in locust-affected countries.
- National training and replacement of obsolete hardware and software need to be secured once the EMPRES programmes end if improvements are to be sustained.

Improving the early warning system
- Swarms quickly spread to countries beyond those permanently involved in the Early Warning System and contingency plans are needed for integrating these rarely affected countries into the new electronic national data collection and dissemination system.
- Seasonal rainfall and temperature forecasts need to be assessed to determine whether they are sufficiently reliable to send warnings and alerts of upsurges to affected countries, donors and other interested institutions earlier in the plague cycle than at present.
- New satellite products for identifying sparse green desert vegetation remain largely untested. Locust units need to undertake extensive ground-truthing exercises to determine the reliability of imagery for locating vegetation and habitats potentially suitable for locust breeding

Timing alerts
- Warnings to increase monitoring are sent immediately to countries where heavy rain has fallen
- Special Alerts are delayed whilst the extent and continuity of gregarization becomes clear, over the following one or two generations.
- Alerts denoting a serious Desert Locust threat are issued as soon as infestations clearly indicate that effective control is needed to prevent an upsurge developing into a plague should the weather continues to support highly successful breeding.
- Earlier indications that this risk might materialise appear in FAO Desert Locust Bulletins and on the Locust Watch web site. This two-fold approach minimises unwarranted alerts but leaves little time for raising external assistance, activating contingency plans and providing campaign managers with the means to pre-empt the upsurge becoming a plague.

Financing plague prevention
- Financing and sharing the financial burden of plague prevention equitably and sustainably without external assistance has yet to be achieved.
- An important objective of affected countries and FAO should be to secure and eventually reduce or replace donor finance. Consequently, there is a need for discussion of long-term plans between countries in the recession area, those in the invasion area and donors to develop mechanisms for funding sustainable plague prevention.
- Many national units have sufficient resources to undertake small to moderate scale control as an upsurge begins. However, some units require external assistance even at this early stage to avoid shortages in control supplies during early upsurge campaigns.
- National units need funds to re-equip and train teams to use new techniques before an emergency arises and to train reserve teams before and not during emergencies.
- Progress in evaluating new control agents and technologies depends on the presence of suitable locust populations and the availability of funds neither of which are likely to be available until the next upsurge starts.
- Most countries require external finance for larger scale control operations and for periodic major capital replacement items such as vehicles.
- Reduced funding from national, regional and international sources during non-upsurge periods at best compromises and at worst may eliminate locust monitoring and control capacities in resource poor countries.
- Past mechanisms for funding emergencies (FAO working capital and Trust Fund Reserves) provide insufficient finance and time lags in receiving funds from direct appeals for international assistance by FAO delay and potentially compromise the ability to mount early upsurge campaigns and exacerbate lack of preparedness.

INTRODUCTION

1. Countries have collaborated since the 1926-33 plague to attain plague prevention but control capacity was too limited, finance was too scarce or recessions were too short to implement this strategy until the 1960s. For 75 years, countries continued to monitor and report locusts for the early warning system and over time developed the control capacity first, to suppress plagues and subsequently to prevent them. Funds and consequently expertise have always diminished as upsurges and plagues end and have not been reinstated sufficiently rapidly to mount campaigns in resource poor countries as a new upsurge starts. Important aspects of the anti-locust technology have often changed during and shortly after each plague but

funds to re-equip and train teams typically does not arrive until the next emergency is underway. In addition, field-testing of new pesticides depends on the presence of locust populations in the field, which will only occur once a new upsurge is underway. Proposed solutions to problems hindering plague prevention identified in earlier chapters are brought together here to gauge their potential for providing technical, organizational and financial improvements needed to achieve the elusive goal of sustainable plague prevention. Desert Locust managers can then assign priorities to solving outstanding problems in line with available funds.

CONTROL STRATEGY AND TACTICS

2. Lecoq, Duranton and Rachadi (1997) suggested that investigating Desert Locust population dynamics might improve strategic concepts. A rapid review of recession populations since 1920 in chapter 2 suggests that the strategic objective of plague prevention was first achieved in the 1960s. On the rare occasions since then when seasonal rains supported population growth to Waloff's plague upsurge and spread stage (see chapter 2), large-scale control and poor rains followed and the populations declined rapidly. Indeed, Skaf (1986) and Skaf, Popov and Roffey (1990) refer to the long recession from 1964 to 1984, which included two such brief plagues and several upsurges (Chapter 2, table 1). Control tactics during post 1964 emergencies progressed from outbreak prevention through upsurge prevention and suppression to upsurge elimination (Fig. 5) before the incipient plagues collapsed and the emergencies ended. Initially, strategists (FAO, 1967a, 1969, 1985b) expected intermittent upsurges even though they suggested controlling all 'dangerous' populations to prevent outbreaks and prolong recessions. Why then, when the third short plague (1987-1989) ended, did observers conclude that the strategy had failed (Joffe, 1995; Gruys, 1994) and needed to be re-examined (US OTA, 1990; van Huis, 1994b)? One explanation is that observers assumed that control had prevented a plague, on occasions when populations declined early in the plague dynamics cycle because rains ceased to promote their growth. This supposition would allow them to conclude that outbreak prevention or upsurge prevention is achievable providing that funding and accessibility enable all incipient outbreaks to be sprayed. Uvarov (1951) clearly stated that the original strategic objective was plague prevention. Later, the less precise term 'preventive control' came to have several objectives. Preventive control and intervention tactics were hotly debated in the 1980s and, as the 1995 Conference on control strategies in Bamako showed had come to have more than one meaning, which hindered constructive discussion. Ould Babah and Showler (1997) limited the term preventive control to outbreak prevention. Showler recommended proactive control, the use of early intervention, as a means of providing a flexible approach to post-gregarization developments. Whereas, Ould Babah used the term curative for interventions during upsurges and plagues and the term palliative for control to protect cultivated zones. Chara (1997) equated preventive control with avoiding swarm invasions (i.e. upsurge prevention or early upsurge suppression). Clearly, opinions on plague prevention tactic(s) have yet to be resolved. The next section postulates that the suitability of populations as spray targets during an upsurge suggests that plague prevention campaigns may progress to upsurge elimination on occasions when rains continue to promote population growth to this stage.

Intervention tactics

3. When the 1949-1963 plague declined, the aim was to prevent a new plague developing by controlling any dangerous locust concentration that might gregarize and give rise to an outbreak1 (FAO, 1968, para. 384.1). This terminology and tactic resembles classical plague prevention in which teams monitor populations in geographically limited outbreak areas and control incipient outbreaks to stop swarms emigrating into the invasion area where they might start a plague. This concept was also promoted by scientists who assumed swarm continuity initiated plagues. An exercise by FAO, its forecasters and technical advisers to define 'important or dangerous' populations (FAO, 1967a, ALRC, 1966; Rainey and Betts, 1979) identified 53 groups of infestations of which 23 were controlled. These were:

- bands and swarms;
- other infestations that were treated;
- infestations estimated as containing 'millions of individuals';

[1] The original French 'resurgence du fleau' better translated as 'outbreak(s) of the pest' than 'plague resurgence'.

- in addition, two infestations related in time and space to other 'important' populations.

4. The selected locusts were those between July 1963 and September 1967 that were gregarious or likely to become so after breeding. The same strategy was still operational in 1985. Ashall (1985) called it 'upsurge prevention' (Fig. 5) and noted the following problems making it difficult to achieve. Firstly, operations may be delayed in remote areas, prevented by hostilities or floods in others and finally, the rapidity with which locusts gregarize making the earliest gregarizations hard locate and treat (Ashall, 1985, para. 35). Secondly, he concluded that, as resources to deal with upsurges were not open-ended that it was necessary to ensure the, maximum number of locusts killed for effort and resources expended. He agreed with Bennett (1976) that early, partly gregarized populations would be geographically too extensive to spray on environmental grounds if not solely for the high cost involved. This, and the fact that such populations are extremely difficult if not impossible to find and to demarcate as suitable targets before the new generation of adults emigrates and/or lays eggs (Symmons, 1992; van Huis, 1994c).led Ashall to recommend upsurge elimination as the tactic to achieve plague prevention (Ashall, 1985, p. 58, recommendation 3). FAO was advised by a Panel of experts to reject this recommendation and the control strategy is activated when gregarization begins.

Recession populations as spray targets

5. Interventions work most effectively when they are adapted to the pest's population dynamics and available control techniques and capacity. Currently, control involves spraying ULV formulations of contact pesticides, including bio-pesticides, onto areas containing locust concentrations. Newer persistent chemicals are being tested to assess their non-target impact and as possible replacements for dieldrin to enable work-efficient barrier spraying to be re-introduced for hopper control. Barrier spacings were designed to control bands, which marched up to 25 km before fledging (Rainey, 1963b). Spacing guidelines for bands typical of early upsurge populations which march shorter distances than large bands are being reviewed and modelled in association with recent trials (Holt and Copper, 2006; Van der Valk, 2006).

6. National Locust Teams control the few localized outbreaks and 'dangerous' populations that occur in recession. years that experience unexceptional rains. The bands and swarms from these outbreaks and as an upsurge starts were smaller and less dense than those typically found later in upsurges and in plagues. The swarms tended to disperse quickly and unlike swarms at the later (plague initiation) stage did not persist. Therefore tracking such swarms by air over an extended period to control them, a common practice during plagues was not feasible (Roffey et al. 1970). Bennett proposed that teams leave these outbreaks unsprayed unless near crops because controlling them was unnecessary in terms of plague prevention. His suggestion has not been adopted probably because there are no well-defined parameters to distinguished localized outbreaks from those capable of initiating upsurges.

7. Suitable habitats are more extensive and remain suitable for breeding longer than normal and support high rates of locust multiplication when seasonal rains are more widespread, frequent, heavier and of longer duration than normal. Upsurges develop when such rains fall in successive seasons in one or more Desert Locust Region. One or two seasons of high population growth are needed before many outbreaks occur simultaneously (Waloff, 1966; FAO, 1968, para. 356) at which time only a small proportion of the locusts are aggregated into sprayable targets. Treating the small proportion of the population present in targets fails to stop the upsurge sequence although it may reduce the size of the next campaign (Bennett 1974, 1976). As the population becomes increasingly gregarious with each successive season of good rains and successful breeding and a higher proportion of the population is aggregated into sprayable targets. At first, the area containing gregarious aggregations amongst scattered locusts increases rapidly beyond the capacity of the permanently retained ground spray teams and managers need to mobilize local and regional reserve teams if they are to locate and control all targets. The area containing gregarious aggregations amongst scattered locusts soon reaches a scale where a switch to aerial spraying is needed if all the band targets are to be sprayed before swarms develop. The unsprayed scattered adults emigrate to breed elsewhere to continue the upsurge providing rains continue to provide good breeding habitats. Complete spraying of the extensive breeding zones, typically 50 000 km^2 or more in area, that occur as an upsurge starts to eliminate both the gregarious aggregations in targets and the scattered locusts would be environmentally unsound. The frequency of rain and longer duration of the rainy season, as an upsurge starts, allow two or three generations of locusts to breed. Many scattered adults, groups and some swarms emigrate after each

generation fledges but some stay to breed so that breeding areas remain active for much longer than normal. This results in infestations occurring simultaneously and not sequentially in complementary breeding areas (see chapter 2, para. 187) and makes managing early control campaigns more complex. First, an area may be reinvaded several times because immigration lasts for a longer than normal and, secondly, some countries will need to mount campaigns simultaneously in two seasonal breeding areas which can prove difficult if resources are limited.

8. Eventually, all populations involved in the upsurge become gregarious. This stage corresponds to the end of a recession and equates to Waloff's plague upsurge and spread stage of plague development. Bennett (1975, 1976) associated this stage with a marked fall in the actual size of the area infested, as the population became increasingly concentrated into bands and swarms, compared to the outbreak and early upsurge stages. She advocated delaying control measures, except for crop protection, until this late stage of an upsurge and then applying a tactic she called 'upsurge elimination' to gain the maximum return for resource and effort expended. During plague suppression campaigns, DLS (Joyce, 1979) had controlled swarms by air, particularly where they congregate seasonally. In addition, whilst DLS carried out large-scale hopper band campaigns, Joyce (1979) and others (Courshee, 1965, 1990; FAO, 1968; Symmons 1992) emphasized that spraying swarms minimized pesticide use and aircraft spraying time because band zones occupy a much greater area than the resultant swarms and additionally only 1-5% of these zones contain bands. Bennett concluded that should upsurge elimination be adopted, delaying control until the swarms became concentrated would also need to be assessed.

9. Ashall recommended changing tactics from upsurge prevention to upsurge elimination and agreed with Courshee (1965), MacCuaig (1970) and Bennett (1974, 1975, 1976) that early, partly gregarized populations would be too extensive to spray on environmental grounds if not solely for the high financial costs involved. Ashall’s recommendation included upsurge suppression as he planned for both early and late upsurge campaigns against gregarious locusts. In the event, consultants advised FAO to reject Ashall's recommendation (FAO, 1985b) but to accept his estimates of the number of permanent survey and control teams needed to find and characterize outbreaks and to mount early upsurge campaigns whilst externally funded supplies were being sought and delivered for the upsurge elimination campaigns.

10. Late upsurge populations that continue to grow first reach plague and then peak plague proportions until checked by drought, migration to hostile habitats, effective control or more usually, a combination of these factors. No plague since 1964 nor the 2003-2005 emergency, reached the dimensions and maximum geographical extent of pre 1964 plagues, when swarms frequently invaded major cropping areas outside the recession area in all three regions simultaneously for several years in succession.

Discussion topics

11. The post 1964 upsurges which became short plagues ended at Waloff’s ‘plague upsurge and spread’ stage which she associated with populations gregarizing and switching to daytime migration as cohesive swarms. This stage is probably identical to the reduction in area caused by gregarization that Bennett (1976) noted as occurring occurred after spring breeding in 1968 and equates to the stage against which Bennett advocates upsurge elimination campaigns are carried out (Bennett, 1976; Waloff, 1966). The fact that campaigns at this stage rapidly eliminated gregarious populations does not justify adopting upsurge elimination tactic without careful scrutiny. Indeed, few managers favour this approach. Inadequate early control may be a feature common to emergencies that is related to funding shortfalls and delays inherent in raising external funds to wage large-scale campaigns. Bennett did not consider whether lack of funds limited the implementation of early campaigns in the 1966-69 upsurge and short plague. Roffey (1982), however, found that although security problems and too few fully equipped permanent control teams hampered control early in the 1977-79 upsurge, external funds for mounting large upsurge campaigns did not arrive until populations were fully gregarious. Consequently, the upsurge elimination tactic was the only one fully implemented in 1977-79 largely due to late arrival of inputs.

12. The current strategy (FAO, 1985b) recommends that countries within the recession area maintain permanent locust units to monitor seasonal breeding areas, to control gregarizing populations and to mount the initial campaigns during an upsurge. Ashall (1985) estimated that national control managers would have about eight months to mobilize an emergency supply of vehicles, insecticides and application machinery from local, regional and international sources before they needed to mount upsurge elimination campaigns.

Ashall did not discuss the role national and regional reserves were expected to play before international assistance arrived. Nor did he examine the time taken from launching an appeal to operational deployment of the resulting assistance. These factors, in particular time lags associated with the arrival of substantial external assistance in a dynamic situation, clearly affect the ability to mount large-scale campaigns in all but the richest countries and need further investigation.

13. Analysis of the early stages of upsurges (Bennett, 1976, Gruys, 1994; Roffey 1982) shows that as gregarization starts not all targets are found. Simulations (FAO, 2004a) indicate that the few teams kept during recessions will unable to monitor adequately the extensive breeding zones (typically 50 000 km^2) as an upsurge starts. In addition, perhaps a half of recession area countries involved are likely to require external assistance to find and control bands as an upsurge starts. This suggests that the limited funding available during recessions will frequently hamper early upsurge campaigns. MacCuaig (1970) postulated that the earlier interventions began against gregarious infestations the smaller the size subsequent populations as an upsurge developed into a plague. The impact of early control interventions during upsurge campaigns has still to be evaluated.

Safeguarding health and the environment

14. The large quantities of pesticide used during the 1987-1989 emergency resulted in increased awareness of the potential adverse environmental impacts of locust campaigns. This led to decisions to develop and introduce safer pesticides and environmental monitoring into control operations. FAO established a Pesticide Referee Group (PRG) in 1989 to provide guidance on pesticides effective against locusts and grasshoppers. The Group established insecticide field trial protocols and on an ongoing basis assesses the results of trials of candidate pesticides along with their suitability in respect of volatility, mammalian toxicity, non-target impact and formulation characteristics. PRG reports list products shown to be effective in trials against locusts and grasshoppers together with dose rates. Information on their speed and mode of action is included as a guide for potential users. Since then, projects have demonstrated that correct application techniques allow dose rates to be lowered minimizing adverse side-effects. However, both ongoing and further training is required to ensure the universal uptake of these practices and to ensure new practices can be embedded within national locust units.

15. Two factors drive changes in control techniques. First, the need to deliver more effective control and secondly the need to deliver control methods that are safer for operators, inhabitants, livestock and the environment. From the late 1960s, the barrier spraying technique using dieldrin began to be replaced by blanket spraying with non-persistent chemicals to offset concerns over the bio-accumulation of dieldrin (Bennett, 1976; FAO 1970). Barrier spraying is, however, highly work efficient and potentially has an environmental advantage over blanket spraying as it leaves unsprayed or lightly sprayed refuges for non-target species, which later may act as a source for recolonizing sprayed areas. Van der Valk (2006) cites and discusses the few cases from trials against locusts providing evidence for these effects.

16. Trials with fipronil and with insect growth regulators suggest that these chemicals may allow barrier spraying to be reintroduced. A review on the environmental effects of barrier spraying with these pesticides indicated that the slower acting IGRs generally had lower environmental side-effects than fipronil, and that the latter should be restricted to barrier treatments in non-crop areas (FAO, 2004c). Van der Valk (2006) in his review found that trials were sub-optimally reported and that potentially valuable data would be revealed by re-analysis of unreported sections of datasets and appropriate statistical analysis of others, which would enable improved trial guidelines to be developed.

17. Another promising product, "Green Muscle®" is a slow acting biopesticide based on a fungus *Metarhizium anisopliae* var. *acridum,* which affects only locusts and grasshoppers. Consequently, its non-target impact is slight. Further large-scale field trials are required to validate parameters for its operational use against Desert Locust.

18. Specialist teams are also being trained so that non-target impacts of pesticide treatments are monitored routinely and environmental surveys in sprayed habitats establish the effects of different pesticides on non-target species during control operations

19. These new developments hold promise to deliver locust control that is more effective and improve safety for operators, inhabitants, livestock and the environment. Good field practices, once assimilated by

control units, will safeguard ecologically important non-target groups such as pollinators, ants, termites and the natural enemies of locusts. This accords well with the needs of farmers practising organic farming or using integrated pest management (IPM). Ensuring the uptake of the safeguards is an important aim of the FAO EMPRES programmes. Paradoxically, the proponents of early control and of upsurge elimination both cite increased environmental safety among the advantages of their control tactic. This dichotomy needs clarification and resolution so that campaign managers can respond to crop protection protocols associated with IPM.

Early warning system

20. Uvarov established the international Early Warning System in the 1930s and although the fundamental processes are unchanged; the system has evolved continuously. Two studies (US OTA, 1990; Joffe, 1995) advocated a need to improve the system by which locust affected countries collect agreed information on infestations that can be mapped, interpreted and analysed at a central location in close to real time so that regular and special early alerts, alerts and appeals can be prepared for affected countries and other stakeholders. As a result national information officers and the Desert Locust Information Service (DLIS) forecasters at FAO now have computers with GIS tools and can display locust, weather and habitat data singly or superimposed when assessing a locust event. The system's current emphasis involves evaluating survey reports, weather and habitat changes in ephemeral seasonal breeding areas to identify sequences of rains and vegetation patterns that could lead to an upsurge. As noted in Chapter 3 (paras 31, 32) forecasting is not an exact science and selecting and interpreting situations analogous to the present and evaluating differences is a key part in predicting future developments. Such experience takes several years to gain and consequently represents a potentially critical staffing issue for the early warning system especially if staff turnover is high. Both DLIS in Rome and national units need adequate staffing, resources, training to maintain the system when an upsurge occurs and the workload suddenly increases which implies rapid access to reserve funds if the early warning system is to be effective when most needed.

Sustaining recent improvements

21. Recent improvements to the Early Warning System for recession area countries where upsurges start were described in chapter 5. The mapping and exchange of data and reports between National Units and DLIS is now computer based and operates effectively. Enhanced processing of satellite imagery now provides products to identify sparse desert vegetation and the widespread use of computers allows its rapid transfer to affected countries. However, the reliability with which the processing identifies sparse green vegetation potentially suitable for locust breeding is largely untested. Locust units should include ground truthing imagery as part of their monitoring system so that in time they can confidently relate imagery signatures to vegetation providing favourable locust breeding habitats.

22. In 2003 and 2004, locusts quickly spread beyond countries in the recession area that were using computers to manage and exchange data electronically. Integrating these rarely affected countries into the new electronic national data collection and dissemination system should implemented in a way appropriate to the frequency that the system will be used and the type of populations that invade these countries.

23. It can now be plausibly argued, though not established, that control has been the major factor in the greatly shortened plagues experienced since the 1960s. The severity of the 1988-1989 plague was exaggerated by inexperienced managers who had very little experience of Desert locust plagues and who could not easily access, often conflicting, data on previous plagues. A by-product of developing computer systems is datasets that will allow managers and others to view the changing distribution of the Desert Locust since 1930.

24. To date, FAO has found funding for annual commercial maintenance contracts for its technically sophisticated, computer based early warning system and for developers to continue to improve and update it. This has enabled the SWARMS, RAMSES and eLocust applications to be developed and to provide improved functionality to meet the changing needs and aspirations of users. Users need further training, however, to benefit fully from the increased functionality of these systems when analysing locust events. Funds to continue development, training and to replace obsolete hardware and software need to be secured once the EMPRES programmes end if these improvements are to be sustained.

Providing survey and control data for biogeographical studies
25. Biogeographical case studies reconstruct locust events plausibly from routinely collected and archived locust and weather observations and not from field data collected specifically to test an hypothesis. Case-studies evaluate the effects of weather on the duration of a specific locust development, the production of suitable breeding habitats and on the downwind displacement of migrating adults. In addition, the effect of control on the survival of locust infestations is assessed. Forecasters use case-studies as analogues to help make their predictions. They also helped managers to develop and test control tactics.

26. During the 1950-63 plague, DLS measured the area of the parent swarms, roughly estimated the hopper numbers within treated band zones and finally, measured the area of fledging swarms. Consequently, managers could evaluate the effect of spraying known quantities of insecticide against infestations (Joyce 1962a, b, 1979). The development and operation of similar techniques in all three Regions were discussed when teams were trying to readjust procedures to the longer plague-free periods (Gunn and Rainey, 1979). Evaluating individual control operations within a campaign and the overall campaign effectiveness used by Bennett in her study of the 1966-69 upsurge and short plague ceased as a routine activity in the 1970s (Roffey, 1982). Before 1964, two factors made such assessments easier. Swarming populations were present in most years and control units often had responsibilities for a region containing the populations belonging to entire, albeit semi-closed migration circuit. Swarms were frequently close to valuable crops which ensured secure funding for operational research, which enabled managers to develop and evaluate techniques suitable for measuring population size and area and evaluating the effectiveness of control applied during campaigns,

27. Control evaluations are now rarely made despite recent workshops encouraging their reintroduction. Independent measurements of infestations and pesticide use similar to that colleted in the 1966-69 upsurge need to be reinstated. Without such evaluations and data, analysts cannot produce plausibly argued case-studies on the impact of control in ending recent upsurges despite their GIS providing a more powerful tool to undertake such analyses. The current practice of estimating the size (area) of infestations by simplistically dividing the quantity of pesticide used by the recommended dose rate is a current practice preventing rigorous analysis.

28. Improving survey techniques was recognized as a way of removing two obstacles noted as standing in the way of plague prevention. These were:

- detecting cryptically behaving, non-gregarious recession populations (FAO, 1968, para. 356)
- recognizing dangerous populations in a given habitat until objective, quantitative methods of assessment are developed (FAO, 1968, para. 357).

29. These obstacles still exist and densities provided by survey teams before an upsurge, fail to indicate the increases in locust numbers occurring within large expanses of vegetation until concentration and gregarization begin. This failing is significant because it affects the timing and accuracy of forecasts and early alerts. Rao (1960), in contrast, indicated that his staff could distinguish population increases marking the onset of an incipient outbreak from those reflecting less significant seasonal variability (see chapter 3, para. 15). A possible reason is that Rao included the variability of transect counts over short distances and estimated densities for ecological units not for each separate site. A related issue is transforming densities at points along survey routes into areas infested. Recalculating recent survey data by Rao's original method would be a simple and possibly a rewarding task.

30. The role of the Early Warning System in alerting national, regional and international managers to impending emergencies is considered in the next section. Two important study topics related to this issue are (a) evaluating different plague prevention tactics, and (b) examining the effects of weather on Desert Locust population dynamics to see if the reliability of upsurge predictions can be improved sufficiently to enable FAO and affected countries to issue alerts and appeals earlier in the upsurge cycle.

Improving forecasts, warnings and alerts
31. Uvarov stressed the need for joint investigations by entomologists and meteorologists and his decision proved very fruitful for understanding locust breeding and migration patterns. Forecasters used rainfall data

to predict seasonal breeding from the 1940s and could issue short term alerts of swarm invasions from the 1960s when DLIS began to use daily weather charts. Forecasts depend, however, on the accuracy and time span of weather predictions. A current constraint is the absence of reliable rainfall predictions for seasonal rainfall perhaps 3-6 months ahead. DLIS is currently testing the value of using experimental seasonal rainfall predictions. If they prove reliable, they will increase the accuracy of long-term Desert Locust forecasts and the reliability of upsurges predictions and alerts. Weather services are still evaluating and improving these seasonal rainfall predictions so it may be sometime before they can be used with full confidence in DLIS.

32. The following study topics also suggest that new collaborative studies with meteorologists and climate change specialists might lead to a better understanding of the weather associated with locust emergencies. Before such studies are commissioned, however, their impact on improving forecasts and likelihood of successful completion should be assessed.

<u>Global circulation affects migration patterns and hence levels of risk</u>
33. Rainey (1989a) speculated that the change in the global circulation pattern, in the 1960s, was associated with a more restricted north-south movement of the Inter-tropical Convergence Zone, which in turn affected the scale of Desert Locust migration. A more comprehensive study than the three locust distributions he mentioned would be needed to test this hypothesis. Another explanation to be considered is that control may have killed the locusts before they reached the formerly threatened countries.

<u>Global circulation patterns affects rainfall frequency and hence the risk of upsurges</u>
34. Bennett (1974, 1976) postulated that the global circulation patterns present before and during upsurges differs from that occurring during years in which only local outbreaks occur. Were this established, it offers a method distinguishing years when upsurges could develop and make decisions to leave local outbreaks uncontrolled tenable.

35. Winstanley (1973, a, b, 1974) described global circulation patterns in which summer rains and winter rains in the Desert Locust area were inversely correlated. In the rainfall series he studied, however, periods occurred when both rains were positively correlated; at times, both were above normal and at others, both were below normal. These latter patterns might be linked to the beginning and end of emergencies.

36. Waloff (1966) noted that each region had a season in which non-gregarious breeding did not occur annually and exceptional breeding in these seasons may be a characteristic of upsurge years.

<u>Seasonal rain predictions, upsurge alerts and response to emergency appeals</u>
37. It is generally assumed that upsurges will continue only if 'suitable rains' continue to fall. Parameters defining 'suitable seasonal rains' are still not established for each Desert Locust breeding season and region. In addition, the relation of 'suitable rains' to seasonal normals must be established before the value of the current generation of experimental seasonal weather forecasts can be evaluated.

38. Post 1960, appeals for assistance were made earlier in the plague cycle and reflect decisions to monitor recession populations regularly rather than a change in upsurge populations between the periods. Studies have yet to evaluate whether earlier alerts or revised financial mechanisms are needed to mobilize assistance fast enough for supplies to arrive in time to implement tactics other than upsurge elimination.

Bulletins, warnings and alerts
39. Early indications that an emergency may occur appear in the monthly FAO Desert Locust Bulletin. Warnings to increase monitoring are sent to countries in which heavy rains have fallen. Additional widespread and heavy rains are required in the same and in complementary breeding areas to initiate an upsurge. Forecasters' must decide from their experience and from the reported response of locust populations if plague inducing rains are falling. Predictions of population levels are at all times conditional on future rainfall. The FAO Bulletin remains the source for transmitting the growing danger of an upsurge during the initial period of population increases and gregarization. Special Alerts and press releases are normally issued one or two generations later, when the extent and continuity of gregarization has become clear. Initially using the Bulletin to make stakeholders aware of the growing danger minimises the number of emergency alerts and appeals for funds that are unwarranted. Once an emergency Alert is issued,

however, little time remains for activating contingency plans and delivering supplies to pre-empt an upsurge becoming a plague.

FINANCING PLAGUE PREVENTION

40. Campaign managers require quick access to contingency funds to avoid delays in receiving control supplies for large-scale campaigns and to select pesticide and application equipment for their teams rather than risk receiving a variety of products from donors. Although many national units have sufficient resources to undertake small to moderate scale control as an upsurge starts, however, some do not and require external assistance even at this early stage. Most countries require external finance during larger scale control operations and for periodic major capital replacement items such as vehicles. They also need to train reserve teams before and not during emergencies. They also need to be accountable for using supplies prudently and for protecting the environment, habits not fostered by dependency on emergency assistance.

41. Anti-locust organizations take longer than locusts to mount an attack. The current plague prevention strategy requires timely and coordinated inputs from national, regional and international sources, each of which depends on accessing reserve funds at short notice. This preliminary desk review was unable to judge whether EMPRES or national funds led to improvements in Central Region response preparedness but this will be compromised, should national regional or international finance cease and not be replaced. Donors invested approximately $12 million during the 12 year EMPRES programme in the Central Region to increase the capacity of countries to prevent plagues but additional funds will still be required to mount large-scale campaigns in some countries. A major constraint to effective control campaigns remains the timely release of funds and/or donor assistance that is provided with sufficient geographic flexibility to enable the delivery of supplies to national and regional teams that match the temporal and spatial mobility of Desert Locusts as they migrate between seasonal breeding areas.

42. Preventing plagues depends on countries in the recession area, including the least developed countries with meagre resources, being able to locate and treat infestations in order to prevent damage during plagues in distant and generally richer countries. Minimizing damage to crops and grazing during upsurges depends on finance being able available for all countries to implement appropriate control throughout an upsurge. Financing and sharing this burden equitably and sustainably without external aid remains to be achieved. This underlying financial weakness reduces preparedness as delays occur between appeals being launched, money being pledged and resources being delivered. In addition, reductions in national funding during upsurge free periods, as in the past, can compromise or even eliminate locust monitoring and control capacities. Past mechanisms to bridge the gap have been disappointing. The need for working capital and reserve funds to finance initial emergency actions were anticipated (UK, 1938; FAO, 1969) but failed to provide sufficient funds (Chapter 1, paras 59-63). In response, FAO created the Emergency Centre for Locust Operations (ECLO) in 1986 to give technical advice and to mobilize the much larger sums needed to respond to emergencies directly from donors.

43. Emergency stocks of equipment and pesticides envisaged by the 1969 strategy proved counter productive in light of infrequent use and changes in perceptions of pesticide safety. A better option was the pesticide bank used in the 1985-1989 emergency. Certainly, funds have materialised during emergencies but it is less certain if they are disbursed early enough or the funds are provided with sufficient flexibility to match changing locust distributions, nor if adequate funding yet exists to maintain adequate monitoring and early upsurge control as envisaged by Ashall (1985) throughout recessions. No comprehensive study on the financing of Desert Locust control exists to gauge the effectiveness of each modality used to supplement national anti-locust budgets. Such a study is long overdue.

44. A further complication, in this gradually evolving system is the change in the responsibility of external funders from being colonial powers responsible for many affected countries, to being Development Agencies disbursing development and emergency funds. Plague prevention does not qualify easily as a justifiable call on either of these budgets. Consequently, donors may forget the integral role assigned to their finance, originally to suppress plagues and latterly to prevent them. Institutional memories are short and an important contingency planning issue, therefore, is to both maintain and raise donors' awareness to the reliance on their finance so that they know in advance that appeals to suppress or eliminate upsurges to

prevent plagues are justifiable and that affected countries are unable jointly to raise the necessary funds. Otherwise, donors may delay or even fail to provide funds.

45. The smaller scale and geographic extent and damage during the 1941-1947 plague were small in relation to those of earlier plagues making the annual costs of control in the invasion areas in Africa, the Near East and southwest Asia worthwhile (Uvarov, 1951). The largely plague and damage free period since 1964 made institutions forget the threat posed by fully developed plagues. As a result, countries became complacent (Skaf, 1986; Skaf, Popov and Roffey, 1990), and transferred finance from locust control units to more pressing agricultural needs and reduced their financial support for the regional control organizations, OCLALAV and DLCO.EA. Donors also increasingly questioned the validity and tactics of the plague prevention strategy (Joffe, 1995; US OTA, 1990; van Huis, 1994b).

46. Currently, FAO EMPRES programmes provide an opportunity to re-evaluate control strategies, prepare contingency plans and update operational procedures with national, regional and international funders. Whichever, tactic is employed; plague prevention requires a national survey and control capacity maintained in operational readiness. with a set of agreed procedures and protocols for add reinforcements when locust numbers and an upsurge begins. At the same time, FAO and national units must be, able to mobilize national, regional and international reinforcements rapidly. EMPRES also provides an opportunity to test recently improved technologies and incorporate them into working practices. This degree of preparedness has proved elusive in the past and recurrent funding, must be secured to ensure that the strategy maintains its functionality when external programme funding ends.

47. To date, international donors have provided a substantial part of the funds needed to mount the large plague prevention campaigns but their willingness to contribute immediately, as in the past, cannot be presumed. One objective of affected countries and FAO must be to secure and eventually reduce or replace donor finance. Consequently, there is a need for discussion of long-term plans between countries in the recession area, those in the invasion area and donors to secure stable finance for sustainable plague prevention.

48. The timeframe envisaged by Ashall (6 to 8 months after an appeal) was adequate for mounting the upsurge elimination campaigns that he advocated. This timing is not suitable for controlling gregarizing populations early in an upsurge; a tactic that the Western Region and the EMPRES CR programme contend is a more effective in preventing plagues. Should this view prevail, after rigorous re-examination of appropriate tactics for dealing with the control targets present during an emergency, then ways of acquiring funds earlier in the upsurge cycle must be justified and implemented.

DISCUSSION

49. This report brings together a vast range of historical data to provide the basis for informed debate on the practice of plague prevention and how to make it sustainable. The 1985 review (reference) concluded that the Central Region was unprepared to carryout plague prevention. However, the level of resources as estimated by the review was flawed as it was based on dieldrin being used, which was not the case then or subsequently. In addition, the resources listed as adequate for control reflected a recommendation to control an upsurge when all involved populations were gregarious. This tactic of upsurge elimination was not adopted in 1985 and subsequently the EMPRES programme has continued to advocate intervention early in an upsurge and given greater prominence to the need to balance plague prevention control against the costs of using pesticides at different stages in an upsurge. Consequently, preparedness in 1985 and 1999 could not be evaluated even in terms of whether sufficient resources were available. This does not mean that current preparedness should not be examined critically but rather that it should be examined by practitioners in the light of present day control techniques and views on adequate environmental safeguards.

50. A second glance at the lessons learned in the 1940s show that they remain relevant today as a new generation seeks to introduce new control practices and adapt to new concerns.

- Funding and consequently expertise diminish as plagues end.
- Strategically planned offensives are feasible but require all countries to cooperate.
- Control strategies need appropriate legislation.

- Campaigns must be planned well in advance, as they require much organization and international coordination.
- Annual costs of protecting crops in the invasion areas in Africa, the Middle East and southwest Asia during the 1940s were high, but the scale, geographic extent and damage were small in relation to those of earlier plagues.
- Requests for supplies are often exaggerated and their eventual use is not always locust control.
- New control methods may demand profound changes in the organization of control and require the amendment of anti-locust legislation and practices.
- Improved techniques have to be actively promoted.
- Physical difficulties are easier to surmount than political ones.
- Some research opportunities exist solely during plagues.

51. Differing views on which tactic best delivers plague prevention leads to different perceptions of the success and failure of the plague prevention strategy. These differences, which may be more apparent than real, need to be resolved. The data presented here provide an overview of how upsurges develop and spread to make it easier for national managers to appreciate the role their infestations play within the dynamics of plague development. Control tactics need to be re-evaluated as new control methods and views on environmental hazards evolve and need accommodating. Tactics may need adjusting to safeguard areas practising IPM.

52. Swarms are visually spectacular and their age-old association with famine lends itself to emotive rather than rational management. Expenditure on locust control has always been questioned. The Desert Locust has the capacity to cause substantial damage to agriculture but losses are often local and not all suffer equally. Earlier studies were criticized for concentrating on cash crops, which the strategy was designed to protect, rather than subsistence crops and grazing affected during upsurges. Consequently, long-term management strategies must be robust and well documented and financed to avoid crisis management when pictures of swarms are beamed round the world by the press and all levels of government face political pressure to intervene.

53. Nevertheless, it should not be forgotten that without continued support for the early warning and control system the full potential of the Desert Locust to damage crops and grazing, not seen since the 1930s could return. The subsequent sustained effort to minimise damage by suppressing plague populations through coordinated campaigns between 1940 and 1965 and the success in avoiding peak plague populations through plague prevention campaigns subsequently must not be interpreted as a threat that has been eliminated. Sustained funding continues to be required for monitoring and control and for developing technologies that are not only more effective but also are safer for users and for the environment

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