Desert locust forecasting manual (Volume 1 of 2)

DESERT LOCUST FORECASTING MANUAL

CENTRE FOR OVERSEAS PEST RESEARCH

VOLUME I

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DESERT LOCUST FORECASTING MANUAL

edited by

D. Pedgley

Centre for Overseas Pest Research
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FOREWORD

FAO has been co-ordinating international co-operation on research and control of the Desert Locust for some 25 years. During that period the Organization has played a leading rôle in assisting the countries in the Desert Locust invasion area to develop their locust reporting and forecasting systems, which are essential elements of the national and international control strategy.

Research and development of Desert Locust forecasting started some 50 years ago at what later became the UK Anti-Locust Research Centre (now the Centre for Overseas Pest Research). This Centre, with the assistance of regional and national locust control organizations and with support from FAO and UNDP, carried out extensive research, development and training projects throughout the Desert Locust area, in order to increase the capacity and efficiency of the reporting and forecasting systems. Over the years the systems have evolved. While the actual reporting and local forecasting are generally carried out by the regional and national organizations, FAO has assumed responsibility, at the international level, for preparing summaries and forecasts of locust activity and for promulgating warnings of invasions.

However, there is still much to be done both in training personnel and assisting the locust forecasting services. I therefore welcome the decision by the Centre for Overseas Pest Research to publish this Desert Locust Forecasting Manual. It will be an invaluable tool in improving the efficacy of the system, so vital to effective Desert Locust control.

For several decades, this important area of activity has provided an unrivalled example of co-operation at national, regional and international levels against this major pest of agriculture in over 50 countries. I trust that this Manual will assist all FAO Member Nations who pursue efforts to control the Desert Locust.

EDOUARD SAOUMA
Director-General
Food and Agriculture Organization
of the United Nations

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PREFACE

This Manual describes, explains and illustrates modern methods of forecasting changes in the size and distribution of Desert Locust populations. It is based upon thirty years of forecasting experience among staff of the Centre for Overseas Pest Research. Brief descriptions of the methods have already been published, but there is a need to have under one cover a detailed account that could be used by forecasters both as an aid during their training and as a practical tool during operations.

The Centre undertook preparation of the Manual when, in 1973, forecasting responsibilities were transferred from the Centre to the five FAO regional locust control organizations. It was originally intended that the Manual should include all known kinds of locust developments, and experiences with them, based on the extensive records that had been gathered, but it became clear that this would require resources way beyond those available. It was therefore decided to limit the contents of the Manual to the basic principles and the necessary background information on the biology and ecology of the insect, supplemented by a number of biogeographical studies of well-documented past events selected to illustrate the kinds of problems that the forecaster may have to solve. The result is a synthesis of published and new work, to which the operational forecaster will be able to add his own experience. More importantly, he will also be able to modify and improve the methods of forecasting, partly from the ever-increasing understanding of locust biology and ecology, and partly from the better use of improved methods of gathering and exchanging field reports about locusts and their environment.

Because weather so strongly affects both breeding and movement of the Desert Locust, meteorological services in the countries afflicted with this pest should be able to use the Manual as an effective aid to getting a greater awareness of the locust forecaster's problems, and of the kind of information and advice he is likely to ask for. The need for strong links between the forecaster and his local meteorological service is abundantly clear throughout the Manual.

The methods of analysing and interpreting field reports of locusts, and of forecasting their distribution and numbers, can undoubtedly be adapted to other insect species that are known or suspected to be migrants. It is therefore confidently expected that those concerned with such migrant species should find this Manual helpful.

Seventeen staff members of the Centre have been involved, from time to time, in the planning, writing, drawing, compiling and editing of this Manual. Planning was first under the leadership of L. Bennett, and later of J. Roffey, but since 1977 the work has been directed by D. Pedgley, who has compiled and edited the Manual, and who wishes to thank all those COPR staff members who have helped to produce this unique book. The colour maps in Volume II were prepared by the Directorate of Overseas Surveys and printed by the Ordnance Survey, and the editor wishes to take this opportunity of thanking them for their valuable advice and assistance.

This publication also signals the formal end of more than fifty years research and development, carried out first in the Imperial Bureau of Entomology, then at the Anti-Locust Research Centre and finally at the Centre for Overseas Pest Research, on locust reporting, forecasting and meteorology. As Dr Saouma, the Director-General of FAO, points out in his Foreword, this work was carried out in collaboration with scientists of the regional and national locust control organisations in the Desert Locust invasion area, and with FAO and UNDP, and at one time involved a collaborative effort with more than three hundred scientists in over fifty countries. We here in the Centre are proud to have been for so many years the focal point of this research and feel that this Forecasting Manual is a fitting epitome of our work, which we hope will assist FAO and the regional and national control organizations in affected countries in organising locust forecasting in the future.

P. T. HASKELL
Director
Centre for Overseas Pest Research

CONTENTS

VOLUME I

1 INTRODUCTION

Sudden and overwhelming invasions by the Desert Locust have long brought devastation to crops and pastures of many lands in Africa and south-west Asia. In the past, killing or scaring away the invaders often had little effect. Nowadays, advanced control techniques, including the use of spray aircraft, are very successful. Effective control, however, requires warnings of where and when large and dense populations of locusts are likely to occur. Adult locusts can migrate long distances, sometimes 5,000 kilometres, between breeding areas of successive generations, so warnings must be based on recognising the migrations that have taken place in recent months, and on assessing the chances of further movement and successful breeding.

Services to provide warnings of both invasions and breeding have evolved from studies of population displacements and of the effects of rainfall in providing good breeding conditions. A system of centralised collection, mapping and analysis of data on the changing distribution of the Desert Locust was set up in 1929 by Uvarov (1951). By 1943, sufficient was known of the seasonal changes in distribution for regular locust situation reports, including forecasts, to be issued monthly by what later became the Anti-Locust Research Centre (now the Centre for Overseas Pest Research). In the first place, these were issued to aid the planning of control operations by the wartime Middle East Anti-Locust Unit and the East African Anti-Locust Directorate (Uvarov 1951), but later they were expanded to cover the whole locust invasion area. From 1958 to 1973, this service was supported financially by the countries concerned through the Food and Agriculture Organization of the United Nations, and in 1961 it was extended with the support of the UN Special Fund to enable current weather data to be used to assist in the interpretation and more detailed forecasting of the locust situation (FAO 1968). In 1973, responsibility for locust forecasting was transferred to five regional organisations which, under the co-ordination of FAO, collectively cover the area subject to invasion (FAO 1972). By 1979, a centralised service had been set up at FAO headquarters in Rome.

This Manual draws upon the many years of locust forecasting experience among staff at the Centre for Overseas Pest Research, London. It deals mainly with problems of forecasting during plagues (when most locusts are in bands and swarms), but there is much that is applicable to recessions (when there are few, if any, bands and swarms, and crop damage is slight), provided the differences in behaviour of the two kinds of populations are borne in mind.

Any forecast is based upon a knowledge of the current state, and how that state is likely to change in the future. In Desert Locust forecasting, the first step is to assess where the locusts are, what kinds of populations are present, their sizes, and what they are doing. From an understanding of locust biology and behaviour, and with the help of analogues from past records, it is then possible to assess the likely changes. Continuity in the assessment of distribution and sizes of population is all-important; and so, too, is an understanding of the effects of weather on locust movement and breeding.

When making a locust forecast, it is essential to apply first principles to the current situation. Throughout this Manual, emphasis is put on the ways of thought needed to assess the current situation and to choose the most likely of the changes that could come about. Part 3 of this volume, Principles of Forecasting, discusses the nature of field reports of locusts, and how they are used to assess the current situation and to produce and verify the forecast. The techniques described are not definitive; the forecaster should be prepared to modify them in the light of experience and of improvements in the understanding of both locust behaviour and the effects of weather on it. Parts 1 and 2 (The Desert Locust and its Way of Life, and Regional Breeding and Migrations) give the background in locust biology and biogeography, as well as the effects of weather on them, that the forecaster will need to bear in mind when making the assessment and forecast. There are many discussions of past locust events, analysed with the benefit of hindsight, and introduced to illustrate a wide variety of movements and breeding, and of problems met when making forecasts. Most of the maps accompanying these discussions have been put into a separate volume for easy reference. It has not been possible to discuss all possible kinds of events, for the locust situation is never quite repeated. The reader must not expect to find ready-made answers to the problems that a forecaster will meet, but there is guidance in the Manual on how to find the answers.

The forecaster may be responsible for only a part of the area subject to invasions by the Desert Locust. Nevertheless, he needs to take account of happenings in the whole invasion area because, as will be shown repeatedly, adult locusts can migrate over long distances: in a few generations they can expand over the whole invasion area.

DESERT LOCUST FORECASTING MANUAL

Users of this Manual will be mainly forecasters in national or regional authorities concerned with locust control. In addition, it is hoped that the principles described and explained here can be used and adapted by economic entomologists concerned with warning and control services for other migrant insect pests. Moreover, all those in universities and other centres of education who are interested in long-range migration by insects should find food for thought.

PART 1

THE DESERT LOCUST AND ITS WAY OF LIFE

This part of the Manual deals with the biology and ecology of the Desert Locust. It provides a background, along with Part 2, that the forecaster will need to refer to repeatedly when preparing assessments and forecasts, as described in Part 3.

Chapter 2 distinguishes between gregarious and non-gregarious populations, and between plagues and recessions. It also outlines the biogeography of seasonal breeding and movements, that of plagues being described in much greater detail in Part 2. The Chapter also includes a discussion of the characteristics of outbreaks and their development into plague upsurges. Chapter 3 discusses the take-off, displacement and settling of flying locusts, including the influences of weather, and outlines the use of weather maps in understanding the day-to-day displacements that can lead to long-range migration, many examples of which are examined in the Case Studies at the end of Part 2. Chapter 4 describes the various stages in the breeding cycle: from maturation of the adult, through egg and hopper development, to fledging of the new generation. It emphasises the influences of weather on laying and on development rates, and explains how rainfall maps are used in the preparation of assessments and forecasts.

These three Chapters are referred to frequently in Parts 2 and 3 of this Manual.

2 THE DESERT LOCUST

2.1 GENERAL

The DESERT LOCUST, *Schistocerca gregaria* (Forskål), is one of about a dozen species of short-horned grasshoppers (Acridoidea) that can form dense, mobile SWARMS (of adults) or HOPPER BANDS (of nymphs) — see Section 2.2. The Desert Locust is one of the most important locust species because of its:

great mobility — up to 1,000 kilometres a week (Section 3.1.9)

vast invasion area (Fig. 2.1)

ability to build up to prodigious numbers (Section 2.3)

ability to eat its own weight of fresh food daily (Chapters 3 and 4).

Damage to a wide variety of crops can be sudden and severe (Bullen 1966, 1969).

The LIFE CYCLE has three stages:

EGG — laid by females in clusters (PODS) in the ground

HOPPER — wingless NYMPHS or LARVAE, separated by moults into 5 or 6 sub-stages (INSTARS)

ADULT — the winged stage (or IMAGO) — a large insect, not necessarily sexually mature (Pasquier 1946), with a wing span of 10 – 15 centimetres (Fig. 2.2), and a weight of 1.5 – 3.0 grams.

(See also Chapters 3 and 4.)

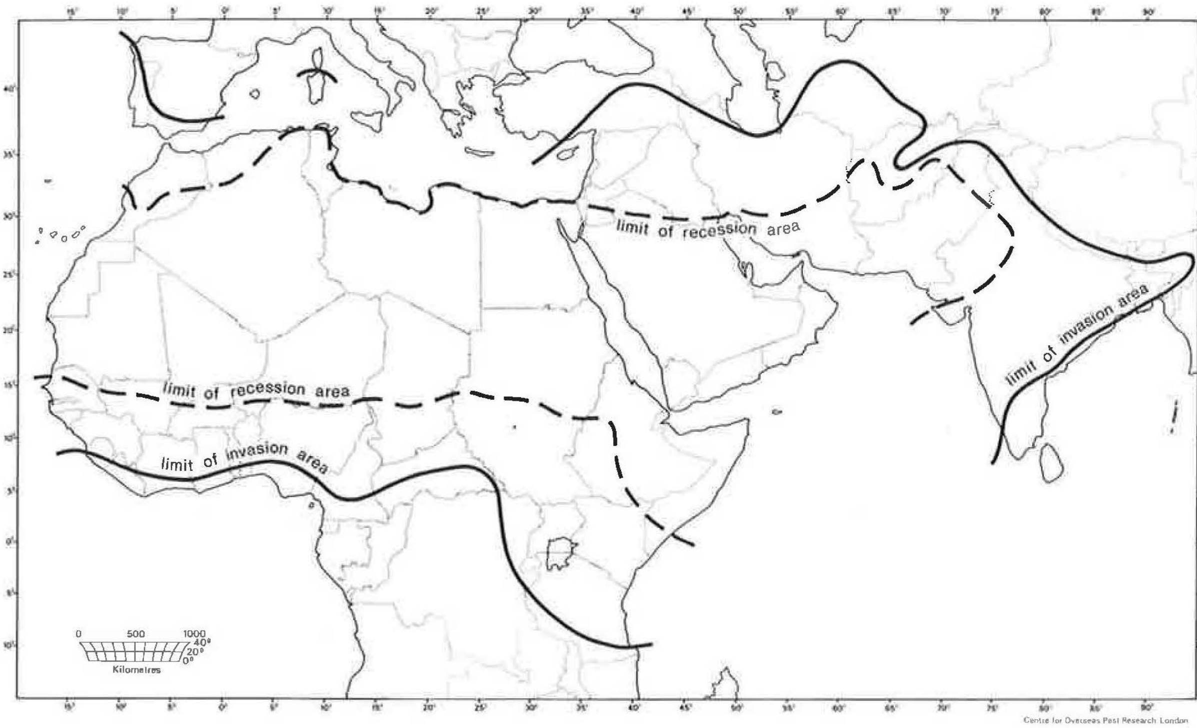


Fig. 2.1 Invasion and recession areas of the Desert Locust (updated from Waloff 1976).

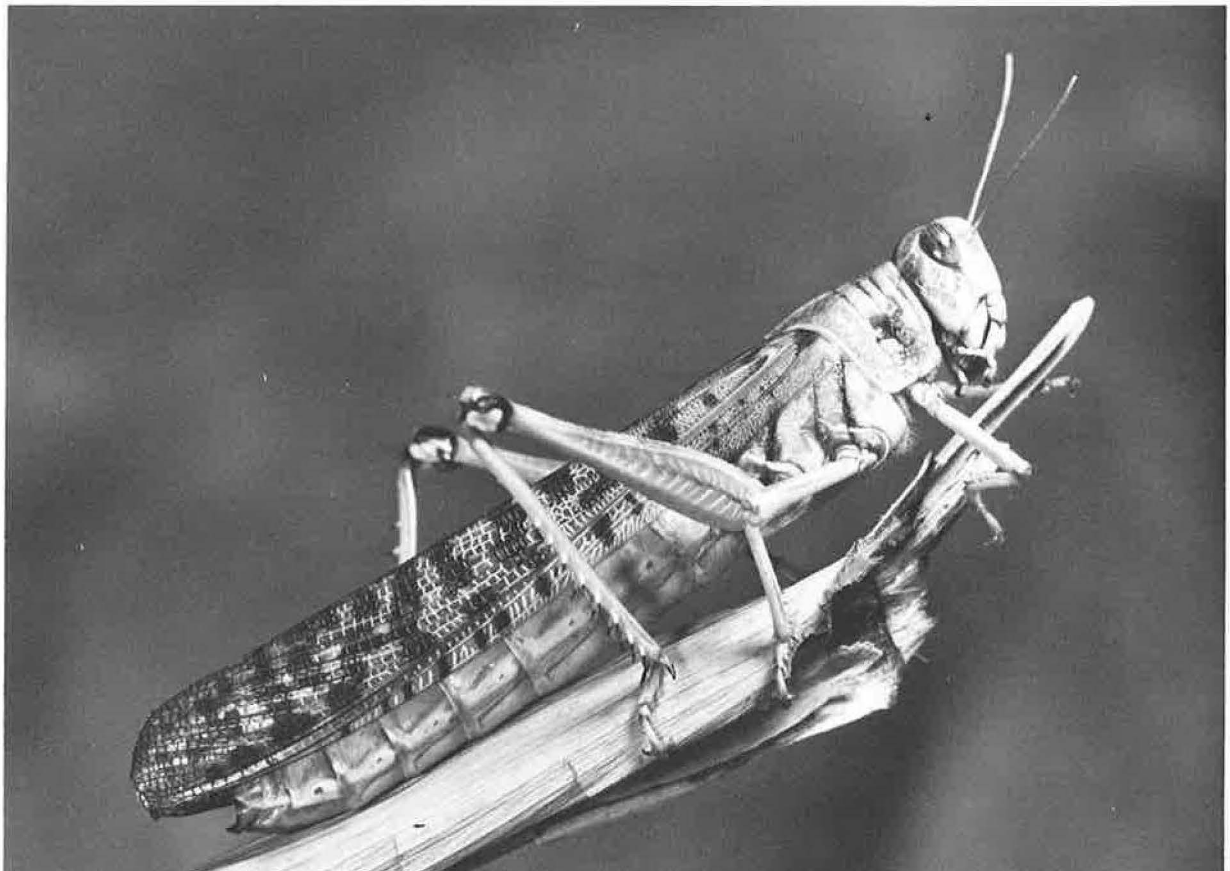


Fig. 2.2 An adult female Desert Locust. (×2). Photograph by G. Colquhoun.

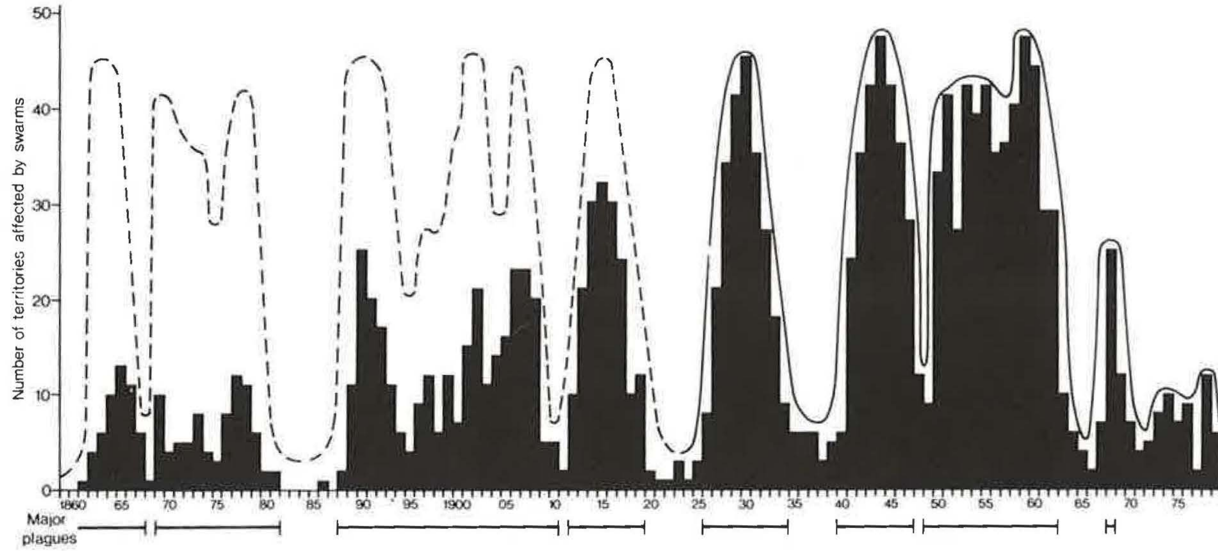


Fig. 2.3 Plagues and recessions of the Desert Locust (updated from Waloff 1976).

When there are many bands and swarms over large areas there is a PLAGUE (Sections 2.3, 2.4 and 2.7), and crop damage can be disastrous. Between any two plagues there is a RECESSION – when there are few, if any, bands and swarms, and crop damage is small (Sections 2.3.2, 2.5 and 2.6). Fig. 2.3 shows the fluctuations in the numbers of territorial units where swarms have been recorded since 1860 (see Table 1 in Waloff 1976), and it illustrates the changes that have taken place from plague to recession and back again. During plagues, swarms may spread over an enormous INVASION AREA (Fig. 2.1) of some 29 million square kilometres, and extending over or into 57 countries. During recessions, locusts occur in a smaller RECESSION AREA (Fig. 2.1) of some 16 million square kilometres in the semi-arid or arid interior of the invasion area, and extending over or into parts of 30 countries. The invasion area has been divided into four major REGIONS: Western, North-Central, South-Central and Eastern (Fig. 2.4). Each Region contains complementary seasonal breeding areas connected by seasonal migration circuits (see Sections 2.4 and 2.5), but it is important to bear in mind that these circuits are not always closed – both swarms and low-density populations often move from one Region to another.

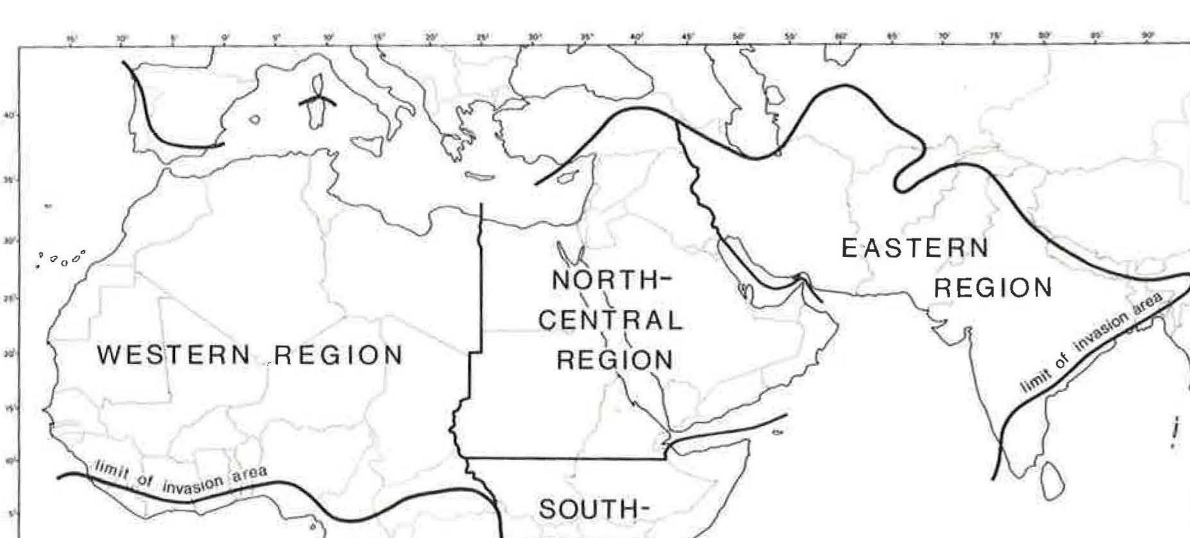


Fig. 2.4 The four Desert Locust Regions (after Waloff 1976).

2.2 PHASE

True locusts differ from grasshoppers by their ability to change behaviour, physiology, colour and shape in response to change in their population density (numbers in unit area). Individuals of the grasshopper-like form are said to be in the SOLITARIOUS PHASE (formerly 'phase *solitaria*') whereas those of the swarming, locust-like form are said to be in the GREGARIOUS PHASE (formerly 'phase *gregaria*'). PHASE TRANSFORMATION was first established by Uvarov (1921) in the Migratory Locust, *Locusta migratoria* (L.). During a plague of that species in southern Russia, the progeny of swarms thinned by control were found to develop into a form previously thought to have been a species of solitary-living grasshopper. The reverse transformation was first established by laboratory experiments, which showed that when individuals of the grasshopper-like form were crowded together they changed their behaviour, colour and shape to that of the swarming form. Phase transformation was later seen repeatedly in the field, and in other locust species including the Desert Locust. Phase transformation can be towards the gregarious phase (GREGARISATION) or towards the solitarious phase (DISSOCIATION). Intermediate forms are said to be in the TRANSIENT PHASE (formerly 'phase *transiens*'), and may be further subdivided into the CONGREGATING PHASE (formerly 'phase *congregans*') and the DISSOCIATING PHASE (formerly 'phase *dissocians*'), depending upon the direction of phase transformation. Most recession populations are in the transient phase (Albrecht 1962, Popov 1965, Waloff 1966, Roffey, Popov & Hemming 1970). A comprehensive review of phase may be found in *Grasshoppers and Locusts* (Uvarov 1966).

Because the Desert Locust gregarises and dissociates very readily, and because most crop damage is done by the gregarious phase, locust forecasters need to be aware of the differences between phases and to watch for signs of transformation. Table 2.1 compares and contrasts the two phases. Information of the kind shown in the table is often included in field reports (Section 9.3), which may then be used to help assess such characteristics of a population as phase status, sexual maturity, age, and changes in composition (e.g., by immigration), as well as to help

Table 2.1 Phase characteristics of the Desert Locust.

	SOLITARIOUS PHASE		GREGARIOUS PHASE
		1. *Behaviour*	
	Do not form groups		Form persistent and cohesive groups — BANDS and SWARMS
	Roost, bask, feed and move as *individuals*		Roost, bask, feed and move *together*
	Hoppers move little, adults fly as individuals *at night*		Very mobile — fly as swarms *by day*. Concerted movement (walking and hopping) by hoppers in a band is MARCHING
		2. *Physiology*	
	Often 6 instars		5 instars
	Egg pods normally with 95–158 eggs (Ashall & Ellis 1962, Roffey & Popov 1968)		Egg pods usually with less than 80 eggs (Ashall & Ellis 1962)
	Usually more than 3 pods laid by each female in the laboratory (Papillon 1960)		Usually 2–3 pods laid by each female (Popov 1958b)
	Often 7 well-marked eye stripes		6 stripes, but eyes often appear to be uniform dark brown
		3. *Colour*	
	Hoppers: uniform green in early instars, but may be brown in last two instars		Hoppers: heavy black pattern on yellow or orange background. (See Stower 1959 for a method of asessing phase status from hopper colour).
	Adults: pale greyish brown, buff or peach coloured. Males change to pale yellow on sexual maturation (but may become bright yellow if crowded during maturation — Volkonsky 1938). Females may show no colour change on maturation if at very low densities		Adults: rosy-pink on fledging, darkening with age to greyish- or brownish-red, then to yellow on sexual maturation (brighter in males)
		4. *Morphometrics* (C = width of head, or caput; E = length of forewing, or elytron; F = length of hind femur)	
F/C	males 3.75 and over		3.15 and under
	females 3.85 and over		3.15 and under
E/F	males 2.025 and under		2.225 and over
	females 2.075 and under		2.272 and over

(Because *gregarious* locusts that have developed at *high* temperatures may have morphometrics similar to those of *solitarious* locusts that have developed at *low* temperatures (Stower, Davies & Jones 1960), it follows that individual locusts with solitarious morphometrics need not have occurred at low density in the hopper stage. By contrast, individual locusts with gregarious morphometrics have almost certainly occurred at high density in the hopper stage.)

	SOLITARIOUS PHASE	GREGARIOUS PHASE
$\frac{\text{female E}}{\text{male E}}$	1.17–1.24	1.07–1.12 (Rainey 1962)

discriminate between different populations and sometimes to deduce possible origins (Waloff 1963). Of particular value are signs of gregarisation in previously solitarious populations, such as:

the formation of basking or feeding groups of hoppers

marching of hoppers

the development of black markings on hoppers

the presence of numerous hoppers in herbs or shrubs

daytime flight after there had been only night flight

flight in discrete and non-dispersing formations

the occurrence of pink adults.

The *rate* of phase transformation in response to change in population density varies with phase character.

Behaviour changes most rapidly. A solitarious hopper placed among gregarious hoppers behaves gregariously within hours (Ellis 1959).

Colour changes most markedly in hoppers, especially at moulting (Stower 1959).

Morphometrics, or measurements of parts of locust bodies, and the ratios between them, change more slowly. It is probable that several generations of crowding are needed for full development of morphometric characteristics of the gregarious phase.

Because of these different rates of phase transformation, it is possible for populations, or even individuals, to have apparently contradictory phase characteristics. For example, locusts in a swarm that is settled amongst dense vegetation may lose their gregarious behaviour but necessarily retain their gregarious morphometrics because these do not change after the final moult (Rainey 1962). There have also been reports of gregariously-behaving swarms composed of locusts with solitarious morphometrics. Such swarms are composed of locusts that have been either at low density in the hopper stage (but have become crowded in the adult stage) or crowded when breeding at high temperatures. Pasquier (1952) proposed adding the following suffixes to phase names:

-gest	for behaviour
-colore	for colour
-form	for morphometrics.

For example, locusts with gregarious morphometrics but solitarious behaviour would be called gregariform and solitarigest.

2.3 PLAGUE AND RECESSION POPULATIONS

2.3.1 PLAGUE POPULATIONS

Populations of all sizes, densities and phases occur during plagues but the great majority of populations, and overwhelmingly the greater number of individual desert locusts, occur at high densities — in hopper bands or swarms.

2.3.1.1 Hopper bands

A HOPPER BAND may be defined as an aggregation of gregarious hoppers which show marching behaviour and move in a concerted manner (Waloff 1966). This definition emphasises the behavioural characteristics of bands and leaves open their size and density, for these are very variable and depend upon many factors, including the habitat, the density of the laying adults, the behaviour and age of the hoppers, and the effects of natural and chemical control.

Hoppers in bands vary in *density* from as high as 30,000 in a square metre to less than one per square metre, and the *size* of hopper bands varies from less than a square metre to many square kilometres.

When hatching is in progress, the newly-emerged hoppers, which are called HATCHLINGS, march very little and form dense 'pools' or groups. They may be so densely packed that they touch one another, and densities as high as 30,000 in a square metre have been recorded (Singh & Bhatia 1952). As hoppers grow older they become larger, and their density decreases when they are engaged in similar activities (Section 4.8). Thus, by the fifth instar, when a hopper has approximately thirty times the plan area of that at first instar, the density in groups may be as high as about 1,000 in a square metre (Singh & Bhatia 1952). Corresponding densities for hoppers in marching bands, when the hoppers spread out, are about 250 – 470 in a square metre in the first and second instars, and about 10 – 30 in the fifth instar (Ashall & Ellis 1962). In areas of uniformly distributed vegetation, hopper bands tend to disperse; Ellis & Ashall (1957) saw third instar hoppers marching at an average density of less than three in a square metre over an area of more than 100 square kilometres.

Quantitative estimates of hopper band density can usually be made only by research teams in the field, because repeated sampling is needed. This can be done photographically, but forecasters will seldom have such quantitative data and they must rely on reports such as '10 – 15 hoppers on each bush; bushes 1 metre apart', from which some idea of the population can be obtained.

The *increase in size* of hopper bands with age can be even greater than the *decrease in density*. This is because, as hopper bands spread out when they march, nearby bands join one another and coalesce to form fewer but larger bands. In a detailed study on the sizes of hopper bands in open *Acacia — Commiphora* woodland in north-eastern Kenya, Roffey & Stower (unpublished) found that the average size of 41 hopper groups on the first day of hatching was 7.5 square metres, and on the second day 38 groups averaged 24.2 square metres. On both days the median size was less than 3 square metres. By the time most of the hoppers were in the *third* instar the average size of band was 52,500 square metres, and by the time most of the hoppers were in the *fifth* instar the average size of 41 measured bands was 373,000 square metres; the median size was 9,200 square metres but the largest was 15,000,000 square metres (or 15 square kilometres; see Fig. 2.5). This was in an area deliberately uncontrolled, and other qualitative data indicate that this particular infestation was representative of heavy infestations in eastern Africa. At times of heavy and widespread breeding, control measures are rarely completely effective. Table 2.2 shows the relative increase with age in the proportion of large and very large bands in a heavy infestation in *Acacia — Commiphora* woodland in the Ogaden area of eastern Ethiopia, and this is typical of such infestations in uniform habitats (only bands of one instar are included in the Table). In other habitats, for example in cultivated areas of Rajasthan or in the Sahel of West Africa, the size distribution of bands may be very different (Roy 1962, Popov — personal communication).

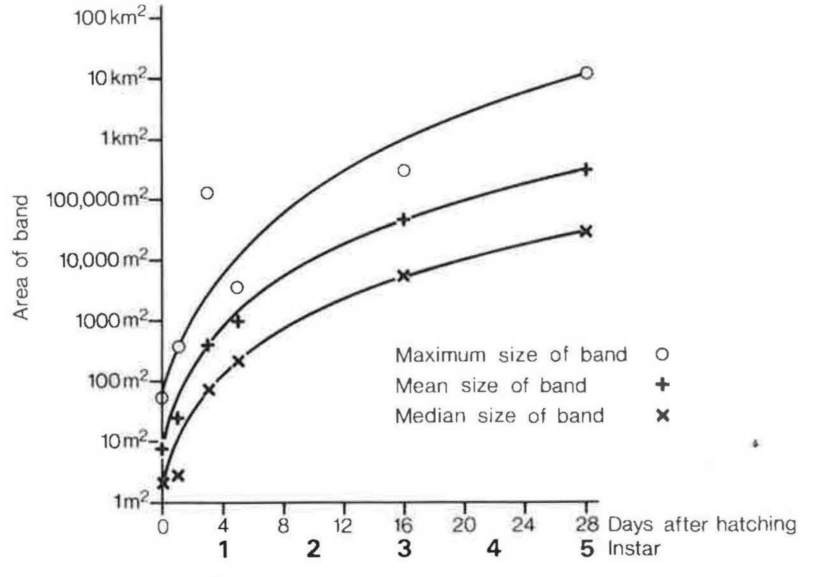


Fig. 2.5 Increase in area of hopper bands with age (after Roffey and Stower, unpublished).

Experienced field observers can usually estimate the sizes of bands classified as small (Table 2.2) to within 10 – 20% when seen from a given viewpoint, but with larger bands it will be necessary to walk or even drive around the edges. Estimating the *size of an area infested with bands* is best done by plotting their positions on a map. Estimating the *number of bands in an infested area* is so difficult that it has probably never been achieved, except over very small areas. Where dusting and baiting have been used as control measures, however, the number of bands controlled may be reported, although it must be remembered that some bands may be treated more than once. Where barrier spraying has been used, it is unlikely that bands will have been counted.

Table 2.2 Observed increase of the size of hopper bands with age in open woodland in eastern Ethiopia 1957. (Desert Locust Survey hopper reports.)

Size	Mean area (hectares)	Instar 1	2	3	4	5
small (5m × 5m – 45m × 45m)	0.02	3875	383	55	43	55
medium (45m × 45m – 180m × 360m)	1.18	389	175	64	44	19
large (180m × 360m – 360m × 720m)	13.35	22	52	33	7	30
very large (over 360m × 720m)	307.6	4	16	1	7	30

From data on the size, number and density of hopper bands, it is sometimes possible to make estimates of the *total number* of hoppers in seasonal breeding areas. For example, in the hopper campaign in the Ogaden area of Ethiopia and adjacent parts of northern Somalia in October – December 1957 (one of the heaviest recorded in eastern Africa during the 1950 – 62 plague) it was estimated that 150,000,000,000, i.e. 1.5×10^{11}, hoppers were killed by baiting operations. There were probably about the same number in southern Somalia. In addition, many hoppers were killed by exhaust nozzle spraying (during which it is not necessary to count individual bands) and some 1,300 square kilometres of swarms escaped. Allowing for natural mortality, it is probable that there were some 500,000,000,000, or 5×10^{11}, hoppers present in this infestation. Even larger hopper infestations are likely to have occurred in the Somali Peninsula in 1954, Sudan in 1958, and Arabia in 1953, to judge from the amount of insecticide used, the number of bands controlled, and the number, size and density of swarms produced.

2.3.1.2 Swarms

A SWARM may be defined as an aggregation of gregarious adults which are able to maintain their cohesion during flight by means of their reactions to one another and to the group (Waloff 1966). Swarms are so variable in structure, density and size, however, and may encounter such a wide range of weather, soil and vegetation during their life, that it is not a rigorous definition. Thus, flying swarms are sometimes temporarily scattered if they experience strong winds, as frequently happens, for example, in northern Somalia between June and September. Also, when swarms are flying in very hot weather they become very scattered but re-form when the weather becomes cooler, for example when they reach Morocco after crossing the Sahara.

There are three main periods in the life of a swarm.

- SWARM FORMATION. During this period, which may take up to two or three weeks, the young, recently-fledged adults, which are initially rather scattered, gradually increase their ability to fly, take longer flights, start to drift downwind from the breeding area, and condense into discrete swarms (see also Section 3.1.1).
- MIGRATION. This is very variable in duration (Sections 2.4 and 3.1.11, and Chapters 5 – 8). Swarming locusts usually migrate in discrete cohesive day-flying swarms, which may persist for months and displace several thousands of kilometres (Sections 2.4 and 3.1.11, and Chapters 5 – 8).
- BREEDING. This commences with the onset of sexual maturity. Swarms break up into smaller units and undergo cyclical patterns of reproductive behaviour, e.g. copulating and egg laying. Flight activity is reduced when swarms are copulating and laying, but mature swarms may migrate actively between reproductive cycles (Section 3.1.10).

Pasquier (1946) proposed a structured series of terms to describe successive stages in the development of adults (Table 2.3). These were based largely on observations of the flying and reproductive behaviour (and associated body colours) amongst swarming desert locusts in North-West Africa. The forecaster needs to know these terms because they are often used in locust reports from that area.

Structure, density and size of swarms

The migratory swarms that are characteristic of plagues vary enormously in *structure, density* and *size,* but they are often tens of square kilometres in area and high-flying, and they contain tens of millions of adults per square kilometre. At night, gregarious adults ROOST on vegetation. In the morning, as their body temperatures rise, they plane down to the ground and form dense BASKING GROUPS. Later, groups start to take off in increasing numbers until the roost site is completely evacuated. In warm, sunny weather, the adults get lifted up by thermal convection (Section 3.3.4), so that the topmost locusts in a swarm are often over a thousand metres above the ground (Rainey 1963). Such high-flying swarms resemble the shape of cumulus clouds and are described as CUMULIFORM. As convective turbulence declines in the late afternoon, swarms decrease in vertical extent and eventually settle. In cool, overcast weather, or in the late afternoon, swarms are of limited vertical extent, they fly close to the ground, and they are described as STRATIFORM. A more detailed account of the structure of swarms is presented in Section 3.1.3.

Detailed studies, particularly in eastern Africa, have provided numerous estimates of the ranges of *density* and *size* of individual swarms. These studies were based on timed aircraft runs (Rainey 1958a), mortality assessments following 'drench' runs of insecticides applied from aircraft (Rainey 1958a, Joyce 1962), vertical photography (Sayer 1956, Waloff 1972b) and radar (Rainey 1955, 1967; Ramana Murty, Roy *et al.* 1964; Schaefer 1972, 1976). Thus, Joyce (1962) found that the *plan-area density* of high-flying migratory swarms in northern Somalia ranged from about 20,000,000 to 150,000,000 in a square kilometre, the average being about 40,000,000 in a square kilometre. Flying swarms are often less dense when they encounter extremely high air temperatures (above about 45°C at the surface, such as occur in the Sahara and the Arabian deserts in summer) and after laying, due to some differentiation in the state of maturity among swarm members, so that some become engaged in mating and laying while others take off and fly away (Popov 1958a, Waloff 1972b). There are many records of swarms with plan-area densities of less than 10 in a square metre. Data on plan-area densities of swarms are reviewed by Bennett & Symmons (1972).

The *volume density* of adults in swarms has frequently been estimated from vertical photographs, and on two occasions by using radar. When swarms are flying in wind convergence zones (Section 3.3.5), volume densities

Table 2.3 Terms used to describe stages in the development of the Desert Locust (after Pasquier 1946).

Terms				Flight and reproductive activity	Colour	Duration of stage	Notes
AILÉ imago imagine adulte s.l. sauterelle volante *winged locust*	AGÉNÉTIQUE immature prémature *immature locust*	NÉPIOGONE *new fledgling*		Marching and some flying in the breeding area	Pink	less than one week	
		NÉOGONE *older fledgling*		Swarm movement near breeding area	Pink		Voracious feeders
		PRÉGÉNETIQUE *migrating immature locust*	HYPOGÉNÉTIQUE *migrating locust not ready to mature*	Migrant	Pink		Full-grown good flyers of Weis-Fogh (1952). Locusts that have reached base weight (Norris 1952)
			PAUSOGÉNÉTIQUE *locust with delayed maturation*	Restricted movement (in North Africa)	Red, later brown	3–4 months in North Africa	
	GÉNÉTIQUE mature mûr adulte, s.st. *mature locust*	EOGÉNÉTIQUE *maturing locust*			Yellowing		In North Africa, associated with warmer, rainy weather, allowing migration and breeding
		NEOGÉNÉTIQUE *newly-matured locust*		First mating and egg laying	Yellowing		
		EUGÉNÉTIQUE *fully mature locust*			Yellow		
		GÉROGÉNÉTIQUE *aged locust*		Fecundity reduced	Yellow (male—pale straw;female—browner, abdomen slate-coloured or violaceous)		

may reach 1 to 2 in a cubic metre (Joyce 1961, Sayer 1962), but immature, high-flying swarms, away from wind convergence zones, have volume densities usually in the range of one in a cubic metre to one in a thousand cubic metres, i.e. one or two orders of magnitude less (Rainey 1958b, Ramana Murty, Roy *et al.* 1964, Waloff 1972b). In hot weather, they may be as low as one locust in ten thousand cubic metres (Schaefer 1976). Volume densities in *stratiform* swarms are also variable and can reach over 10 in a cubic metre. Gunn, Perry *et al.* (1948) calculated there were 11.5 to 14 locusts in a cubic metre in the lowest few metres above the ground in a stratiform swarm as it was settling. When locusts are roosting densely their volume density may rise to hundreds or even thousands in a cubic metre, and there are records of branches breaking under the weight of settled locusts.

Such quantitative estimates of density will seldom be available to forecasters, who must therefore rely on the qualitative terms 'low, medium and high density' as recommended on the standard reporting forms (see Section 9.2), but it must be remembered that the density of a given swarm can vary during the day. For example, a high-flying swarm reported to be of low or medium density may later be reported as high density when it has settled.

The *sizes* of plague swarms vary enormously, from a few hectares up to a thousand square kilometres; most are many square kilometres in area. In one detailed study (of the sizes of swarms which invaded northern Somalia in 1960) it was found that they were distributed log-normally, that is, there were a few large* swarms, numerous medium-sized swarms and few small swarms. It was shown that of the 1,875 square kilometres of swarms that entered the area, a half was in swarms larger than 300 square kilometres (Joyce 1962). The significance of this finding to forecasters is that if a report is received of a single swarm measuring, say, 300 square kilometres, then it is highly probable that there will be other swarms in the general area. There are some occasions, however, when all the swarms in an invasion join together to form a single swarm, as happened, for example, in eastern Ethiopia in October-November 1958 (see later in this Section).

Most reports of swarm size are only estimates. These are notoriously difficult to make by ground traverses unless the swarms are small or settled. The best method is to fly along one side of the swarm, noting the time between seeing the first and last locusts abeam of the aircraft, and then do the same on a second leg about 90° from the first. The distance flown on each leg can then be calculated from the airspeed, and hence the area found, but because swarms are in general not rectangular it is necessary to reduce the area by about 30%. For example, suppose locusts in a swarm are seen for 3 and 4 minutes on the two legs from an aircraft flying at 180 kilometres an hour, the swarm area is about

$$\frac{3}{60} \times 180 \times \frac{4}{60} \times 180 \times \frac{70}{100} = 75 \text{ square kilometres.}$$

Knowing the sizes of individual swarms, it is possible to estimate the total swarm area, which is likely to be dominated by a few large swarms.

The ground area infested with swarms can be estimated only by plotting all sightings on a map, preferably daily and making due allowance for movement.

By daily aerial reconnaissance for swarms, and by using radar, it has been possible to estimate the *total number of locusts in a seasonal migration*. Some examples are shown in Table 2.4. It may be noted that if all the females in these populations laid twice, then the potential number of first instar hoppers in seasonal breeding areas would be of the order of 10^{13}. In fact, such large numbers of young hoppers have never been recorded, partly because of control measures against the adults before they laid, and probably partly because of the high mortality which occurs amongst hatchlings (Section 4.7.5).

Table 2.4 Examples of the numbers of locusts in seasonal migrations.

Country	Period	Area of swarms km^2	Estimated number of adults	References
Kenya	January 1954	1250	5×10^{10}	Rainey 1958a
Somalia	June–September 1955	3700		Joyce 1962
Somalia	June–August 1960	1875	7.5×10^{10}	Joyce 1962
India	July 1962	900–1400+	10^{11}	Rainey 1965b

It is also important to be aware of the *age* of swarms. At first, fledglings fly in small groups that later coalesce to form larger groups until, two to three weeks after fledging, swarms are formed. These migrate and ultimately reach areas where they can mature. The swarms then break up to form copulating and laying groups, but later they may be reconstituted and resume their migration. Thus, swarms tend to be largest when they are immature and migrating.

* At the time, a *large* swarm was one exceeding 50 square miles, a *medium-sized* swarm was 0.5–50 square miles, and a *small* swarm was less than 0.5 square miles. It is suggested that in metric units a *large* swarm should be one exceeding 100 square kilometres, a *medium-sized* swarm should be 1–100 square kilometres, and a *small* swarm less than 1 square kilometre.

Cohesion of swarms

Detailed studies from both the ground and the air have provided a number of examples of the cohesion of individual swarms for periods of up to about a month. Gunn, Perry *et al.* (1948) tracked one swarm for 26 days before it split up, and another for 17 days before it matured. Rainey (1963) recorded the track of a swarm which was followed for 29 days. Another example of cohesion is provided by a very large swarm which reached the Jigjiga area of eastern Ethiopia on about 10 October 1958. The locusts which formed this swarm were produced in eastern Sudan and western Eritrea in September 1958 (Joyce 1962). Young adults formed into numerous medium-sized swarms in Eritrea and these later moved to Jigjiga, where they formed one single swarm. This swarm stayed in the Jigjiga area for about 10 days (causing severe damage to cereal crops and leading to the remission of taxes for a year), and it was then tracked by air until it reached the Galkayo area of Somalia on 17 November. Although the swarm split into three sections in late November, these rejoined and the swarm continued as a single entity until it split up again, after which it flew down the coastal escarpment in northern Somalia on 16 December.

Break-up, which may only be temporary, may happen under the following circumstances.

- When swarms contain individuals in different stages of maturation. The earlier maturing adults form copulating and laying groups, while the less mature individuals may fly off and lay in nearby areas (Popov 1954, and see Section 4.4.1). After the latter have in turn copulated and laid, all parts of the swarm may resume migration as a cohesive whole.
- When swarms encounter strong winds. Two separate effects of strong winds have been recorded in northern Somalia between June and September during the south-west monsoon season. Waloff (1972b) described how individuals in a swarm, instead of departing together from their overnight roost sites, left the roost by very intermittent and low flights during relative lulls in the wind. As the lulls became longer the flights became longer so that the swarm became stretched downwind from the roost. Such swarms normally reformed during the afternoon at the wind convergence line that forms on many days near the escarpment. The second effect occurs during the afternoon if swarms encounter strong winds blowing outwards from rain storms (Sayer 1962).

2.3.2 RECESSION POPULATIONS

During recessions, overall numbers of the Desert Locust are much lower than during plagues, and most populations occur at low densities. It is necessary, however, to amplify this statement because, in fact, a very wide range of recession populations has been recorded. Table 2.5 provides some examples of the variability of recession populations with respect to size, density and behaviour. It will be seen that there are three main behavioural categories: low-density populations, populations showing some grouping, and high-density populations.

The term LOW-DENSITY POPULATION is a very general one, used to describe populations in which the individual hoppers and adults are likely to be out of range of mutual perception. Because of the variability of locust habitats and of locust behaviour, there is no fixed distance beyond which locusts can be assumed to be out of range of mutual perception. Thus, in dense herbaceous vegetation such as *Tribulus* or *Heliotropium* there may be up to 10 hoppers on each plant (which may be a metre across), all behaving independently of one another (Kennedy 1939, Stower, Davies & Jones 1960, Popov 1968, Roffey & Popov 1968). By contrast, hoppers in plants with a sparse habit of growth, such as *Malcolmia aegyptiaca* or *Dipterygium glaucum*, may react to each other when there are only two or three on a plant (Guichard 1955). Similarly, the maximum density at which adults have been observed to occur without reacting to the presence of one another is highly variable. For settled immature adults there is often no obvious mutual perception when individuals are some five metres apart, so that populations at densities of less than 500 in a hectare are usually regarded as being low-density. The terms ISOLATED and SCATTERED are further subdivisions: ISOLATED is used to describe populations when there are five or less in a hectare, and SCATTERED when there are 5 to 500 in a hectare, unless there is evidence of grouping. When adults become sexually mature they actively seek out individuals of the opposite sex and may form recognisable groups even though the average density within the population is less than 500 in a hectare. Among flying adults, the maximum densities at which locusts can occur without reacting towards one another is very much less, and may be no more than a few in a hectare. Radar observations on very low-density, but cohesive, *swarms* in the Sahara showed that their volume density was as low as one adult in a thousand cubic metres (Schaefer 1976).

The terms GROUPING POPULATIONS or GROUPS are used to describe populations in which hoppers or adults react towards the presence of one another but, unless carefully observed, *grouping behaviour* may not be recognised. It does not include isolated pairs of copulating locusts. There may be other evidence, however, that individuals are reacting towards the presence of one another: for example, solitarious green hoppers starting to develop black markings, or grey solitarious adults starting to develop yellow colouration on their hind wings (Section 2.2). Examples of group formation by hoppers and by adults are given in Section 2.6.

The term HIGH-DENSITY POPULATIONS is normally used to describe large populations that behave gregariously, i.e. hopper bands or swarms. But during recession periods such populations are usually smaller and less persistent, and have far fewer individuals than those characteristic of heavy infestations during plagues. Indeed, there may be gaps of several months between reports of hopper bands or swarms from anywhere within the Desert Locust area (as in 1977). It is unusual for recession *hopper bands* to persist from hatching to fledging. Much more frequently, hopper bands only form in the later instars as a result of crowding, and small hopper bands present in the first instar often disperse in the middle instars due to predators. When there are large recession populations, however (as, for example, in the Eastern Region in the summer of 1973), hopper bands may be large and persistent and thus resemble the smaller, but not the larger, infestations during plagues. Table 2.5 gives examples of the sizes of high-density hopper populations during recessions.

Table 2.5 Examples of the variability in size, density and behaviour of populations during recessions.

Type of population	Locality and country	Date	Area of population	Density of population	Estimated number in population	Behaviour and remarks
Low-density adults						
large population	around Atar, Mauritania	December 1965	20,000 km^2	1 per 100 paces; up to 30 per hectare	Tens of millions	
small population	In Akarbai, Tamesna, Niger	November 1965	600 m $\times$ 700 m	Less than 50 per hectare	Less than 2,000	Flying at night (Popov 1968)
Low-density hoppers						
large population	Akbanazuf, Eritrea	January 1950	31 km^2		153,000,000$\pm$75,000	Solitarious: mainly first and second instars (Waloff 1966, Popov 1968)
small population	Tchissigtam, Tamesna, Niger	July 1966	10 ha	2 – 3 per 10 paces	About 25,000	
Populations showing some grouping						
Adults						
large population	Mauritania	September 1969	60,000 km^2	Up to 100 per 100 paces	About 100,000,000	Some hopper bands formed in October
small population	Mbikas, Tamesna, Niger	October 1967	15 ha	1,200 per hectare	18,000	Groups of up to 29 egg-laying females (Roffey & Popov 1968)
Hoppers						
large population	Mauritania	September – November 1969	60,000 km^2	Up to 100 per *Panicum* and *Aerva*	Hundreds of millions	Some bands formed
small population	In Akarbai, Tamesna, Niger	November 1965	0.3 ha	Up to 30 per *Tribulus*	About 8,000	Spontaneous marching observed (Popov 1968)
High-density Populations						
Swarms						
large	Morocco	December 1974	7 km^2	100 – 150 per square metre	700,000,000 – 1,050,000,000	Day-flying, split up into four swarms and controlled
small	Tikikiten, Tamesna, Niger	June 1967	42 ha	825 per hectare	35,000	Followed for three days
Hoppers						
large	Pakistan – India	October – November 1973	20,500 km^2	Over 3000 bands controlled, including over 300 very large	$2 - 3 \times 10^{10}$	Many swarms produced despite control
small	People's Democratic Republic of Yemen	October 1972	100 km^2	107 bands, each 4 – 200 square metres	$10^5 - 10^6$	

Similarly, the *swarms* reported during recession periods are usually much smaller and less persistent than those characteristic of plague periods; they are also much fewer. Whereas swarms during plagues are often tens or hundreds of square kilometres in extent, and typically contain 20,000,000 – 150,000,000 individuals in each square kilometre (Section 2.3.1.2), those during recessions are often less than a square kilometre or only a few square kilometres in extent, and are often much less dense. Thus, the Tikikiten swarm in Niger in June 1967 (Table 2.5) contained some three orders of magnitude fewer locusts than would be present in a small medium-density plague swarm measuring one square kilometre. Even the largest swarms reported during recessions are an order of magnitude smaller than the largest plague swarms. Swarms during recessions are frequently reported as mature;

after copulating and laying for a day or two, they are reported to have dispersed, and thus they are likely to represent no more than groups of adults coming together at the time of laying, such as is known to occur amongst low-density populations (Roffey & Popov 1968). Less frequently, small swarms of young locusts are reported at the end of a breeding season but only rarely are these large and dense enough to migrate and reach the next breeding area as cohesive swarms (Hemming, Popov *et al.* 1979), in contrast to swarms migrating between breeding areas during plagues.

There are few estimates of the *total number* of locusts in seasonal breeding areas during recessions, and none of the numbers of adults which migrate. Waloff (1966), in a review of all recession populations and outbreaks between 1920 and 1964 (see also Section 2.6), suggested that populations of the order of 10^7 to 10^8 could develop during local outbreaks, and thus implied that smaller numbers could be present in non-outbreak seasons and that larger numbers could occur in a large outbreak. Subsequent experience supports these approximations (Table 2.5). Thus, the infestations in India and Pakistan in 1973 (Section 2.6.2.2) possibly produced $2-3 \times 10^{10}$ hoppers in the second generation, whereas in West Africa the infestations which developed in Mauritania, Mali and Niger from July 1969 possibly gave rise to some 10^9 hoppers and fledglings by November 1969, and in the following year there were possibly 7×10^9 hoppers and adults by September in the same three countries. At the other end of the scale, there have been occasions when there have been only a few reports of low-density populations in a seasonal breeding area, e.g., in West Africa South of the Sahara in the summer of 1963. Although the paucity of reports in such seasons must in part be due to the inability of survey teams to locate more than a small proportion of the total population, they do appear to be indicative of very low numbers in a region (perhaps no more than a few million).

Estimates of total numbers in low-density populations are especially important if breeding is likely and there is a risk of local outbreaks developing, or even a more widespread upsurge. The forecaster needs to know the average density (e.g., the number of adults in a given length of foot or vehicle traverse, or the number of hoppers on a plant and the spacing of plants) and the size of the area infested. Many reports, however, give density but not the area infested. Even where such quantitative data are given, they are usually for a few sites only, so the forecaster must learn (by visits, by using ecological maps, and by reading about the areas infested) to estimate the likely extent of infestation.

Opinions differ on the relative importance of low-density and high-density recession populations in the formation of outbreaks (Section 2.6) and plague upsurges (Section 2.7). One view, which may be called the swarm continuity hypothesis, is that high-density populations are usually, if not always, present even though unreported, and that such populations are the most important because, it is claimed, even a single small swarm can contain as many locusts as exceptionally large, low-density populations. The proponents of this view consider that high-density populations persist from generation to generation during recessions, and that some of the gregarious populations at the end of one plague can be linked to similar populations at the beginning of the next. For a fuller exposition of this hypothesis see Rainey & Betts (1979).

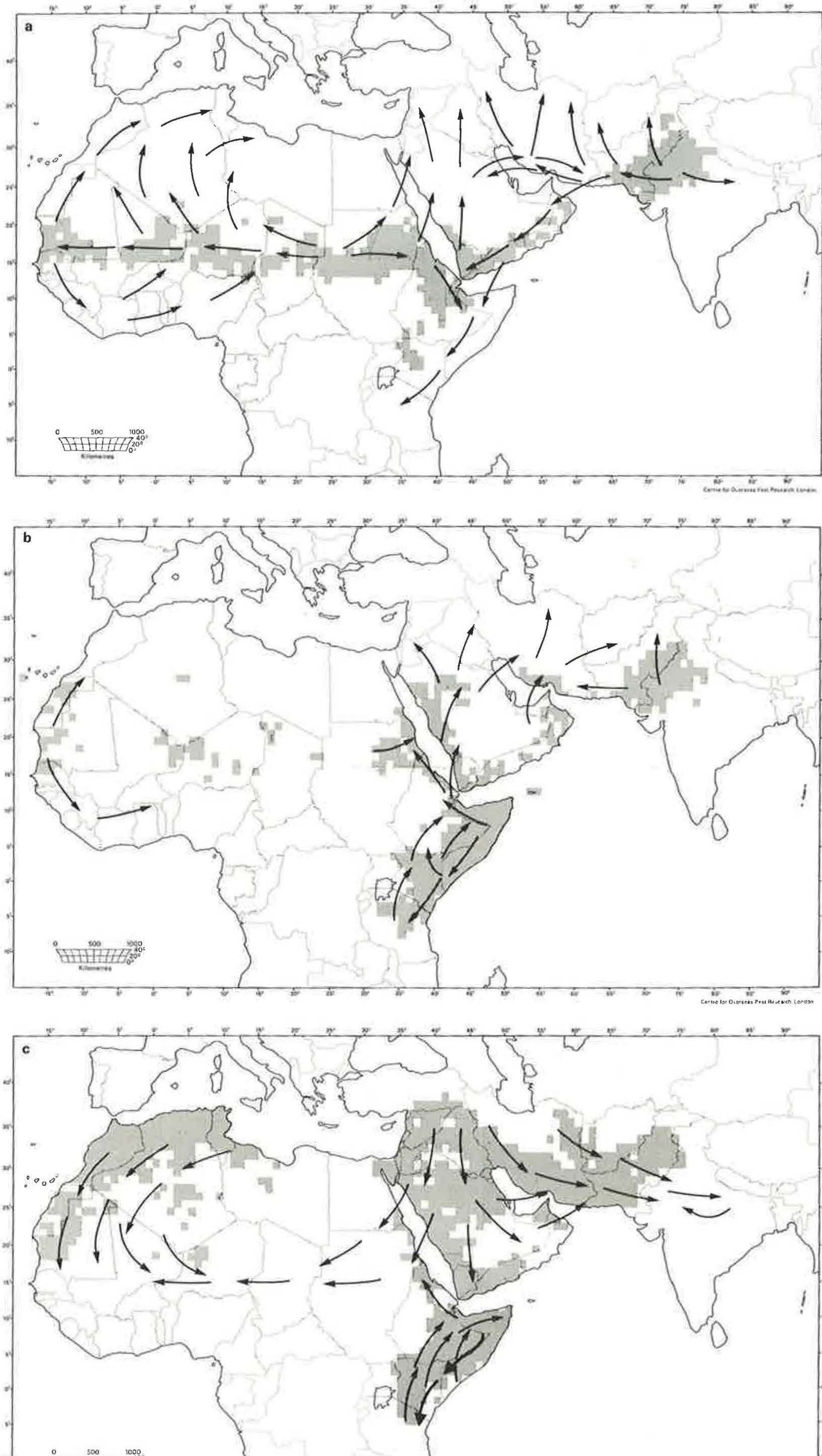
The alternative view, which may be called the gregarisation hypothesis, is that during recessions most locusts usually occur at low densities, but that following successful breeding higher-density populations are easily and frequently produced. These are usually smaller, are of lower density and are less persistent than bands and swarms which occur during plagues, although, at times when recession numbers are high, gregarious populations may persist for two or three generations and may approach smaller plague populations in size and density. The proponents of this view regard the occurrence of sequences of exceptionally favourable breeding conditions as the essential pre-requisite for the onset of a plague (see Section 2.7). For a fuller exposition of this hypothesis see Hemming, Popov *et al.* (1979)

2.4 SEASONAL BREEDING AND MOVEMENTS OF SWARMS DURING PLAGUES

The invasion area of swarms of the Desert Locust is very large (Fig. 2.1). It extends over 113 degrees of longitude, from the Canary Islands off West Africa to Assam (from 18°W to 95°E), and 51 degrees of latitude, from Turkey to Tanzania (41°N to 10°S). It covers about 29 million square kilometres, and comprises the whole or parts of 57 countries as well as a considerable range of climatic regimes. In addition, swarms, groups and isolated locusts have all been seen at sea, both flying and in the water, as far as 2,400 kilometres from land (Waloff 1960).

Most of the climates in the Desert Locust area have, however, a common characteristic in that they are dry, with low average rainfall that falls either sporadically or, more commonly, is restricted to limited seasons. Desert locusts need moist soil for egg laying and incubation (Sections 4.4.1 and 4.5.1), and fresh vegetation for hopper development (Section 4.7.1), and in their generally arid environment they can reproduce only during periods of rainfall.

Two major seasonal belts in which rains fall and in which locusts breed (respectively, the northern hemisphere *summer* and *spring*) run from west to east through the Desert Locust invasion area (Fig. 2.6a and c). Between the two belts, and partly overlapping with each, lies a third belt, of *winter* breeding, which is particularly important on the Somali Peninsula and around the Red Sea (Fig. 2.6b). Within these seasonal belts, the distribution and extent of breeding varies from year to year, and their different frequencies in different parts can be shown by means of frequency maps.


a
b
c
0 500 1000
Kilometres
Centre for Overseas Pest Research London

Young swarms as a rule leave their source areas at the end of the rains, and the greater parts of the seasonal breeding belts become free of swarms during their dry seasons. The emigrating swarms move downwind to the next or next-but-one breeding belt, and these migrations usually result in seasonal translocation of entire swarming populations between complementary seasonal areas, often thousands of kilometres apart.

In many parts of the immense area over which the Desert Locust occurs, the seasons of the year are described by local names, the adoption of which in this Manual would result in a complex nomenclature and risk of confusion. To avoid this, and to reach a compromise found in practice to fit seasonal events over most of the Desert Locust area, the following conventional names have been used to designate rainy seasons, locust generations, and seasons of movement.

	Rainy season	*Locust generation (months of hatching)*	*Locust movements*
MONSOON (Eastern Region)	June — September	July — September	
SHORT RAINS (South-Central Region)	October — December	October — January	
LONG RAINS (South-Central Region)	February — June	February — June	
SUMMER	June — September	July — September	June — September
WINTER	October — January	October — January	October — January
SPRING	February — May	February — July	February — May

The seasonal breeding and migrations are described in greater detail in Chapters 5–8, which include many summarised examples of swarm movements and Case Studies of weather systems with which they are associated. Here, only an outline is given of seasonal breeding and redistribution of swarms.

2.4.1 FREQUENCY MAPS

The numbers of years with Desert Locust reports (hopper bands and swarms) during the 37-year period 1939–75, for each month of the year and each 'square' of one degree of latitude and longitude, are shown in the FREQUENCY MAPS at the beginning of Volume II. These maps have been compiled from reports sent to the Centre for Overseas Pest Research (until 1970, the Anti-Locust Research Centre) from all parts of the Desert Locust invasion area. The reports were regularly plotted on monthly maps at scales of 1:1 million to 1:4 million, with the plotting summarised on monthly maps of 1:11 million (see Section 9.5). The majority of reports were sufficiently precise to allow initial plotting within 10 minutes of latitude and longitude, so these maps were suitable to serve as a basis for compiling the frequency maps using one-degree squares as units.

The maps show:

- the total areas over which Desert Locust bands and swarms have been reported in each calendar month for the 37-year period
- the distribution of reports within those areas, particularly the parts where reports have been most frequent
- the changes in distribution from month to month.

When using the maps, it should be remembered that 24 of the 37 years had heavy and widespread plagues, and that large parts of the invasion area were under-reported. Hence, not only do the maps reflect locust distributions during heavy plague years, they also need some adjustment to allow for under-reporting. Although the greatest

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Fig. 2.6 Breeding areas and major movements of resulting swarms *(opposite).*

a Summer. Degree squares with hopper band infestations in at least *two* years during the period 1939 to 1975 from August to October, but only August and September on the Somali Peninsula. Degree squares with infestations in at least *one* year are shown in Arabia east of 50°E. Arrows show major movements of summer swarms in the following winter and spring.

b Winter. Degree squares with hopper band infestations in at least *one* year during the period 1939 to 1975 from November to January, but October to January on the Somali Peninsula. Arrows show major movements of winter swarms in winter and spring.

c Spring. Degree squares with hopper band infestations in at least *two* years during the period 1939 to 1975 from March to June. Degree squares with infestations in at least *one* year are shown in West Africa west of 15°E and in Arabia east of 50°E. Arrows show major movements of spring swarms in spring and summer. Heavy arrows in East Africa show the movements in the following winter.

frequencies, 16 to 19 years in each of the four Regions, are about only one half of the total number of years considered, they are 80 – 90% of the number of years with widespread infestations in the respective Regions, based on Waloff (1976). Because it is unlikely that a given square would have locusts every time the Region in which it lies is widely infested, these greatest frequencies are probably little affected by under-reporting and may therefore be taken as being close to the true frequencies in those squares for the 37-year period. The same would be true for neighbouring squares with similar patterns of human settlement and reporting systems. Thus, the maps probably need little or no correction for under-reporting in the following countries:

India
Pakistan
Sudan (except the north-west desert)
northern and eastern Ethiopia (except Danakil)
Somalia
Kenya
Tanzania
Uganda.

Elsewhere, there is under-reporting, due either to a complete absence of reports in a few years (mostly in the early 1940s) or to a lack of reports in sparsely inhabited areas. The presence of locusts in neighbouring countries during years with no reports suggests that frequencies should be increased by the following number of years:

Tunisia	1
Saudi Arabia (west coast)	2
Gefara (north-west Libya)	3.

Over about half the invasion area, most reports come from isolated settlements or main routes between them. Frequencies in squares containing such places are probably representative of much wider areas. The following is a list of countries where such considerations must be borne in mind (together with the number of years when there was no reporting system):

Afghanistan	7
United Arab Emirates	3
east, north and central Saudi Arabia	
Yemen Arab Republic	2
People's Democratic Republic of Yemen	
Egypt	
Libya	3
Chad	4
Niger	
Mali	
Mauritania	
Western Sahara	11
Iran (except southern coast)	1
Iraq (except river plains).	

In some of these countries there are areas where locusts are very seldom reported, but where Case Studies suggest that locusts overfly at certain seasons in some years:

the empty quarter of Arabia — southern Saudi Arabia and interior Muscat and Oman,

eastern Sahara — south-west Egypt, north-west Sudan, north Chad and north Niger,

western Sahara — north-west Mali, north-west Mauritania and west Algerian Sahara.

Low frequencies in most countries around the edge of the invasion area seem likely to be near the true frequencies:

Bangladesh
Turkey
USSR
Nigeria
Upper Volta
Ivory Coast
Ghana
Togo
Benin
Canary Islands
Madeira
Portugal
Spain

and probably also

eastern Zaire
Ruanda-Burundi
Sierra Leone.

Guinea may be under-reported, and so also may be Portuguese Guinea and Liberia, but these last two are not certain.

The forecaster should also remember that locusts have been reported at places beyond the areas infested during the period 1939–75 and used for these maps (notably during 1926–34; see Uvarov 1933a, 1933b and 1934, and compare the frequency maps with Fig. 2.1). It is therefore necessary to bear in mind that locusts may move, during years with heavy infestations, into area as diverse as southern Tanzania, northern Zaire, Sardinia and Cyprus.

2.4.2 SUMMER BREEDING AND MOVEMENTS OF SUMMER SWARMS (Fig. 2.6a)

In August and September, swarms can be found in a comparatively narrow belt running to the south of the Sahara and the deserts of north-eastern Africa from the Atlantic shore to Ethiopia and the Red Sea, and extending southward through Ethiopa to north-west Kenya, and eastward through southern Arabia and the northern Somali Peninsula to eastern Pakistan and north-west India (see swarm frequency maps for August and September). Summer breeding can occur throughout this belt (with the exception of the north-eastern Somali Peninsula), between late July and September or October, on the monsoon rains associated with the Inter-Tropical Convergence Zone (ITCZ; see Section 3.3.4).

The summer generation swarms usually appear between late August and October, and they clear the summer breeding belt between September and November. They then move towards and over the winter and spring breeding belts (cf. Figs. 2.6b and c). The generalised directions of the movements of summer swarms are shown on Fig. 2.6a.

In West Africa, they move in a general north-westward or northward and then north-eastward direction to north-western and northern Africa (Fig. 2.6a); on occasion the invaders of north-western Africa include swarms originating as far east as Sudan (Section 8.7). Sometimes some of the summer swarms over-winter to the south of the Sahara, and perform the so called 'Southern Circuit', during which they remain immature (Section 8.9). From the countries bordering the Red Sea, swarms move north and north-east to the spring breeding areas in Arabia and the Middle East, occasionally spreading as far as Iran and even further east; other summer generation swarms from these countries may move south-eastward on to the Somali Peninsula (Sections 6.8 and 6.12). In the meantime, the summer monsoon swarms produced in India and Pakistan move out in general westward and then northward directions to spring breeding areas in Pakistan, Afghanistan, Iran and Arabia. In some years some of them continue south-westward through south Arabia and across the Gulf of Aden to the Somali Peninsula (Sections 5.8 and 5.12).

2.4.3 WINTER BREEDING AND MOVEMENTS OF WINTER SWARMS (Fig. 2.6b)

Not all the summer generation swarms reach the spring breeding areas, for some of them may mature and breed in winter if late autumn or winter rains occur within the summer belt before they have left it, or if they encounter rains on their way to the spring belt. During this winter breeding, hopper bands occur between October-November and January-February, and new swarms appear between late November-December and February-March. As can be seen from Fig. 2.6b, winter breeding may take place in all the four major Regions into which the invasion area has been divided, and in most areas winter swarms move in the same general directions as the summer swarms (cf. Figs. 2.6b and a) and breed in the spring breeding belt.

Some local winter breeding has been recorded within the summer breeding belt in each country of the Western Region through which the belt runs, and to the north of it in northern Mauritania, Western Sahara (former Spanish Sahara) and in the Algerian Sahara. Winter swarms originating in the countries bordering the Atlantic move either north to breed in north-west Africa, or south to become involved in the Southern Circuit. It is probable that similar migrations are performed by winter swarms originating in other parts of the Western Region. In the Eastern Region the summer monsoon breeding may continue into winter if monsoon rains last till late autumn, and the resultant swarms may either follow the summer swarms westward or move northward to breed during spring in northern Pakistan and India. Further west in the Eastern Region, swarms may sometimes breed in winter on the coasts of south-east Pakistan and Iran and in south-eastern Arabia, with the resultant swarms joining in the spring breeding around the Persian Gulf and the Gulf of Oman, or spreading further north in Iran and the Middle East. Important winter breeding also often takes place on both shores of the Red Sea, which receive winter rains and are traversed by many summer swarms from north-east Africa and south-west Arabia. Their progeny either stay on the coasts, to breed there in spring, or follow the summer swarms to the spring breeding areas in interior Arabia and the Middle East. The other main area of winter breeding lies over the Somali Peninsula, and in some years extends into Kenya and northern Tanzania (Fig. 2.6b). The swarms breeding in this area and season are those of the previous spring generation (locally known as Long Rains swarms, Section 7.4) that had passed the summer in the northern Somali Peninsula without maturing, and summer swarms invading the Peninsula from Sudan and Ethiopia, or from southern Arabia, or India and Pakistan (Section 7.7). The winter breeding takes place on the rains (locally called 'Short Rains' — Section 7.3) associated with the Inter-Tropical Convergence Zone, which is then making its seasonal southward movement over the area. The new Short Rains swarms usually appear between late November and January. Quite often some of them move out to the north and north-east, to breed in spring areas on both shores of the Red Sea and in Arabia and the Middle East, sometimes as far as Iran and Afghanistan (cf. Fig. 2.6b and Sections 5.10, 6.10 and 7.10). The more usual movement of the Short Rains swarms is to the south and south-west over the Somali Peninsula and East Africa, with the trend reversing to the north and north-east in spring, in the wake of the northward-moving ITCZ.

2.4.4 SPRING BREEDING AND MOVEMENTS OF SPRING SWARMS (Fig. 2.6c)

In the northern spring, i.e. between March and May-June, the distribution of Desert Locust swarms tends to be more widespread than in all other seasons (see swarm frequency maps for April, May and June). During this period, swarms breed over a belt running from north-western and northern Africa, through Arabia and the Middle East, eastward to Pakistan and extreme north-western India. In the central part of the invasion area this belt extends southward through countries bordering the Red Sea to the Somali Peninsula and East Africa. Over most of the spring belt, breeding takes place on rains associated with the eastward passage of weather systems, but in East Africa and on the Somali Peninsula the rains are also associated with the seasonal northward advance of the Inter-Tropical Convergence Zone.

In some parts of the spring breeding belt, where breeding may start already in winter (and notably in countries bordering the Atlantic, in the Sahara, in the Red Sea coastal areas, in south and south-east Arabia, and on the northern coasts of the Persian Gulf and the Gulf of Oman), swarms may breed in early spring, sometimes continuing with the breeding which had started in winter, and giving rise to progeny fledging in March and April. The earlier of these young swarms may follow the summer and winter swarms in a general northward direction, and even mature and breed within the spring belt during the later stages of spring breeding. But over most of the spring belt the spring generation swarms are formed between late April-May and June-July, and from May onwards they emigrate from the spring belt. The generalised directions of their movements are shown on Fig. 2.6c.

From north-western and northern Africa, swarms move in a general south-westward and southward direction to the countries lying to the south of the Sahara, while from the Arabian Peninsula and the Middle East countries they move southward and south-westward to southern Arabia and African countries bordering the Red Sea, where they may converge with spring (Long Rains) swarms moving into northern Ethiopia and Sudan from the Somali Peninsula (Section 7.14). On occasion, the swarms invading Sudan continue westward far into West Africa (Section 8.15). During the same season, other spring swarms from Arabia and countries to the north, as well as spring swarms produced in Iran, Afghanistan and Pakistan, move south-eastward and eastward towards the summer breeding areas of Pakistan and India. In East Africa and on the Somali Peninsula the initial movements of spring (Long Rains) swarms have a northward bias, with swarms moving towards areas bordering the Gulf of Aden and the Red Sea. As noted above, some continue northward to north Ethiopia and Sudan, while others remain on the northern part of the Somali Peninsula without breeding until the following Short Rains (Sections 7.13 and 7.6). During autumn and winter these swarms, together with summer generation swarms, move southward over the Somali Peninsula and East Africa (see Figs. 2.6a and c) and breed on the Short Rains.

As a result of all these movements, the spring breeding belt becomes clear of swarms, which become concentrated by late July-August into the belt of summer rains and summer breeding (Fig. 2.6a).

2.5 SEASONAL BREEDING AND MOVEMENTS OF RECESSION POPULATIONS

The area in which Desert Locusts are found during recessions, or the recession area (Fig. 2.7a), is more restricted than the invasion area (cf. Fig. 2.1), but is nevertheless very large. It covers nearly 16 million square kilometres and includes all or parts of 30 countries. It also occupies the dry belt of deserts and semi-deserts running west to east through the central part of the invasion area, from the Atlantic shores to north-west India. Latitudinally, it extends over the whole of the drier parts of West and North Africa, from the southern slopes of the Atlas Mountains (though very rarely adults may reach the Mediterranean seaboard in eastern Algeria and Tunisia) and the Mediterranean shores of Libya and Egypt, southward to about latitude 13°N, with the southern limit swinging south in Ethiopia, and reaching 1°N on the Somali Peninsula. In south-west Asia it includes the whole of the Arabian Peninsula north to about 31°N, southern and eastern Iran, the lower-lying areas of Afghanistan and Pakistan north to about 35°N, and north-western India east to about 77°E.

Because recession populations are small, less dense and less conspicuous than plague populations, and fly mostly at night, they are less frequently reported than the latter, and there is, in general, less direct evidence of their seasonal displacements. Nevertheless, all available evidence indicates that the *movements* of recession populations follow the same seasonal trends as those of the plague populations (see Section 2.4), though the range of their movements is often less. This is because, in the northern part of the recession area, low night temperatures inhibit flight by low-density adults between autumn and spring, when northward movements are most likely to occur, whereas in the south and east the limit appears to be set by the greater ecological selectivity of low-density adults, whose responses to their physical environment are not swamped by gregarious behaviour.

Similarly, *breeding* by recession populations occurs over a more restricted area than by the plague swarms, and is almost entirely restricted to areas where the average annual rainfall is less than 200 mm (cf. Fig. 2.7b); much of it, in fact, occurs in areas with an average annual rainfall of less than 100 mm (Waloff 1972). The seasonal distribution of recession hoppers shows less well defined latitudinal zonation than that of plague hopper populations, but still reflecrs the seasonal shifts in breeding, following the seasonal shifts in rains and the movements of adult locusts.

Thus, like the summer breeding of plague swarms (cf. Fig. 2.6a), the main *summer breeding* of recession populations (Fig. 2.7c) takes place on the rains associated with the ITCZ and south-west monsoon in a belt running to the south of the great deserts, from the Atlantic to countries bordering the Red Sea and Gulf of Aden, and then through south-east Arabia to summer breeding areas of Pakistan and India.

Following the summer breeding, young locusts, unless they are retained by late rains within the summer belt, begin to migrate towards the winter and spring breeding areas, moving in general with the same winds and in the same synoptic weather systems as the plague swarms (cf. Chapters 5–8). In West Africa these movements are mainly in a general northward direction (cf. Popov 1965, Waloff 1966); in Sudan and northern Ethiopia they are towards the Red Sea and Gulf of Aden; on the Somali Peninsula the locusts probably move southward; while in India and Pakistan the movement is mainly westward to west Pakistan, Iran and south-eastern Arabia (Rao 1942, 1960).

The *winter breeding* areas of recession populations (Fig. 2.7d) partly overlap with the summer breeding areas in western, central and eastern parts of the recession area, but extend further north into northern Mauritania and Western Sahara, around the Saharan highlands, and along the shores of the Red Sea. Winter breeding may also occur in the coastal areas of Pakistan, in countries bordering the Gulf of Oman, and may be very important in the interior of Oman (cf. Sections 2.7.2 and 2.7.3).

Following the winter breeding, the summer and the young winter generation locusts continue to spread in a general northward direction in West Africa (Popov 1965, Waloff 1966). Around the Red Sea, locusts tend to move further north in the coastal areas, or north-east into the interior and northern part of the Arabian Peninsula, or sometimes east to Iran and Afghanistan (Section 2.6.2.2); similarly they may spread further north and north-east from areas around the Gulf of Oman and south-eastern Iran (cf. Section 2.7.3 and Rao 1942, 1960). As a result of these movements, the *spring breeding* of recession populations (Fig. 2.7e), while often overlapping with the winter breeding, may take place also much further to the north, and in the Western Region may extend into southern Morocco, central and northern Algerian Sahara and western and north-western Libya. In the central part of the recession area it may extend north along both shores of the Red Sea and into central and northern Saudi Arabia, while in the Eastern Region it may extend far to the north in Pakistan, Afghanistan, and probably eastern Iran.

After the completion of spring breeding and the fledging of spring adults, recession populations tend, like plague swarms, to move downwind towards the ITCZ in the Western and Central Regions, and towards the area of monsoon rains in Pakistan and north-west India, and become concentrated by August-September, mainly within the summer breeding belt (Popov 1965, Waloff 1966, Rao 1942, 1960).

2.6 OUTBREAKS

2.6.1 THE NATURE OF OUTBREAKS

In this and the following Section we consider the process by which recessions may be transformed into plagues. First, it is necessary to define some terms.

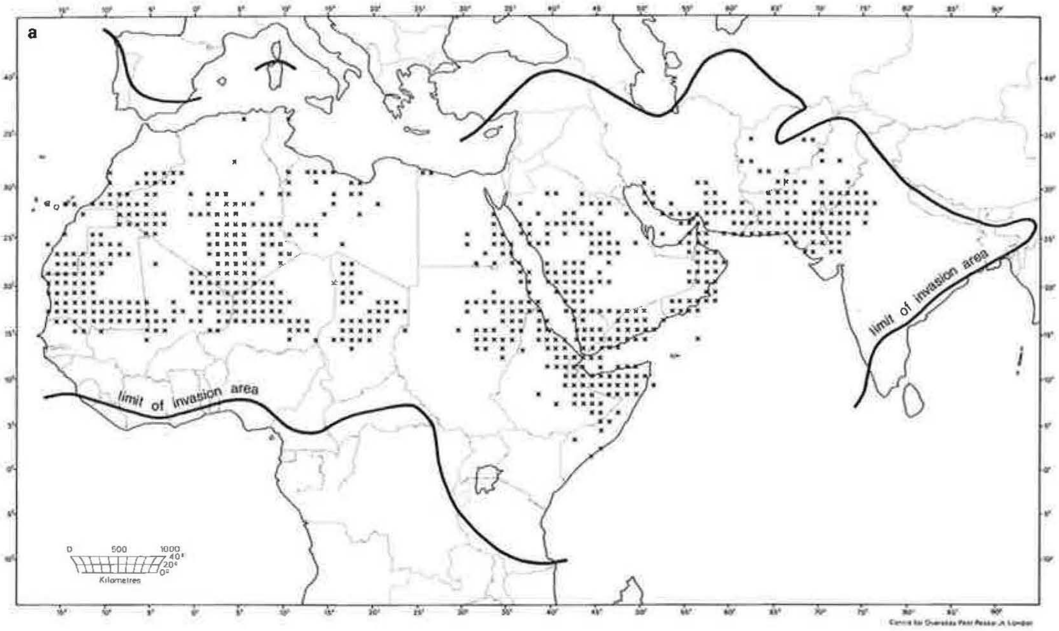
An OUTBREAK is a marked increase in the numbers of locusts as a result of *concentration, multiplication* and *gregarisation* (Section 2.2), leading, unless checked, to the formation of hopper bands and swarms.

CONCENTRATION is an increase in population *density* as a result of convergent movement by hoppers and adults due to their independent reactions to external environmental factors (Kennedy 1939). Concentration on two scales has been recognised (Roffey & Popov 1968): (a) on the *large scale*, for example, when flying adults are assembled from a larger into a smaller area by convergent airflow (Rainey 1951), or when non-swarming night-flying adults settle selectively in patches of green vegetation (Roffey & Popov 1968); (b) on the *small scale*, when locusts that have been concentrated on a large scale move into preferred micro-habitats, for example, to bask, feed or lay (Roffey & Popov 1968).

MULTIPLICATION is an increase in *numbers* as a result of breeding (Waloff 1966). Since a female Desert Locust lays 50–160 eggs per egg pod and usually two or three egg pods, the period of breeding is always potentially one of multiplication. Whether or not there is an actual increase in numbers from one stage in the life cycle in one generation to the same stage in the next generation depends upon how many die.

GREGARISATION is an acquisition of behavioural and other characteristics of the *gregarious phase* (Section 2.2). Examples of the gregarisation processes are described in Section 2.6. The most important feature of gregarisation is the formation of *bands* of hoppers and *swarms* of adults, which remain cohesive even when on the move. Sometimes gregarisation is only partial and may be followed by dissociation in either the hopper or the adult stages.

Outbreaks occur over a wide range of areas, from less than a hectare to tens of thousands of square kilometres, and over one or more generations. The significance of an outbreak is likewise very variable: it depends on the number of locusts initially involved, and on the success of their breeding. The sites where gregarisation has been observed or deduced between 1926 and 1976 are shown on Fig. 2.8. Though these sites are widely distributed over



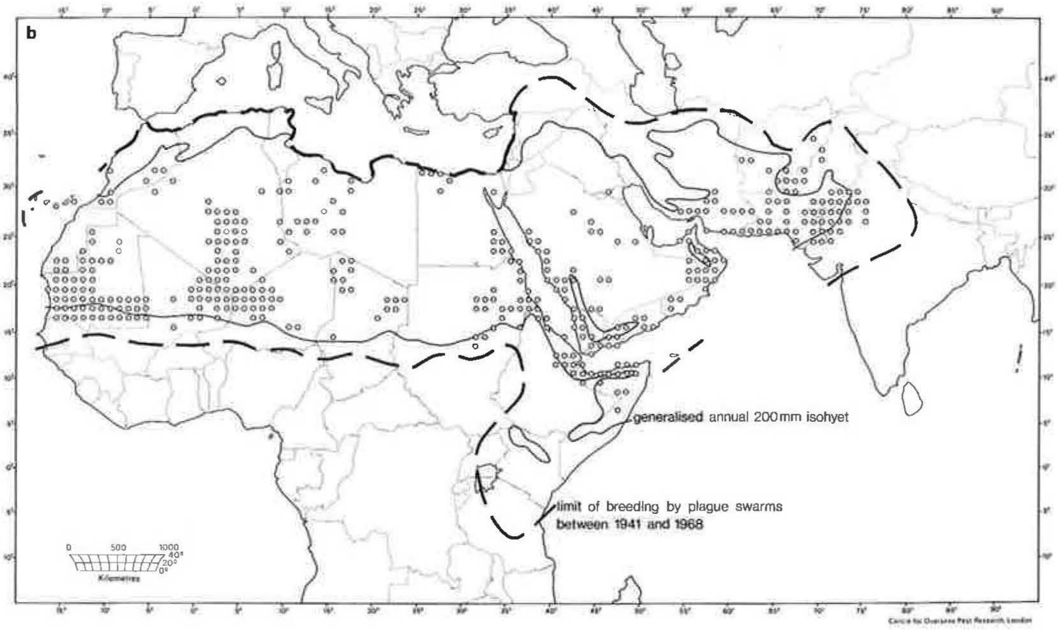


Fig. 2.7 Occurrence of the Desert Locust during recessions.

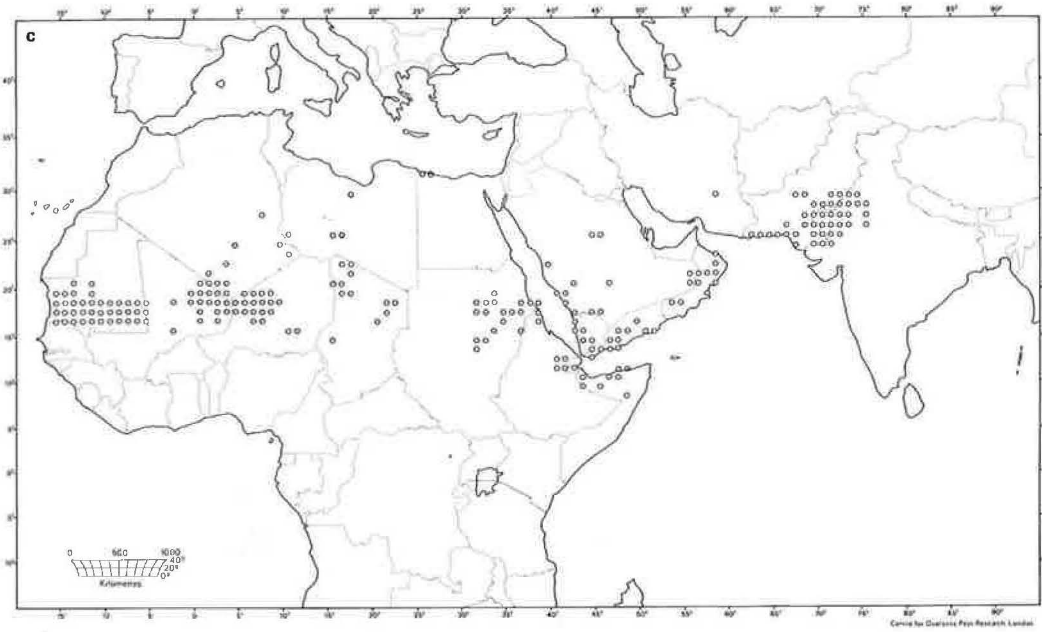
a Adults. Degree squares where adults have been recorded during recession periods from July 1963 to December 1967, and from 1969 to 1976.

b Hoppers. Degree squares where hoppers have been recorded during recession periods from 1920 to 1948 (after Waloff 1966), and from 1963 to 1976.

c Summer generation hoppers. Degree squares where hoppers have been recorded from July to October (July to September on the Somali Peninsula) during recession periods from 1920 to 1948 (after Waloff 1966), and from 1963 to 1976.

d Winter generation hoppers. Degree squares where hoppers have been recorded from November to January (October to January on the Somali Peninsula) during recession periods from 1920 to 1948 (after Waloff 1966), and from 1963 to 1976.

e Spring generation hoppers. Degree squares where hoppers have been recorded from February to June during recession periods from 1920 to 1948 (after Waloff 1966), and from 1963 to 1976.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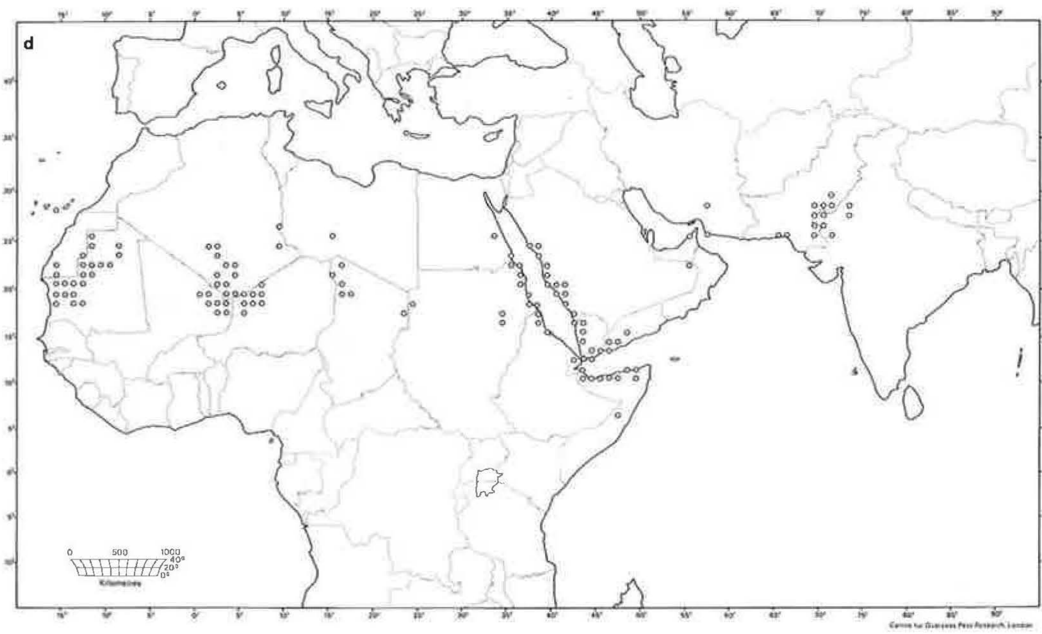
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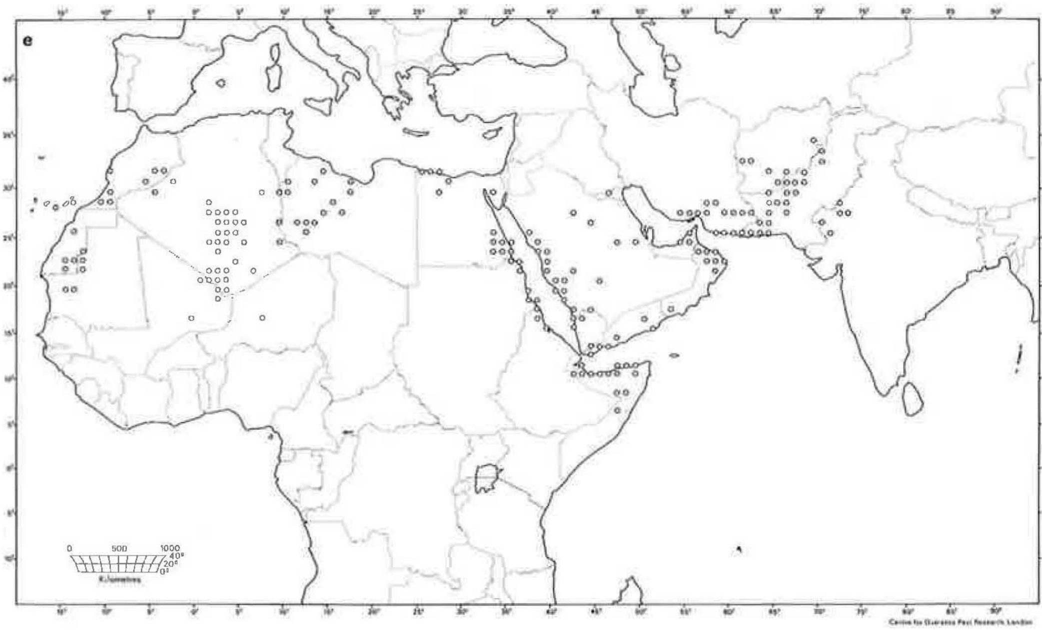
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the recession area, the map suggests that outbreaks occur most frequently: (a) on the borders of highland areas in desert regions (e.g., the margins of central Saharan highlands, the southern borders of the Atlas Mountains, Tamesna, the western borders of the Oman mountains, the valleys of Mekran), where run-off can provide favourable breeding sites (Popov 1965); (b) in the Indo-Pakistan summer breeding areas, with their complex mesoscale convergence systems (see Rao 1942, Cochemé 1966a); (c) in the Red Sea and Gulf of Aden basin, with its complex rainfall regime (Waloff 1972a).

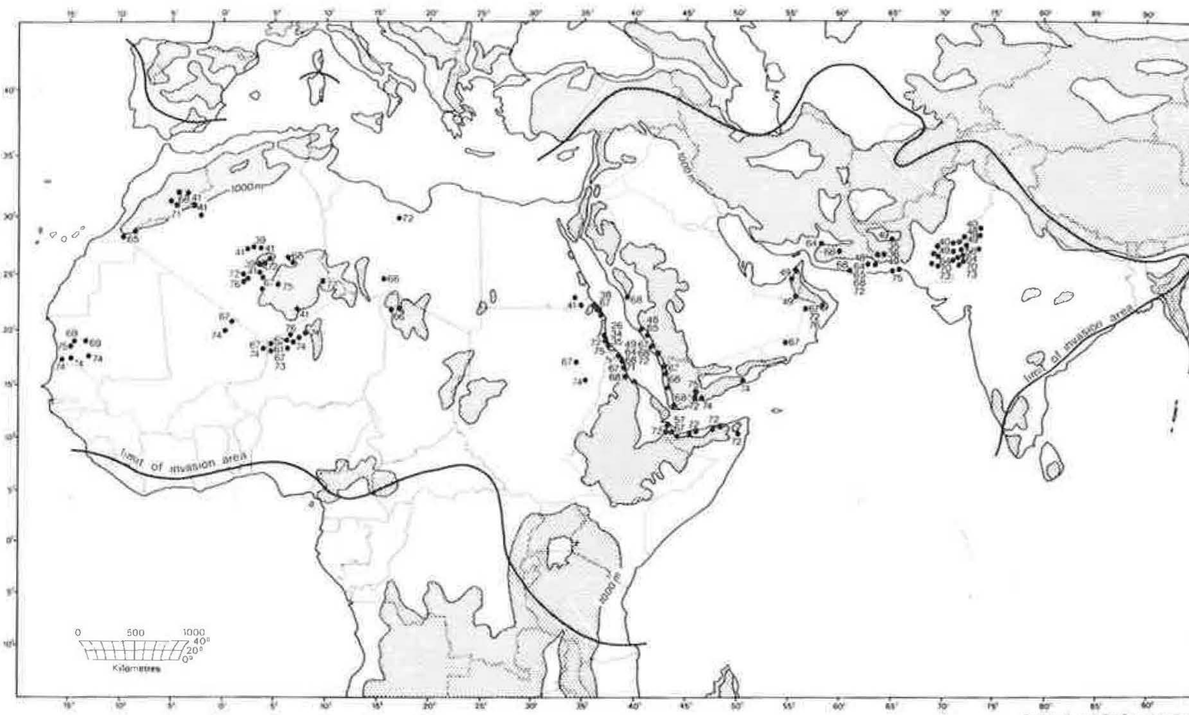


Fig. 2.8 Sites of observed or deduced gregarisation, 1926 – 1976)modified after Waloff 1972).

Small-scale outbreaks have been recorded frequently; large-scale outbreaks, resulting in the production of numerous hopper bands and swarms, less frequently. When outbreaks occur over large areas and over several successive generations they may lead to plagues (Section 2.7).

Although no two outbreaks are identical, there are a number of recurrent aspects which are common to many.

- *Rainfall* adequate to allow prolonged breeding and building up of large locust numbers. Whereas a single fall of approximately 20 mm of rain is sufficient to initiate breeding (Magor 1962, and Section 4.6.1), large amounts, and falling over periods of months, are usually associated with outbreaks, because they can lead to two or more successive generations.
- Environmental features that lead to an initial concentration of adults on the *large scale*. These include:

  convergent wind systems that concentrate flying locusts, development of localised areas of green vegetation in which overflying locusts selectively settle (such green areas may develop, for example, on higher ground receiving more rainfall than the surrounding lowlands, or along the wadis draining from such highlands, or when rains fall over localised plains with a characteristic moisture-retaining soil structure (Section 2.6.2.1)).
- Environmental features leading to concentration of locusts on the *small scale*. The most important of these are habitats with patchy vegetation communities, consisting of perennial bushes and herbs (usually below a metre in height), and annual grasses and herbs. These together form the *food* and the *shelter* habitat of the locusts. Such plant communities include areas of bare ground which form *egg-laying (oviposition)* habitats (Popov 1965). The differential drying out of vegetation leads to the concentration of, and formation into groups of, hoppers or adults (Section 2.6.2.1), and the drying out of the soil (Section 2.6.2.3) leads to formation of groups on the more humid sites (Section 2.6.2.1). In contrast to the patchy vegetation communities, in the uniform habitats (e.g., *Panicum* steppes) locust populations tend to be diffuse.
- Locust populations characteristic of outbreaks.

  There are individuals of all stages: eggs, all nymphal instars, immature adults and mature adults, i.e. there are overlapping generations. This happens because the immigrant adults, which may come from several different sources, arrive and lay at different times.

Young hoppers in the early stages of an outbreak are characteristically green, but in the later instars they develop black markings, and groups form as the vegetation dries out differentially.

If the early breeding has been successful, sufficient adults may be produced to form swarms when they mature and lay.

In any second generation, the locusts are typically more gregarious than those in the first and, if there are sufficiently large numbers present, hopper bands and swarms may form.

2.6.2 SOME EXAMPLES OF OUTBREAKS

The following two examples have been selected to illustrate some of the main features of outbreaks.

2.6.2.1 The 1967 outbreak in Tamesna of Niger and Mali

Between September and November 1967 an outbreak occurred in the Tamesna area of Niger and Mali Republics (Figs. 2.9 and 2.10) and provided exceptionally favourable opportunities to study the processes by which gregarious populations may be produced by the progeny of individuals initially occurring at low densities. (For a fuller account see Roffey & Popov 1968.)

Tamesna is a vast plain lying between the massifs of Adrar des Iforas, Ahaggar and Aïr, and has been formed as a result of clay deposits accumulating in drainage channels from these massifs. Considerable quantities of sand are also present, partly as dunes but partly as constituents of characteristic soils consisting of clay with deep cracks which become filled with loose, wind-blown sand. Rain water is rapidly taken up by the sand but only slowly percolates into the clay blocks, where it is retained much longer than in the sand. The development of communities of *Tribulus, Schouwia* and other plants which form the most important locust habitats, is associated with these soils.

Following unusually heavy rain in August 1967, when 123 mm were recorded at the OCLALAV base at In Abangharit (18°N 6°E) (which may be compared with its suggested mean annual rainfall of about 60 mm — Popov 1968), increasing numbers of solitariform adults, migrating as isolated individuals at night, arrived in Tamesna during September and early October. Most of these probably originated in the Sahelian zone some 100 – 300 kilometres to the south, where there had been good earlier rains and breeding started in July. In addition, there was a small number of the adults which reached Tamesna in July, having originated in central Algeria, where another outbreak had occurred between March and June (Fig. 2.10).

Daytime observations on the distribution of adults showed that practically all were confined to patches of green annual vegetation, particularly *Tribulus* and *Schouwia*, which were located and mapped from the air in early September and which together occupied less than 10% of the study area (Fig. 2.9). In early September, 89% of adult locusts were recorded in *Tribulus* and *Schouwia* habitats, which constituted only 21.7% of a 493 kilometre survey route, and only 4.4% were found in dry areas that had not received sufficient rain to allow annual vegetation to germinate, and which represented 65% of the route. This distribution suggested strongly that locusts flying at night were selectively settling in areas of *Tribulus* and *Schouwia*. From vehicle and foot traverses it was estimated that there were probably 100,000 – 200,000 adults in Tamesna at this time. Since the total area within which the studies were made was about 2,500,000 hectares, the average density of adults was about 0.04 – 0.08 a hectare. But within green areas, adult densities were up to 210 a hectare, so that concentration on the larger scale due to selective settling by the immigrant adults resulted in densities being some thousands of times greater than the average density in the area studied. By early October, further waves of immigrants had arrived and the total number of adults in Tamesna was estimated to have been some 8,000,000, and adult densities locally reached 1,800 a hectare.

As the adults moved slowly across Tamesna they concentrated in the *Tribulus* and *Schouwia* habitats, which provided food and shelter, and induced very rapid sexual maturation. This was marked by development of yellow colouration and by short rapid daytime flights, pouncing and crawling as the sexes sought one another, and the females searched for laying sites. By mid October, when most laying was observed, the upper soil had dried to a depth of 12 – 15 cm over most of the area and was therefore unsuitable for laying (Popov 1958a), but in restricted sites, where the soil was still moist to within 10 cm of the surface, females concentrated to lay. An example of the selectivity of females during egg laying was seem at Mbikas (Fig. 2.9), where the average depth at which the soil was moist was 10 cm. In the late afternoon a vehicle was driven through the site and by 21.30 hours groups of up to 29 females were found laying eggs in its tracks, which were some 3 – 4 cm deep and below which moist soil was present within 6 – 7 cm of the surface. Other observations at Mbikas revealed the presence of groups of egg pods as large and as dense as those typical of gregarious locusts (up to 71 in 0.09 square metre). Unlike the synchronised egg deposits laid by gregarious locusts, however, they comprised eggs ranging from those just laid to those ready to hatch. Movements within the favourable habitats, representing concentration on the smaller scale and culminating in the formation of laying groups, therefore resulted in adults being concentrated by a factor of approximately four million from the average density throughout the whole of Tamesna.

The observations at Mbikas emphasised the importance of prolonged availability of soil water, allowing successive waves of females to lay and the eggs to incubate successfully. It has been usual to consider that this is provided by prolonged rainfall but it is clear that some soils can retain sufficient moisture and remain suitable for breeding at least two months after heavy but not prolonged rainfall.

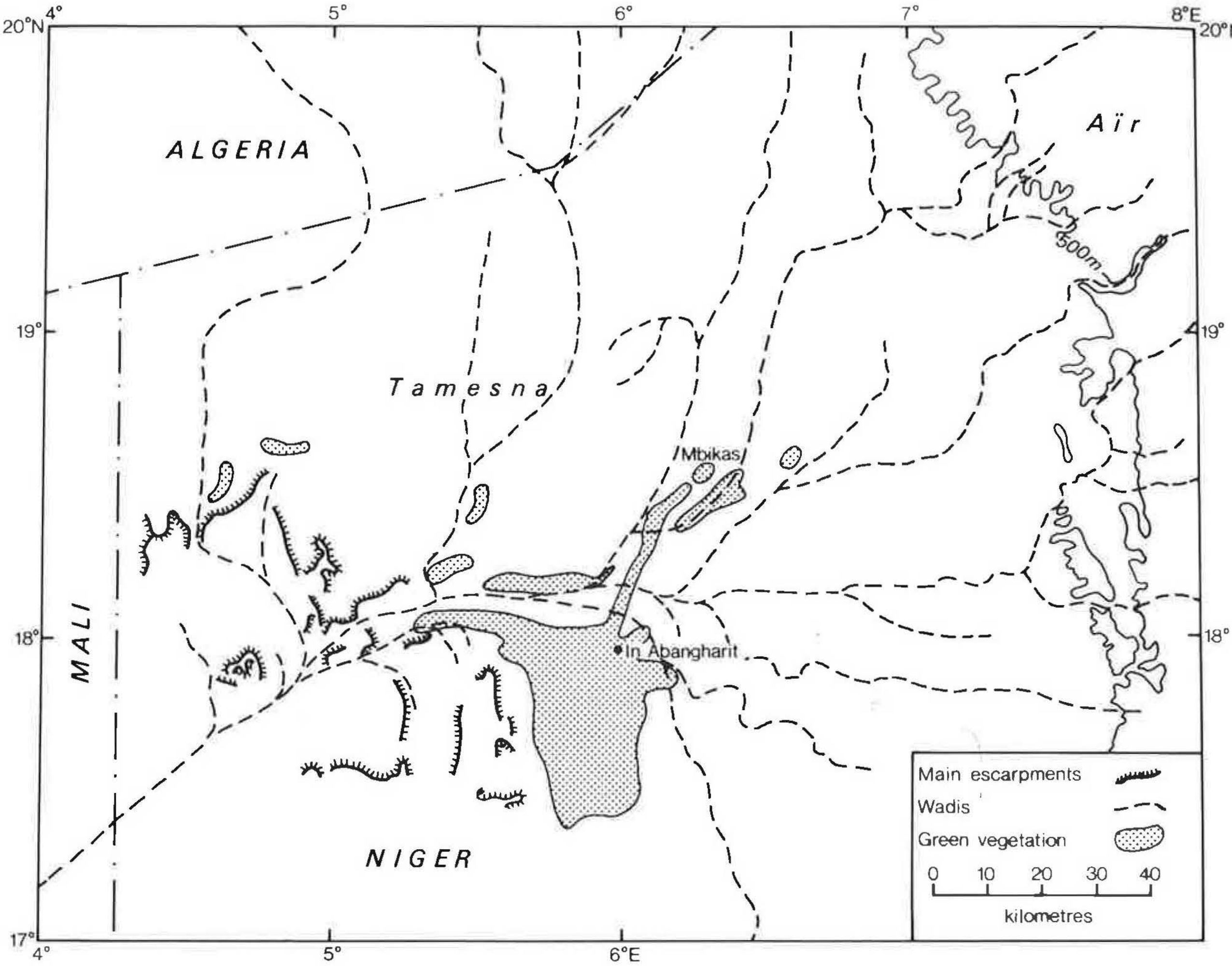


Fig. 2.9 The main habitats of the 1967 outbreak in Tamesna, Niger.

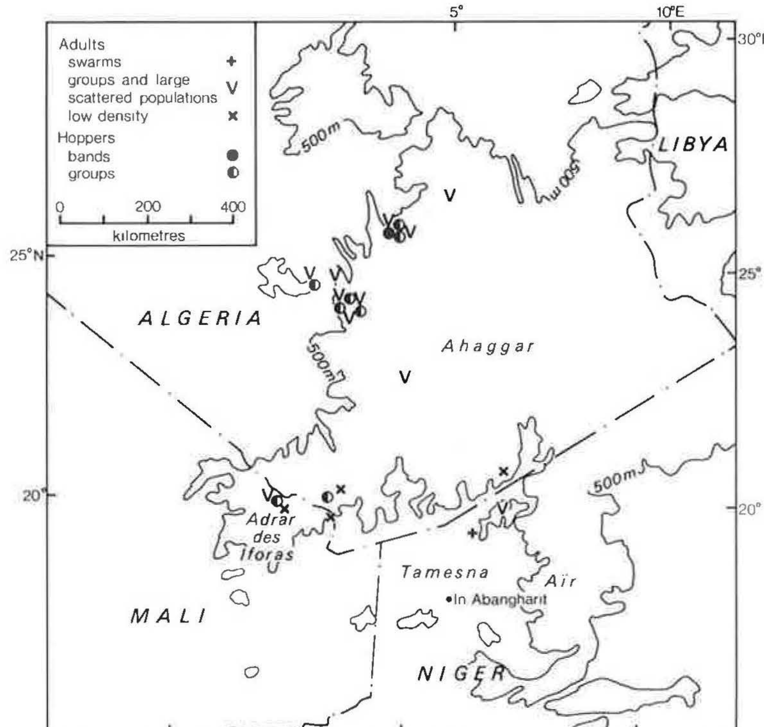


Fig. 2.10 The main Desert Locust populations in West Africa, March to August 1967.

Inspection of individual egg pods showed that the average number of eggs in a pod was 133 (range 107 – 158). Dissection of females showed that the great majority laid two egg pods, and most laid three; some very old females appeared to have laid four or five times. Assuming that all females laid an average of three egg pods, each would have laid about 400 eggs. Since there were about the same number of males and females, repeated laying by females resulted in a potential multiplication of about 200 times in a single generation. Among the several hundred egg pods examined there was no parasitisation nor predation. This contrasts with the often considerable mortality experienced by eggs laid by swarms, which may reach 90% (Greathead 1966).

Hatching started in August and continued until late October so that hoppers of all instars were present throughout the study period. Hatching occurred first in the south and later in the north, corresponding to the northward movement of adults produced in the Sahel across Tamesna. At first there were only one or two hoppers per plant, but as hatching continued their numbers and density increased rapidly. In most sites, first instar hoppers at low and moderate densities (up to about 20 in a square metre) were of the green extreme colour type (Stower 1959), but at Mbikas, where the densest laying occurred, a proportion were of the black extreme colour type. In areas where hopper densities remained low the hoppers retained their solitarious colouration and behaviour, but in most areas, as densities rose, they developed the black markings which are characteristic of congregating hoppers, and they changed behaviour towards that of the gregarious phase. Detailed observations showed that the first signs of behaviour change occurred when the densities of hoppers increased and they started to encounter one another more and more frequently as they changed their positions on plants in response to the continually changing micro-environment, and in order to feed. At first the hoppers reacted to one another by moving apart, but later they tolerated, and eventually became mutally attracted to, one another. Later, small roosting, feeding and basking groups were formed and, as densities rose due to further hatching and the vegetation started to dry out, these groups became larger and denser, and the hoppers became much more active, and started to march for short distances, particularly when they were disturbed. In Tamesna, large herds of camels were feeding on the preferred food plants of hoppers, and they further promoted gregarisation by disturbing the hoppers and by reducing the extent of the food and shelter habitats. Eventually, marching bands formed in open habitats, but in the denser habitats the amount of vegetation delayed the development of fully gregarious hopper behaviour. In Tamesna of Niger, the introduction of chemical control prevented the formation of day-flying swarms, but three such swarmlets were produced in Mali.

Even though hopper development was greatly favoured, there was very high mortality, which could not be accounted for by predators (mainly birds). Estimates of the total hopper population in late October, when its median age was fourth instar, suggested that there were about 80 million individuals in Tamesna of Niger. These were the progeny of some 8 million adults, which were estimated to have laid some 1,600 million eggs, most of which probably hatched successfully. Mortality between hatching and the fourth instar was therefore about 95%, and the multiplication rate from immigrant parent adults to fourth instar in the next generation was about ten times.

The main features of this outbreak were as follows.

- Widespread and heavy rainfall, leading to the formation of very favourable but restricted egg-laying sites, and to the development of patches of green vegetation that provided food and shelter for the hoppers.
- Concentration of waves of immigrant adults in restricted laying sites, resulting in the formation of groups of laying females.
- Very high adult fecundity resulting in a high potential rate of multiplication.
- Adequate soil moisture and almost complete absence of egg parasites and predators, resulting in very successful egg development.
- Luxuriant vegetation, later drying out and promoting gregarisation, manifested by the formation of groups of hoppers and the development of black markings on the hoppers.
- Prolonged hatching, with younger hoppers augmenting older, gregarising ones.
- The presence of large herds of camels, progressively eating out some of the main food plants and repeatedly disturbing the hoppers, thus further promoting gregarious behaviour.

2.6.2.2 The 1973 outbreak in India and Pakistan

Another example of the production of gregarious populations from previously solitary living individuals occurred in the summer breeding area of India and Pakistan between July and November 1973. The parent (F_0) generation comprised individuals from three sources.

- Small numbers of adults which had overwintered in Rajasthan and adjacent areas of Pakistan following monsoon breeding in 1972.
- Larger numbers of immigrants from the west, arriving at low densities in April and May (Fig. 2.11a). These almost certainly originated in Red Sea coastal areas of Arabia, where an earlier gregarising outbreak with hopper bands occurred between November 1972 and March 1973. Some of the adults reached Afghanistan by mid April, and others reached Rajasthan, where maximum reported densities rose from 50 a square kilometre in April to 1,275 in May (Fig. 2.11b).

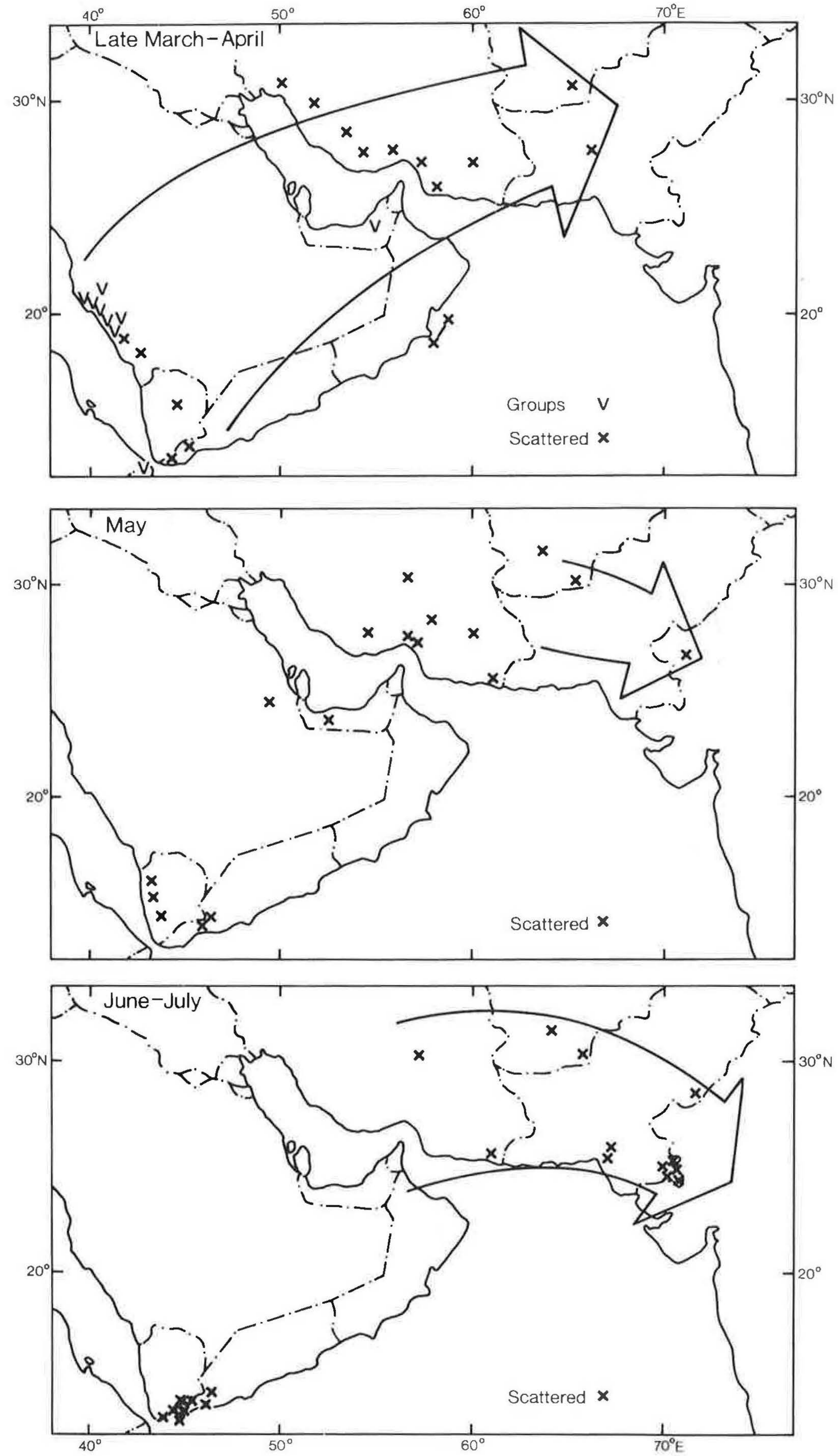


Fig. 2.11 Movement of the Desert Locust into India and Pakistan, March–July 1973.

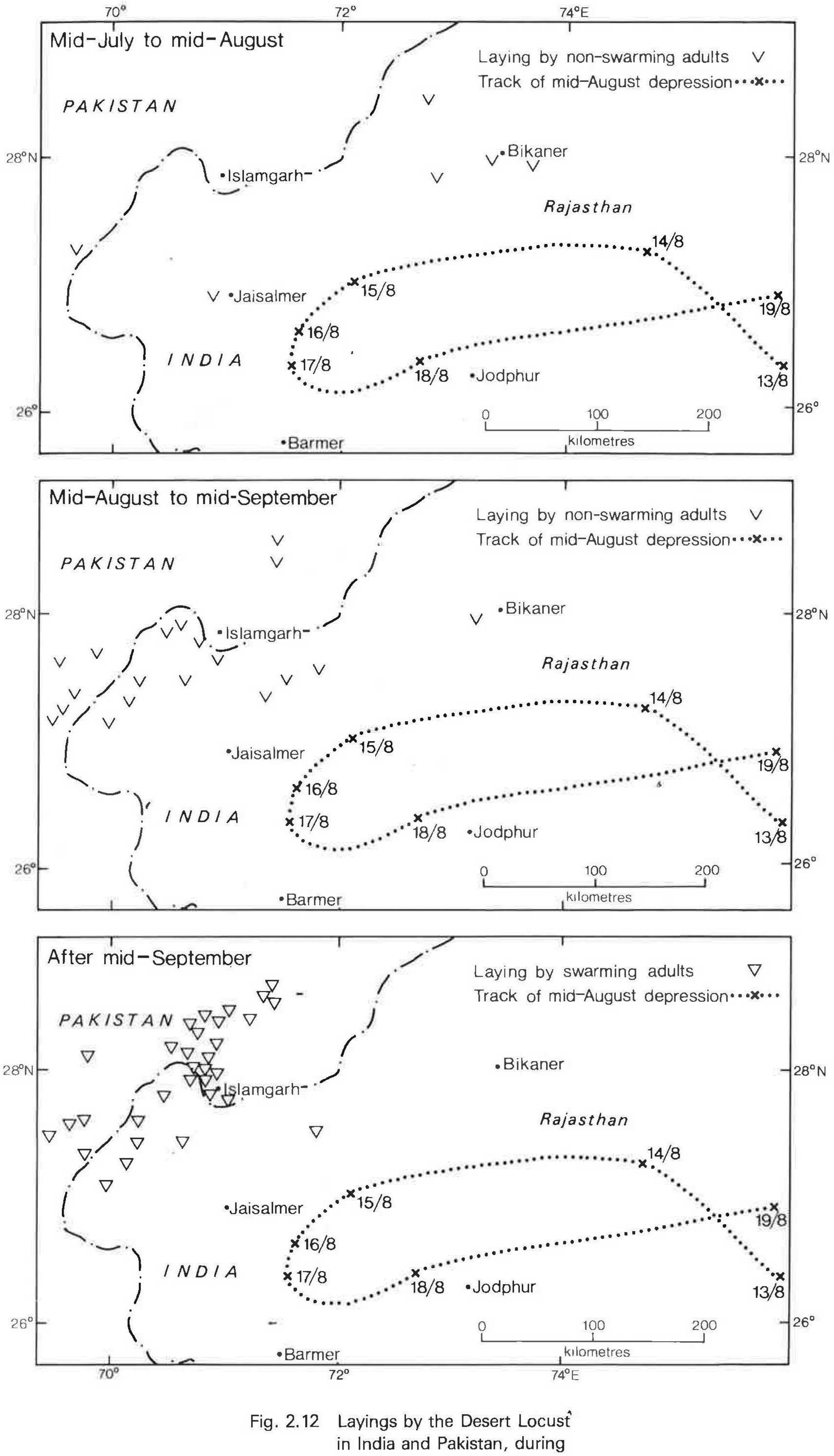


Fig. 2.12 Layings by the Desert Locust in India and Pakistan, during the 1973 monsoon.

- Further low-density immigrants arriving in July and August from Iran and Afghanistan, where widely spread low-density breeding occurred between April and July (Fig. 2.11c).

Following the first widespread monsoon rainfall in north-west Rajasthan between 3 and 6 July, and heavy rain in Karachi district in the first half of July, adults started to lay at low densities in Bikaner district (28°N 73°E) on about 8 July, and in Las Bela district (26°N 66°E) on about 19 July (Fig. 2.12a). The emergent (F_1 generation) hoppers were at low densities, were green in colour, and were estimated to have started to fledge in mid August.

Judging by subsequent events, larger numbers of low-density adults than were reported at the time must have started to lay on both sides of the Indo-Pakistan border north and west of Jaisalmer (27°N 71°E) in the first week of August. There were some reports of early instar hoppers at low densities in late August from localities close to unsurveyed border areas, and it is probable that laying on a considerably larger scale also occurred simultaneously in the unsurveyed areas in view of the sudden and unexpected appearance of immature and mature swarms in the border area near Islamgarh (28°N 71°E) in late September.

Between 13 and 19 August, a slow-moving depression (see Section 3.3.2.3) gave very heavy rainfall over west Rajasthan, with daily totals of over 200 mm being recorded at Jaisalmer on 16 August, and at Barmer (26°N 71°E) on 18 August. Renewed laying by surviving F_0 adults, augmented by late arrivals from the west and by rapidly maturing early F_1 adults, started on about 23 August and continued until at least 10 September. The main layings were in areas some 50 – 200 km north and west of the track of the depression (Fig. 2.12b and c). These produced numerous hopper bands of mixed instars (indicating successive layings), and immature swarms from mid October.

The first reports of swarms, however, during this outbreak referred to ones copulating and laying near Islamgarh in late September, some 100 – 200 km north of the track of the depression. Their origin and mode of formation were not recorded, but it seems most probable that they consisted of F_1 generation adults which became concentrated and formed groups as they laid (see Section 2.3; although, in the case of the one immature swarm, gregarisation probably occurred in the hopper stage). Successive layings over two months by these swarms and by the numerous scattered adults, following the heavy rainfall of mid August, resulted in the formation of some 3,000 hopper bands within an infested area of about 20,000 square kilometres. Despite intensive ground and aerial control operations, numerous swarms were produced in November.

The main features of this outbreak were as follows.

- The multiple source areas of the immigrant adult populations.
- The very low densities at which both adults and hoppers were reported in the early stage of the outbreak.
- Almost undetected breeding in the first generation in border areas normally difficult of access, resulting in the production of sufficiently large numbers of adults to form some swarms on maturation.
- Heavy rainfall, associated with a slow-moving depression, in mid August in areas close to or encompassing those where first-generation hoppers were present. These rains provided moist soil favouring two months of laying and egg development, and abundant vegetation favouring three months of hopper development.
- Concentration of first-generation adults and the formation of groups of laying adults close to the areas which received heavy rain in mid August.
- Very successful breeding in the second generation, which resulted in the production of thousands of hopper bands and numerous swarms, some of which, despite intensive control operations, persisted as swarms to breed again in the spring of 1974.

2.6.2.3 Some other outbreaks

Other outbreaks which have been described include the following.

Western Region

Algeria 1939. In the 1938–39 season, abundant rains fell over most of the central Sahara, and benefitted in particular the Ahnet and Mouydir uplands and the Tademait plateau. The wadis in the Botha basin, which drain Mouydir, were heavily flooded in early November 1938 and again in early March 1939. In early May, numerous adult desert locusts were seen on the northern borders of Mouydir. In late May and early June, M.A. and M.T. Volkonsky found mature, copulating and laying adults, some in groups of up to 250 locusts a square metre, solitaricolor and transiticolor hoppers of all instars, and newly fledged solitaricolor adults over an area of 60 square kilometres in Wadi Botha (27°N 3°E). By 9 June, the average density of young adults was estimated at 3 – 5 a square metre; some adults were concentrating into groups of 50 – 300 individuals, and two flying swarms were reported on 10 and 13 June. Hatching continued until mid June, the hoppers being gregaricolor and forming marching bands (Volkonsky & Volkonsky 1939). Waloff (1966) considered that breeding might have been in progress in the central Sahara ever since the heavy November rain, and that the populations seen in May and June represented overlapping generations.

North-Central Region

Sudan 1926. Following exceptionally heavy rains in November and December 1925 on the Red Sea coast of Sudan, moderate concentrations of laying adults were found between Port Sudan (20°N 37°E) and Tokar (18°N 38°E) in late February 1926. These comprised individuals which exhibited a wide range of morphometrics and their progeny consisted of gregarious hopper bands (Johnston 1926). Johnston considered that the gregarious individuals had arisen as a result of breeding and gregarisation among the original solitarious population. Although few details of this outbreak are recorded it is included because it appears to be the first recorded case of phase transformation in the Desert Locust.

Egypt 1941. Exceptional rains fell in the south-eastern desert of Egypt in December 1940 and January 1941. On a survey in April 1941, hoppers were found at varying densities in almost all wadis between Aswan (24°N 33°E), Abraq (23°N 35°E), Wadi Hammid (24°N 35°E) and Kom Ombo (24°N 33°E). Densities were highest in those wadis which received run-off from neighbouring hillocks and supported rich perennial vegetation. The early instars were solitarious, but phase transformation occurred in the later instars as the vegetation dried out at different rates in hot dry winds, and the older hoppers concentrated in the shelter of the greener vegetation (Hussein 1941).

Saudi Arabia 1948. Very heavy and widespread rains fell on the Tihamah between Lith (20°N 40°E) and Hali (19°N 41°E) in late November 1947. There were further showers over the area between December and February 1948, and more showers fell in the Wadi Doga (20°N 41°E) and Wadi Qanuna (19°N 41°E) areas in April. In mid March, low-density solitariform adults and some hoppers were found at several localities between Lith and Hali. By the end of March the vegetation was drying out and older-instar hoppers were concentrating in stands of green *Heliotropium*. All first- and second-instar hoppers were green, but the older stages were showing a progressively increasing black pattern and about 25% of the older hoppers were typically gregarious in colour. As the vegetation dried out the hoppers became more concentrated in the remaining green vegetation, and eventually a marching band and several swarmlets and loose swarms were formed (Popov 1948).

Eritrea 1949. Good rains fell on the Eritrean coast north of 17°N in November 1948 and February 1949, and continued in the Karora (18°N 38°E) area in March. The parent adults were solitariform and at low densities but they gradually increased in number, possibly due to selective settling by individuals leaving habitats further south, which were then drying out. The early breeding was not observed, but in an area of unweeded *Pennisetum* cultivations incipient band formation was observed in mid March. Hatching continued until mid April and all the first-instar hoppers were green. Late instars acquired increasingly transient-to-gregarious colouration and started to march, eventually forming a large moving population some 20 km wide and 6 km deep, in which the density of the older hoppers varied from 0.1 to 25 a square metre. This population constitutes one of the largest initially solitarious hopper populations ever assessed; it was estimated that there were about 200 million individuals in an area of 21 square kilometres (Stower 1959, Stower, Davies & Jones 1960).

Eastern Region

Pakistan 1935. Copious rain fell in coastal Baluchistan and Iran and there was moderate rain in the interior of Mekran in April and May. Solitarious hoppers were observed in coastal areas in March — May, and fledglings were produced from the first week in April. These adults apparently migrated inland, for in May — July uncontrolled hopper bands were found in interior Mekran in three areas. Rao (1937) considered that these hoppers had been produced by adults which became concentrated on restricted laying sites such as mounds of blown silt at the bases of rocky hills, in sandy beds of hill streams, and in patches of *Sorghum*.

India 1949. Between May and July 1949, estimated maximum adult densities rose from 300 to 7,400 a square kilo metre in Rajasthan. Good rains fell at the end of May and in the first half of June and gave rise to luxuriant growth of the grasses *Cenchrus biflorus* and *Andropogon halepense* in flat gravelly areas. By contrast, the irregular sandy dunes were almost devoid of vegetation. As the immigrant adults matured they moved from the flat gravelly areas to the dunes and laid. The hoppers on hatching were solitaricolor, but when they moved down from the dunes into adjacent cultivations they formed groups and developed gregarious colouration. The fledglings, which began to appear in late July, were pink and mostly gregariform (Singh 1952, Waloff 1966).

India 1956. 1956 was a year of regional recession in the Eastern Region and only low-density populations migrated from the west into the summer breeding area of Pakistan and India. Between 27 and 29 June there was an influx of low-density adults into the Suratgarh (28°N 76°E) area of Sri Ganganagar district of Rajasthan, at a time when there was well-marked low-level convergence of winds (see Section 4.11.2) over Ganganagar, and there were appreciable falls of rain (Suratgarh recording 31 mm on 30 June). When the area was visited in mid August, large numbers of hoppers were present. The young hoppers were green whereas the older instars were green, pale green or orange. The adult progeny included both grey and pink individuals, which were solitariform and transitiform morphometrically. G.N. Bhatia (1961) suggested that the parent adults had first been concentrated by convergent airflow in the area of rainfall and then matured, and that crowding of the subsequent hoppers resulted in partial phase transformation.

2.7 PLAGUES: THEIR UPSURGES AND EXPANSIONS

2.7.1 INTRODUCTORY REMARKS

Both plagues and recessions of the Desert Locust can be considered in relation to the whole invasion area, or to each of its four major Regions (Fig. 2.4). Once a plague starts in one or in two adjoining Regions it may expand within the first year to other parts of the Desert Locust area (Section 2.7.4) and become a major plague. Similarly, recessions which affect most or all of the Desert Locust area are designated major recessions.

From available historical data it is known that all the major plagues back to 1890 have affected all four major Regions, and have almost certainly done so before then (Waloff 1976). Fig. 2.3 illustrates the distribution in time of the major plagues back to 1860, and shows that since then there have been seven, lasting from seven to possibly 22 years, and an eighth brief plague which developed in 1967 – 68 and declined in 1969. After that year and to date there have been no major plagues.

A PLAGUE UPSURGE can be defined as a period, following a recession, marked by a very large increase in locust numbers and increased gregariousness in many populations, leading to the production of unbroken sequences of hopper bands and swarms that occupy an expanding area. Examination of the intervals between successive major plagues has provided no evidence of any regular periodicity in plague upsurges. Similarly, the intervals between successive *regional* plagues were found to fluctuate irregularly in all the Regions (Waloff 1976).

This Section deals with the two last and best documented plague upsurges and expansions, and with conditions which brought them about. It also reviews briefly the available data on these aspects of earlier plagues.

2.7.2 THE 1949 PLAGUE UPSURGE AND THE SPREAD OF THE PLAGUE

The following account is largely based on data summarised in Waloff (1966).

Synopsis

The early stages of the 1949 upsurge were associated with heavy and widespread rains brought to south-eastern Arabia in October 1948 by a cyclone from the Arabian Sea, followed by further heavy rains there in December 1948 and March 1949. Breeding which developed in interior Oman during the winter of 1948 – 49 led to the appearance in the United Arab Emirates of large scattered populations and some swarms in February — March 1949. Further breeding by these locusts in the Emirates led to the appearance of more swarms in May.

During the same spring, some concentrated breeding occurred in western Pakistan and possibly Iran, but the formation of swarms there was prevented by control. Elsewhere in the Desert Locust area, the Western and the South-Central Regions were clear, but a small local outbreak occurred on the western Red Sea Coast at the Ethiopia — Sudan border, giving rise to a few swarmlets which apparently dispersed.

From south-eastern Arabia, the locusts moved out both to the south-west and to the east. Emigrants to the south-west bred in south-western Arabia in May — June, and swarms of their progeny appeared in July but disappeared after September. Emigrants to the east reached the summer breeding areas in Pakistan and India in scattered formation from May to July, and greatly augmented the populations moving there from the spring breeding areas of Iran and Pakistan.

Important summer breeding developed in 1949 in Pakistan and India, where monsoon rains were protracted. There were two to three successive generations, and numerous swarms were formed between September and December. Some of these remained in the Eastern Region, where their progeny continued the plague in the following year. Many moved out in November — December to south-eastern Arabia, from where some spread to south-western and western Arabia (thus reviving the plague in the North-Central Region), while others spread to the South-Central Region by crossing the Gulf of Aden to the Somali Peninsula. The immigrants bred in early 1950 on the northern coastal areas of the Somali Republic, with the breeding becoming more widespread on the peninsula in April — May. New swarms were formed between April and July, and some of them moved out, in May — June, northward to northern Ethiopia and Sudan.

Other immigrant swarms bred in early 1950 in the Peoples Democratic Republic of Yemen (P.D.R. Yemen), Yemen Arab Republic and the Tihamah of Saudi Arabia. The first spring swarms formed in March — April, when breeding spread into central and north-western Saudi Arabia. Many swarms were formed in May — June, and these moved out, crossing the Red Sea to Sudan and northern Ethiopia, where they converged with swarms arriving from the Somali Peninsula. In Sudan, the swarms moved west across the country, and some of them spread into eastern Chad. Numerous further swarms were produced during the summer of 1950 through breeding by these swarms in Sudan and Chad, and in October there was a westward emigration from these countries that carried the plague far and wide over the Western Region.

Situation in 1948

It was during this year that the 1940–48 plague finally came to an end, giving way to a brief recession terminated by the plague upsurge in 1949.

In the Western Region, the 1948 spring breeding was restricted to two limited areas in, respectively, Morocco and the Fezzan in Libya. In Libya, the hoppers were said to have perished 'from sun and wind', but several new swarms were produced in Morocco. In June–July these moved out to southern Mauritania (Fig. 2.13a), but did not breed in the summer belt due to drought and were thought to have dispersed. After this there were no reports of gregarious populations in the Western Region until 1950.

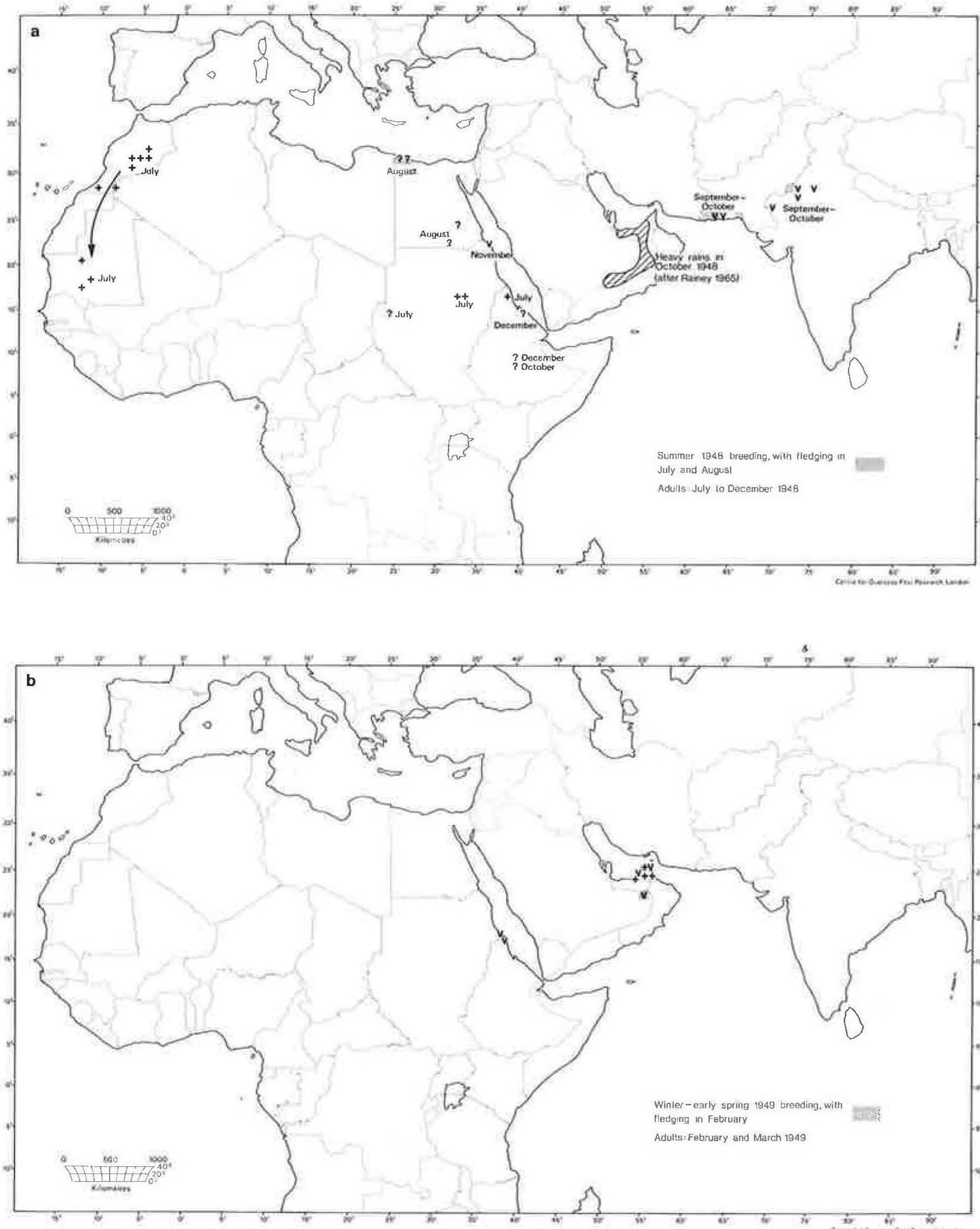
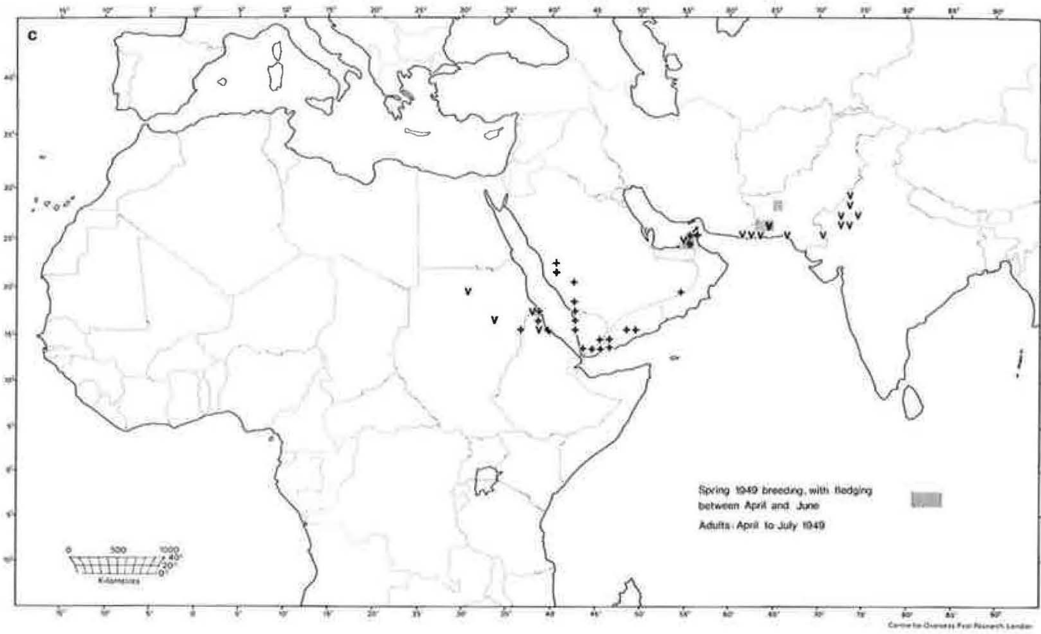
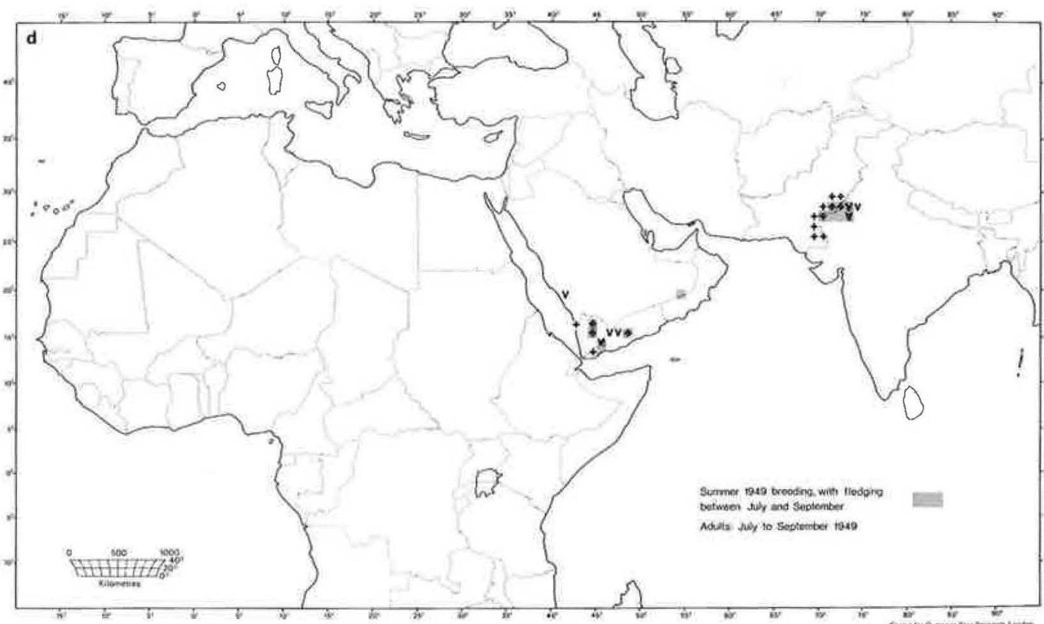


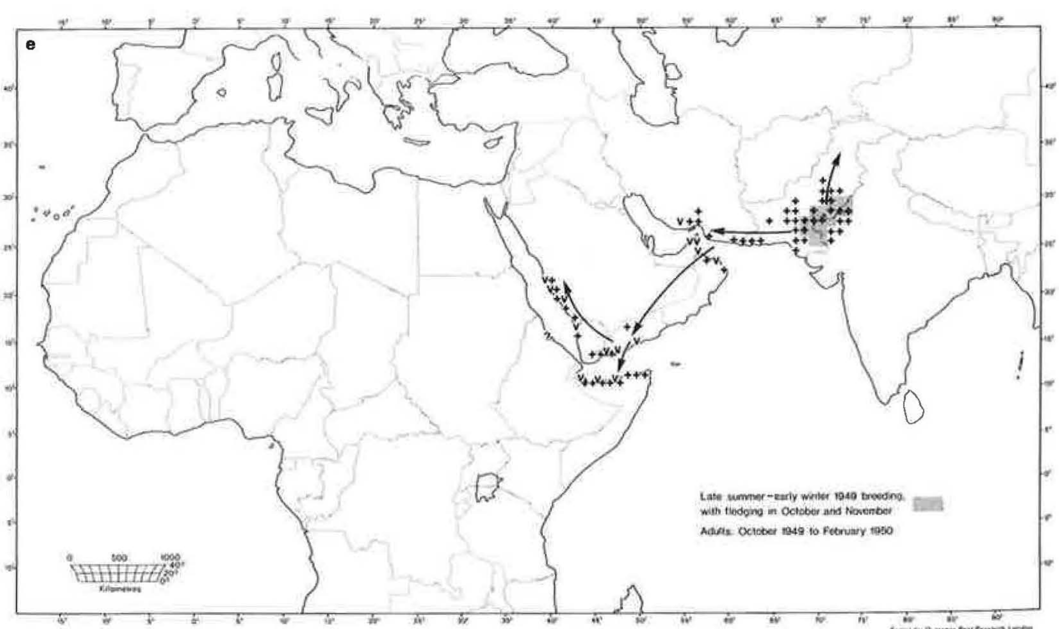
Fig. 2.13 a to h. The 1948 plague upsurge and spread (continued on next two pages).

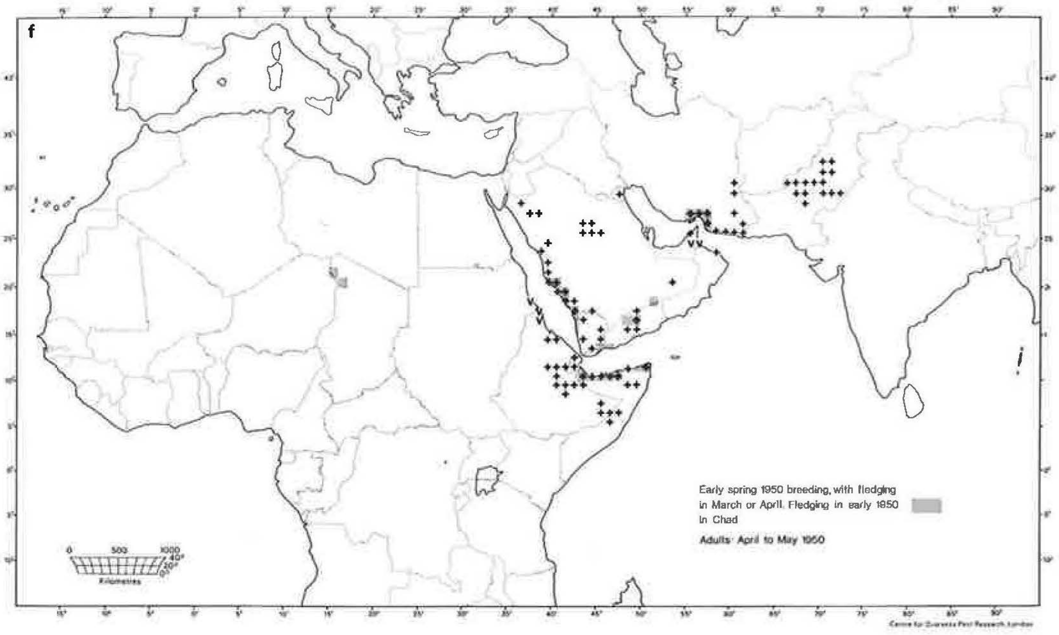
Degree squares with records of
- breeding
- large scattered populations or groups V
- swarms +
- unconfirmed swarms or swarms of uncertain species ?

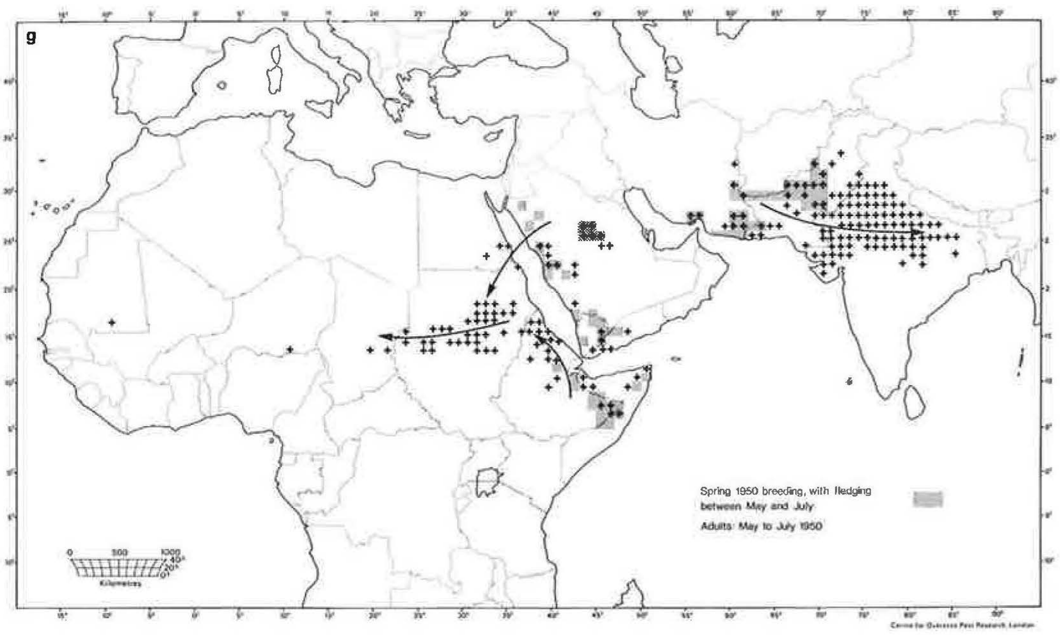
Generalised directions of spread →

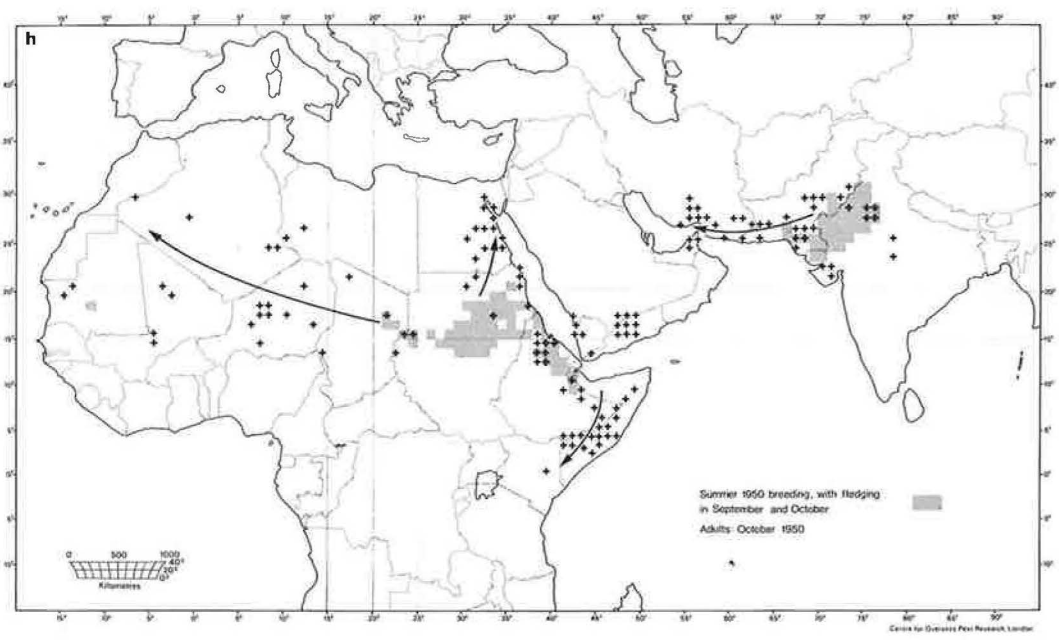

c
Spring 1949 breeding, with fledging between April and June
Adults: April to July 1949
Kilometres
Centre for Overseas Pest Research London


d
Summer 1949 breeding, with fledging between July and September
Adults: July to September 1949
Kilometres
Centre for Overseas Pest Research London


e
Late summer–early winter 1949 breeding, with fledging in October and November
Adults: October 1949 to February 1950
Kilometres
Centre for Overseas Pest Research London


f
Early spring 1950 breeding, with fledging in March or April. Fledging in early 1950 in Chad
Adults: April to May 1950
0 500 1000
Kilometres
Centre for Overseas Pest Research, London


g
Spring 1950 breeding, with fledging between May and July
Adults: May to July 1950
0 500 1000
Kilometres
Centre for Overseas Pest Research, London


h
Summer 1950 breeding, with fledging in September and October
Adults: October 1950
0 500 1000
Kilometres
Centre for Overseas Pest Research, London

In the North-Central Region, following the mainly abortive hopper infestations in summer 1947, there were only a few reports of small and isolated swarms in the Red Sea area in the 1947–48 season. Some loose bands occurred over a limited area on the Sudan coast in April — May and were controlled. On the Arabian coast, following good winter rains, a local outbreak developed on the Tihamah of Saudi Arabia, with gregarising hoppers forming bands in April — May and giving rise to a few swarms which disappeared after May. The swarms apparently emigrated to Sudan and the Eritrea Province of northern Ethiopia, where some swarms appeared in the coastal areas in June and further inland in June and July (Fig. 2.13a), before disappearing without trace. In eastern Arabia, heavy rains fell in February and March 1948 along the northern edges of the Rub al Khali in the interior of Oman, and quite numerous scattered and solitariform locusts were found in April in the Buraimi Oasis (24°N 56°E) (Thesiger 1950–51).

Further north in the North-Central Region, mixed hopper populations of Desert Locusts, *Anacridium aegyptium* and *Locusta* appeared in the cultivations on the Mediterranean coast of north-western Egypt between June and August, and in August there were reports of swarmlets in both the coastal areas and Upper Egypt (Fig. 2.13a). There was uncertainty about the species involved and the swarmlets could have been of *Anacridium,* which does form swarms in these areas (Section 9.3.6).

In the South-Central Region, following poor rains and failure of breeding during the 1947–48 Short Rains, a few summer-generation swarms survived in central Ethiopia till early March 1948. They then disappeared, and no gregarious breeding was subsequently reported in any part of the Region until its re-invasion at the end of 1949 (see below).

Thus, following the disappearance of the last authentic Desert Locust swarms in July 1948, there were no reports of gregarious breeding anywhere in the African part of the Desert Locust area for the rest of that year. Nor were there any further reports of swarms — except for two unconfirmed reports of isolated swarms within the Ethiopian Rift, in early October and in December, and an unconfirmed report of a swarm on the Red Sea coast in Eritrea in December (Fig. 2.13a). There was, however, some evidence of the usual movement of locusts from the inland summer areas of Sudan to the Red Sea coastal areas (Section 6.6), as some "flying locusts" (possibly a group) appeared on the coast of northern Sudan (at 22°N 36°E) in November.

In the Eastern Region, where the plague came to an end in 1946, groups or swarmlets of adults occurred in south-eastern Iran and south-western Pakistan in the winter of 1947–48 and, following good March rains, some hopper bands appeared there in May, though control prevented formation of swarms. After further good rains in June, infestations of gregarising hoppers developed in July — August 1948 in south-western and southern Pakistan and in western Rajasthan (Fig. 2.13a). Again swarm formation was prevented by control, but large populations of scattered locusts were present in these areas in September and early October, and then they declined.

Winter — spring breeding 1948–49 and the spread of resultant swarms

To west of the Red Sea, following good rains on the Eritrean coast north of 17°N, breeding in February — March by solitariform and initially scattered locusts at Halibai (17°N 38°E), on the Ethiopia — Sudan border (Fig. 2.13c), gave rise to gregarising hopper populations which fledged in April — May. In spite of control, the infestations gave rise to some adult concentrations and a few small swarms with transitiform morphometrics (Stower 1959). In May and June these moved westward into interior Sudan and Eritrea (Fig. 2.13c), but were not seen after June and apparently dispersed.

In Arabia, only low-density populations were observed in winter and early spring in the Red Sea coastal areas, but further east on the peninsula important breeding, constituting the initial stage of the subsequent plague upsurge, was taking place in Oman.

In late October 1948, a tropical cyclone from the Arabian Sea crossed into south-eastern Arabia and produced heavy rains over a wide belt running across the southern Rub al Khali and northward to the coast of the Persian Gulf (Fig. 2.13a). More heavy rain fell along the eastern and north-eastern edges of the sands in December 1948 and March 1949 (Thesiger 1950–51, Rainey 1965a). Thus conditions were favourable for breeding in Oman and the United Arab Emirates throughout the winter and spring of 1948–49.

In early February 1949, concentrations of late instar hoppers and of immature and mature locusts were found in interior Oman in Wadi Ain (22°N 55°E), and a loose swarmlet of immature and mature locusts appeared in the United Arab Emirates to the south-east of Dubai (25°N 55°E). In late February and March, scattered populations and more swarms of mixed maturities appeared in the United Arab Emirates and on the coast of Muscat; those sampled to south-east of Dubai were transitiform. Breeding by these locusts gave rise to gregarising and gregarious hopper population which began to fledge in early May and formed some swarms by mid May; young locusts sampled in several parts of the United Arab Emirates ranged from solitariform to gregariform.

With regard to the origin of the initial populations that bred in the interior of Oman (including Wadi Ain) after the late October 1948 rains, it has been pointed out by Rainey (1965a) that the air drawn into the October cyclone may have collected locusts from an area extending from Eritrea to western Pakistan. The transportation of locusts to, and their relative concentration along, the path of the cyclone suggested by Rainey is very plausible. It is uncertain, however, that any locusts which may have been brought into south-eastern Arabia included swarms, for there had been no confirmed swarms in north-east or east Africa since July, and none had been formed in the 1948 monsoon season in the Eastern Region. On the other hand, large scattered populations were present in October in India and

Pakistan, and emigration from these countries westward to Oman frequently occurs in the autumn (see Section 5.6). Thus locusts may have reached Oman from the east independently of the cyclone, but once there they may have become concentrated in areas made particularly favourable for breeding by the abundant rainfall — as they have been seen to do elsewhere (Section 2.6). Another possible source of initial populations, which could have become concentrated, either by the cyclone or by favourable breeding conditions or by both, may have been the progeny of locusts seen in the interior of Oman in April 1948 (see above).

It is likely that there were at least two successive generations in Oman between November 1948 and May 1949. If the initial populations (F_o) laid soon after the late October 1948 cyclone — say by 10 November — then, under average seasonal weather in the interior of Oman, the fledging of F_1 adults could have been expected from mid January (Wardhaugh *et al.* 1969, Symmons *et al.* 1973, 1974). Groups and swarms of mixed maturity seen in Oman from early February could accordingly have consisted of F_1 locusts, while swarms forming by mid May in the United Arab Emirates would be F_2. Similarly, swarms of locusts of mixed maturities invading south-western Arabia from Oman in early May (see below) were likely to comprise locusts of the F_2 generation.

The populations produced in Oman spread both to south-west and to the east. Thus, in the first ten days of May, swarms of mixed maturities invaded Wadi Mugshin (19°N 54°E), the interior P.D.R. Yemen and the southern Tihamah of Saudi Arabia; by the end of May they had spread to southern Yemen, and northward in Saudi Arabia to Taif (21°N 40°E) (see Fig. 2.13c). The appearance of these swarms at the time when young swarms were only just forming in northern Oman strongly suggests that winter — spring breeding in south-eastern Arabia had not been restricted to the areas from which it was reported, but had been much more widespread over the extensive region that had received abundant cyclonic rains (cf. Fig. 2.13a).

To the north and east of Oman, only very low density populations were recorded in the 1948–49 winter season in Iran, Pakistan and north-west India, though numbers were somewhat higher in south-east Iran, near the Pakistan border, where some breeding began in March. In April, a group or a swarmlet appeared in this area and the number and densities of scattered populations increased in Pakistan, suggesting an immigration from the west. In May — June, breeding described as bordering on gregarious developed in western and south-western Pakistan but the formation of swarms was prevented by control (Ahmed 1950). From May onwards the populations of scattered locusts in the summer breeding areas of Pakistan and India were increasing, with immigration of scattered locusts continuing in June and July; those sampled in July in Rajasthan were transitiform. It is clear from subsequent events that very considerable populations invaded the eastern summer areas, and it appears likely that the invaders from the spring breeding areas of Iran and Pakistan were augmented and probably outnumbered by those from Oman.

Late spring — summer breeding 1949 and the spread of resultant swarms

Only low-density hoppers and adults were recorded in the African section of the North-Central Region throughout the second half of 1949, apart from an unconfirmed report of a swarm on the Eritrean coast in December, which might have come from Arabia.

Swarms which invaded southern and south-western Arabia in May laid in May and June, and by June — July there were hopper infestations in Wadi Mugshin (at 19°N 54°E), P.D.R. Yemen and Yemen A.R. These fledged in July, giving rise to scattered populations and a few swarms, which were reported in August and September and were then lost sight of (Fig. 2.13d).

Heavier and more extensive summer breeding developed in the Eastern Region, where the 1949 monsoon rains were protracted (Magor 1962), and enabled locusts to pass through two to three generations in rapid succession. Thus, laying by scattered adults began in June; in July gregarisation of hoppers was seen in Rajasthan (Gurdas Singh 1952); and fledging of the F_1 monsoon generation began by the end of the month. Layings continued till October — at first by scattered populations, but from early September by groups or swarms, which were observed in eastern Pakistan and in Rajasthan when the increasing populations of F_1 adults apparently became concentrated on maturation. Serious hopper infestations developed in both countries in October and November (Fig. 2.13e). The formation of young swarms began in September and continued till early December. The earlier swarms would have comprised the overlapping F_1 and F_2 monsoon generations; the October swarms were probably mainly of F_2; while the late November — December fledgings could have comprised both F_2 and F_3 monsoon generations.

The swarming populations produced during the 1949 monsoon breeding in the Eastern Region were very considerable. While some of them remained and bred in spring 1950 in the Eastern Region, others spread far and wide, and invaded the North-Central and the South-Central Regions. The westward movement out of monsoon breeding areas (Fig. 2.13e) began in November, when swarms reached south-western Pakistan and southern Iran and scattered locusts appeared in Oman. In late November — early December there were reports of swarms on the Oman Peninsula, and scattered locusts, groups and swarms reached the northern coast of Somali Republic (North) (cf. movements of monsoon swarms in 1952, Summary 3). Later in December, swarms and scattered populations appeared in P.D.R. Yemen and southern Yemen A.R., and in January — February 1950 spread northward along the Tihamah (Fig. 2.13e). It is quite likely that populations spreading through south-western and western Arabia in late 1949 and early 1950 included remnants of swarms produced in southern and south-western Arabia in early summer 1949, but lost sight of since September.

Winter — spring breeding 1949—50 and the spread of resultant swarms

In the Eastern Region, some of the monsoon swarms which had invaded Iran bred from January 1950 in the coastal areas, and swarms of their progeny fledged in April (Fig. 2.13f). These early spring generation swarms apparently matured rapidly and joined the monsoon swarms in their breeding, which in the meantime had been in progress in eastern Iran and northern Pakistan (Fig. 2.13g). The numerous spring generation swarms that formed in these countries between May and July (cf. Summary 7) moved eastward into the summer areas of the Eastern Region.

In Africa, the Red Sea coastal areas of Sudan and Ethiopia remained free of gregarious breeding throughout the 1949—50 season, but further west, in the Western Region, bands of hoppers, possibly resulting from a local outbreak, were reported from some wadis in Tibesti in Chad (Fig. 2.13f). These would have fledged in early 1950, but there were no reports of resultant swarms.

In the South-Central Region the scattered locusts and swarms that had invaded the Gulf of Aden coastal areas gave rise to heavy hopper infestations there in early 1950, and to new early spring swarms in April (Fig. 2.13f). Breeding by the old and the rapidly maturing new swarms became more widespread over the Somali Peninsula in April — May, and gave rise to spring (Long Rains) generation swarms in June and July (Fig. 2.13g). Similarly, in the Arabian section of the North-Central Region, gregarious breeding by monsoon swarms that had immigrated from the Eastern Region developed in early 1950 in P.D.R. Yemen and Yemen A.R., and extended northward along the Tihamah of Saudi Arabia, where there had been heavy rains in November — December. A number of early spring generation swarms appeared in March — April (Fig. 2.13f). Breeding by surviving monsoon swarms, together with rapidly maturing early spring swarms, continued throughout spring in south-western and western Arabia, and spread into north-western and central Saudi Arabia (cf. Fig. 2.13g), giving rise in May — June to numerous spring generation swarms.

The invasion of the North-Central summer breeding areas by spring swarms began in May and June, when numerous swarms moved south-westward from the Arabian Peninsula to Sudan and north-eastern Ethiopia; at the same time these countries were invaded by spring generation swarms from the Somali Peninsula (cf. Fig. 2.13g). A similar convergence in northern Ethiopia and Sudan of swarms from these two sources took place during the spread of the plague in 1968 (Section 2.7.3) and in 1954 and 1955 (cf. Summaries 11 and 12). In Sudan, the invading swarms moved westward right across the country and as far as eastern Chad, thus spreading the plague into the eastern part of the Western Region. It would appear that some swarms may have spread even further west (as they did in June 1968 — see Section 2.7.3), for isolated swarms were reported in Niger in June and in southern Mauritania in July, but in view of the occurrence of hopper bands in Tibesti in January 1950 the West African origin of these swarms cannot be ruled out.

Summer breeding 1950 and the spread of resultant swarms

Swarms invading the summer breeding areas in the North-Central and Eastern Regions bred there on the summer rains, and numerous summer generation swarms appeared in September — October in both Regions. In October, monsoon swarms were moving westward out of the eastern summer areas into Iran and on to Oman, while in the South-Central Region 1950 Long Rains swarms which had remained through the summer on the northern Somali Peninsula were spreading southward towards Kenya. In the North-Central Region, young swarms moved in September northward from Sudan into Egypt on the way to the spring breeding areas in Arabia, while in October there was a widespread emigration of young swarms from Sudan and eastern Chad towards the west and north-west, carrying the plague far and wide over the Western Region (Fig. 2.13h). Thus 20 months and some six locust generations after the appearance of the first swarms in northern Oman in February — March 1949, the plague had spread widely over all four major Regions.

2.7.3 THE 1967—68 PLAGUE UPSURGE AND THE SPREAD OF THE PLAGUE

The main developments of the 1967—68 upsurge took place on the Arabian Peninsula and neighbouring African countries

In November 1966, a tropical cyclone (see Sections 3.3.4 and 5.3) brought heavy rains to southern Oman. Then in March and April 1967, heavy and widespread rains fell over south-eastern and southern Arabia, and further heavy

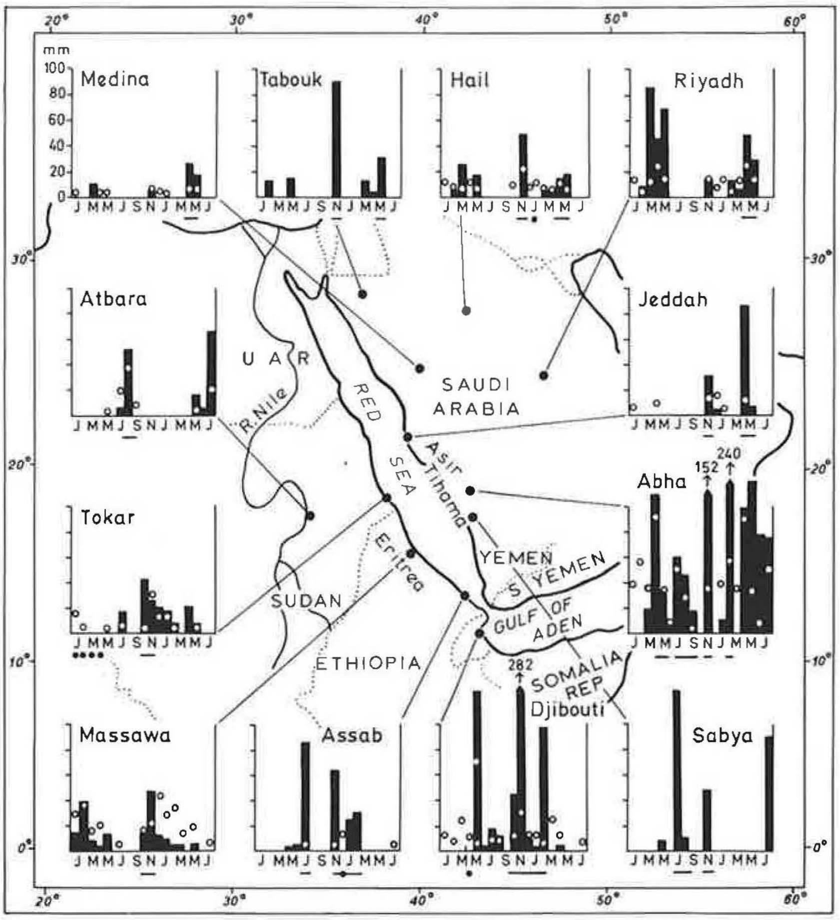


Fig. 2.14 Monthly rainfall at a selection of places within the areas of population build-up around the Red Sea and Gulf of Aden during the period January 1967 to July 1968 (from Pedgley & Symmons 1968).

rains fell there in July in association with an unusual monsoon depression. There were signs that, by May 1967, locust populations had increased in the area, and this was followed, between July and November, by extensive, locally concentrated and entirely uncontrolled breeding in south-eastern Oman.

Locusts began to spread out from south-eastern Arabia in October 1967, when they invaded the Saudi and Yemen Tihamahs, inland Saudi Arabia and the Peoples Democratic Republic of Yemen (P.D.R. Yemen). The immigrants were mostly at low densities, but in Asir and P.D.R. Yemen they included small swarms. Then, in December, groups and swarms crossed the seas to Somalia and to Iran. During the same season large scattered populations, most probably the progeny of numerous locusts produced in spring 1967 in south-eastern Egypt, invaded the Red Sea coasts of Ethiopia and Sudan; there was also an increase of scattered locusts on the northern shores of Somalia.

In the 1967–68 season, very favourable breeding conditions occurred around the Red Sea and western Gulf of Aden and over central and northern Arabia — following heavy and widespread rains in November 1967 and February 1968, as well as late and abundant rains over Saudi Arabia in April and May 1968 (Fig. 2.14).

On the Red Sea coastal areas of Ethiopia and Sudan, locusts passed through at least two gregarising generations between November and March–April, but were mostly eliminated by control. Further south, following the December invasion from Oman, two generations were produced during spring 1968 in the coastal areas of the north-western Somali Peninsula. Numerous young swarms appeared there by May, when most of them emigrated northward to northern Ethiopia and eastern Sudan.

In Arabia also, at least two gregarising generations were passed in the Red Sea coastal areas and in P.D.R. Yemen between November and March, when numerous groups and swarms spread inland from the coasts. Breeding continued in inland and coastal areas, leading to the formation of a large number of swarms between late April and June. From early June, many of these moved across the sea to Egypt and on to Sudan, where some converged with swarms from the Somali Peninsula. The Arabian swarms then spread west across Sudan and some continued into West Africa, reaching Niger, Mali and southern Algeria in the second half of June, and probably southern Mauritania in early July.

Some breeding continued in Arabia into June, and the last of the new swarms moved in July–August to south-western and southern Arabia, and possibly (via Oman) to Pakistan and India. During the same period, some swarms from the Somali Peninsula bred in Eritrea and eastern Sudan, and in August their progeny moved southward back to the Somali Peninsula.

In the meantime, the summer breeding by Arabian swarms began in Sudan, and in spite of control operations gave rise to a large number of young swarms. In September–October, these emigrated both eastward to the winter breeding areas round the Red Sea, and westward into the Western Region, reaching as far as Mauritania, Western Sahara and Morocco by the end of October.

Only localised outbreaks, which were largely controlled, occurred in the Western Region in spring and autumn 1967, and with the exception of some localised gregarious breeding in the Algerian Sahara in May most of the spring 1968 breeding was at low density. No large swarming populations appeared in the Region until the invasions from the east in June and, particularly, October 1968.

In the Eastern Region (as on the Somali Peninsula), the upsurge developed following the December 1967 invasion from south-eastern Arabia. The immigrants bred in spring 1968 in Iran and south-western Pakistan, and in July–August swarms of their progeny, possibly supplemented by further swarms from Arabia, moved into the summer breeding areas of Pakistan and India. The invading swarms bred on arrival, but owing to drought few of their progeny reached the adult stage and no new swarms were formed. The failure of breeding cleared the Eastern Region of the plague.

Situation in the second half of 1966

In this period, all reports from the *North-Central* and the *Eastern* Regions referred to small-scale, low-density populations. A potentially significant event occurred in November 1966, when a tropical cyclone brought heavy rains to southern Oman, and created favourable breeding conditions for any locust populations which might have been present or had moved into these areas.

In the *South-Central Region*, there were some unconfirmed reports of swarming populations on the northern Somali Peninsula in the last quarter of 1966. In October, a herd boy reported "hopper bands" near the Somalia-Ethiopia border south of Hargeisa (8°N 44°E), in an area where there had been rains in September. The locality could not be visited, and there was no authoritative confirmation of the species concerned, and no certainty that the report did not refer to grouping grasshoppers — as similar reports did in spring 1967 (see below). A few days later, a small pink swarm and a group were reported in western Somali Republic (North) (at 9°N 44°E, 45°E), but no confirmatory evidence could be obtained when the area was visited by an experienced observer within two days. In November and December, there were reports of a swarm and of a group in north-eastern coastal areas (at 11°N 47°E and 11°N 49°E), but again these were unconfirmed. Thus, there was no unequivocal evidence that any swarming Desert Locust populations had been present in the Region. But it is possible that populations there had not been negligible — especially as quite considerable populations of scattered locusts had been seen in central Somali Republic (North) in the preceding June. It is also possible that some populations moved from the Somali Peninsula to southern Arabia with the winds associated with the November 1966 cyclone.

In the *Western Region,* considerable populations of scattered and grouping hoppers were controlled in August–September in northern Tibesti in Chad (at 22°N 16°E, 17°E). Fledging took place in September–October, and any escapes emigrated. Some infestation extended into Fezzan in Libya, where hoppers and young adults were controlled in November to south-east of Murzuk (at 24°N 15°E, 25°N 15°E).

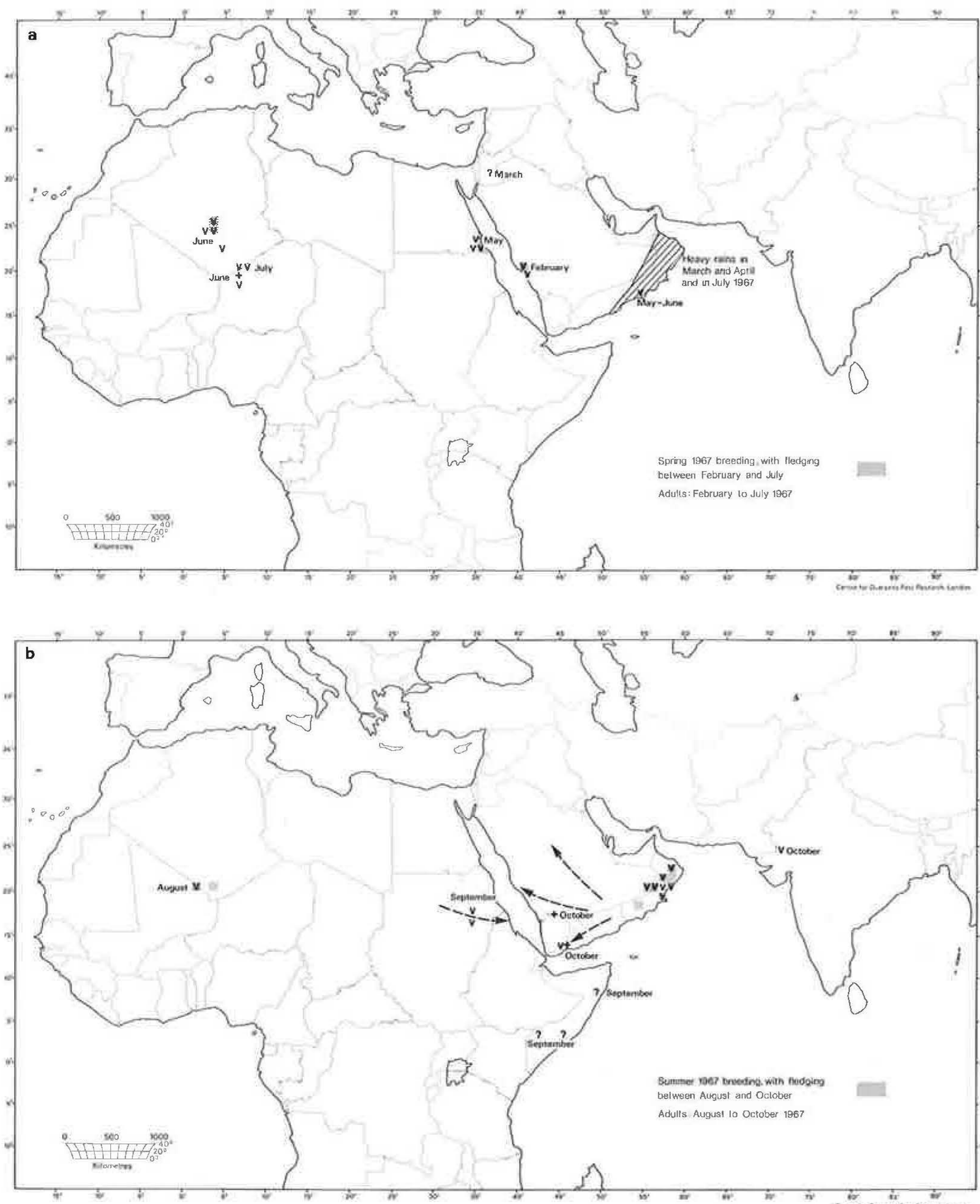
Developments in 1967 in the Western Region

Only isolated or very low-density scattered locusts were reported in the first half of 1967 in the Western Region, with the exception of populations on the western and northern borders of Mouydir in central Algerian Sahara (at 24°N 3°E, 25°N 3°E, Fig. 2.15a). Here good rains had fallen in February, and mating, grouping and laying adults were found in March at densities up to 100 in 100 paces; it is possible that they had immigrated from Tibesti and Fezzan. In April, breeding was in progress over some 100 kilometres of wadis within an area of 2,000 square kilometres, and by the middle of the month hoppers ranged from first to fifth instars, and although they were mainly solitaricolor their densities locally reached 100 per *Schouwia* plant and there were some bands. Fledging began in April and, in spite of control operations, in June densities of young adults ranged up to 2,500 a hectare and groups were seen on trees in Mouydir and Ahnet (24°N 2°E, 3°E; 25°N 3°E). While some layings and hatchings were still continuing in June, the young populations were moving out southward, and small groups appeared in south-western Ahaggar and near the Algerian border in north-west Niger (Fig. 2.15a). In addition, a 42-hectares swarmlet was seen there in late June in the midst of a night-flying scattered population spread between points 260 kilometres apart.

These assemblages apparently dispersed, and the subsequent summer 1967 breeding in West African countries was by low-density populations and not gregarious. Good rains fell in early summer in north-western Mali and southern Algeria, and some grouping populations of adults and hoppers occurred in August over a very limited area in Adrar des Iforas (at 20°N 1°E) and to north of Fort Pierre Bodas (at 20°N 3°E) (Fig. 2.15b), but they were controlled.

In August, heavy rains fell over Tamesna, in Niger and Mali. In September–October, low-density populations were widespread in West Africa and quite large numbers of scattered immature adults, migrating as single individuals at night, arrived in Tamesna from the south. Their gradual accumulation in Tamesna of Niger and Mali led to an outbreak in which their progeny gregarised in the hopper stage (see full account in Section 2.6.2.1). Fledging took place between November 1967 and January 1968 (Fig. 2.15c), and in spite of control a few small swarmlets formed in Mali, though their formation was prevented in Niger.

In the same season (November 1967), some control operations were carried out over about 1,700 hectares in the Mourdi depression (17°N 21°E, 18°N 22°E) in Chad (Fig. 2.15c) against late instar hoppers at densities up to 5 in a square metre. The parents of these hoppers could have been derived from the summer breeding belt in West Africa, or in Sudan.



Degree squares with records of

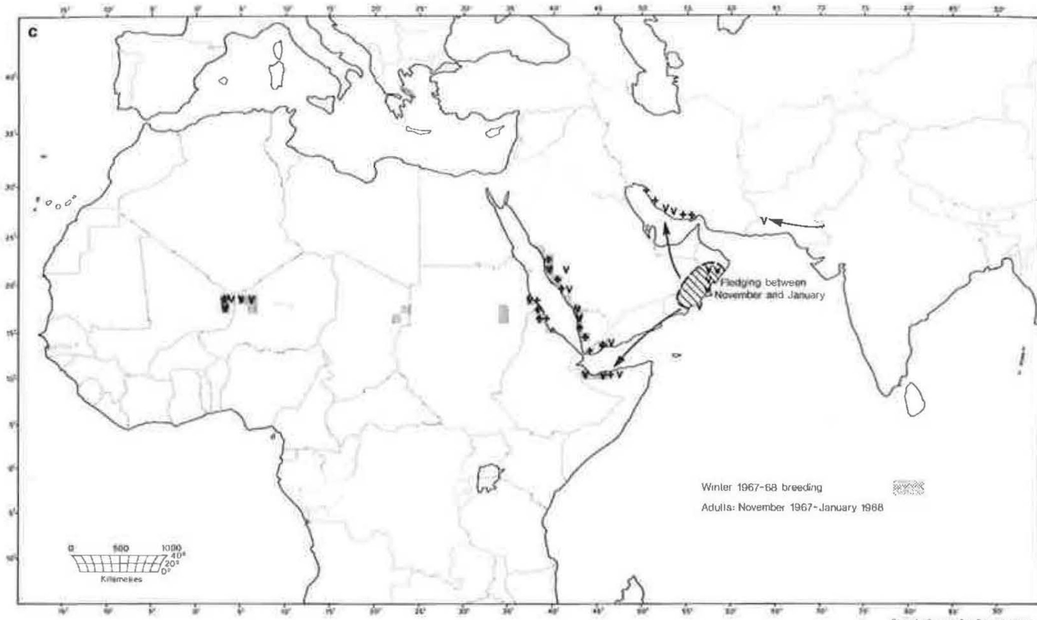
- breeding
- large scattered populations or groups — V
- swarms — +
- unconfirmed swarms or swarms of uncertain species — ?

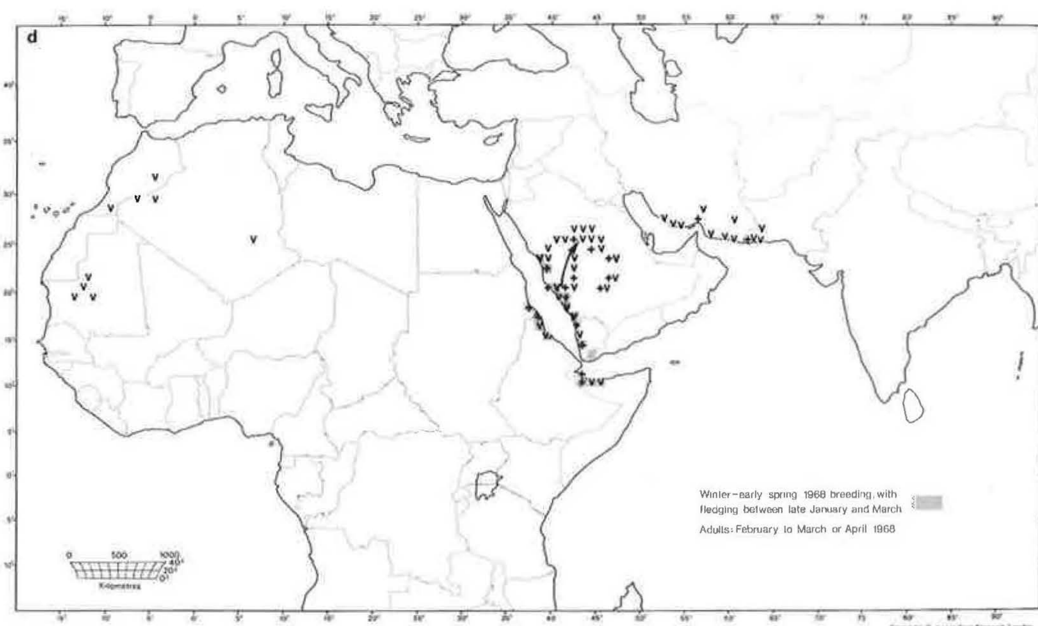
Generalised directions of spread — ⟶

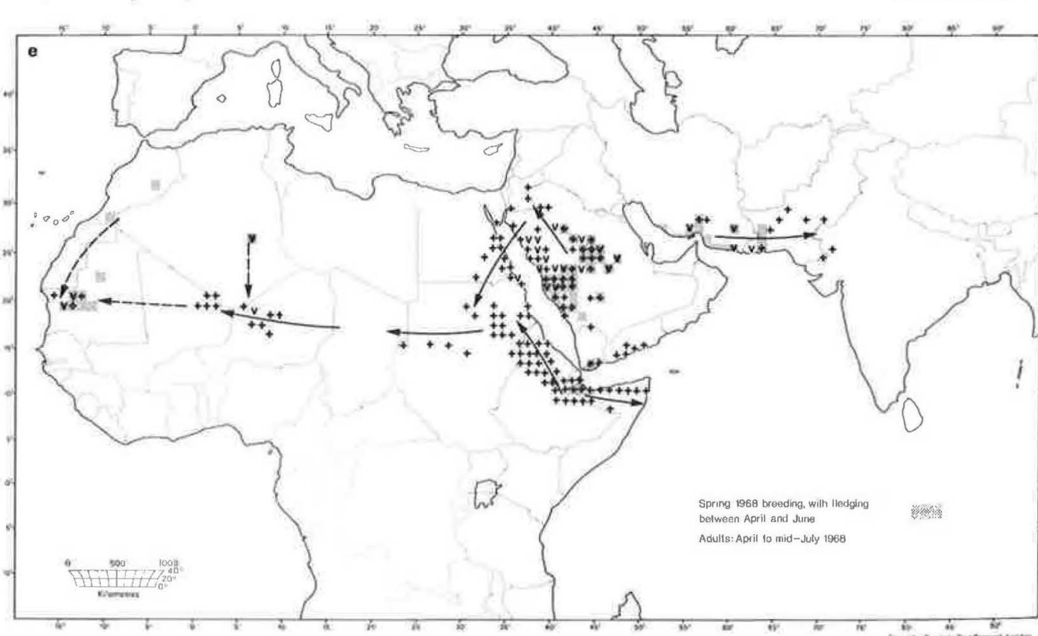
Generalised directions of hypothetical spread — – –⟶

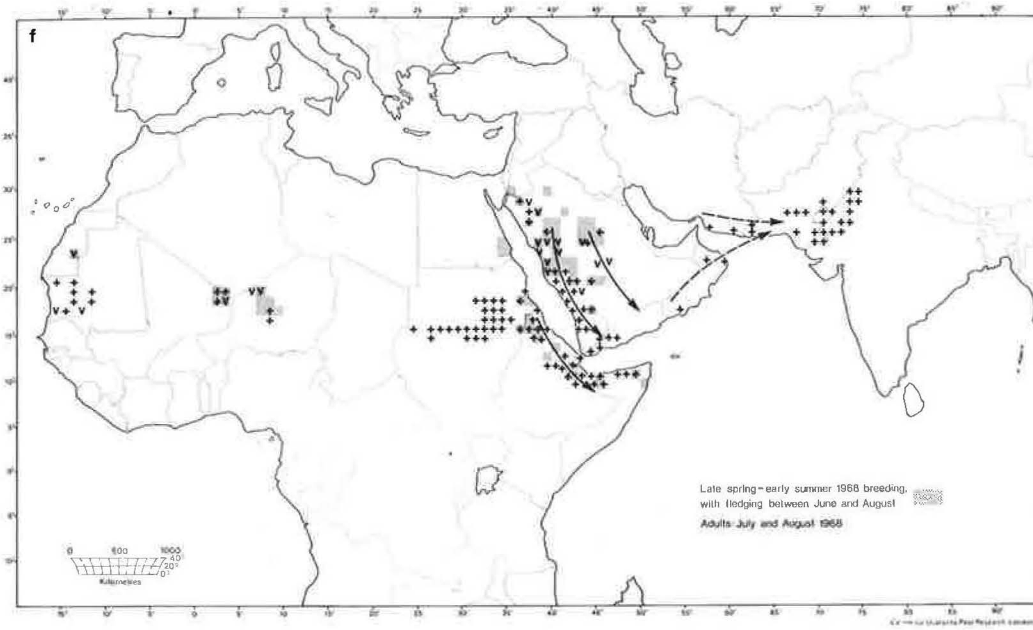
Fig. 2.15 a to g. The 1967–68 plague upsurge and spread

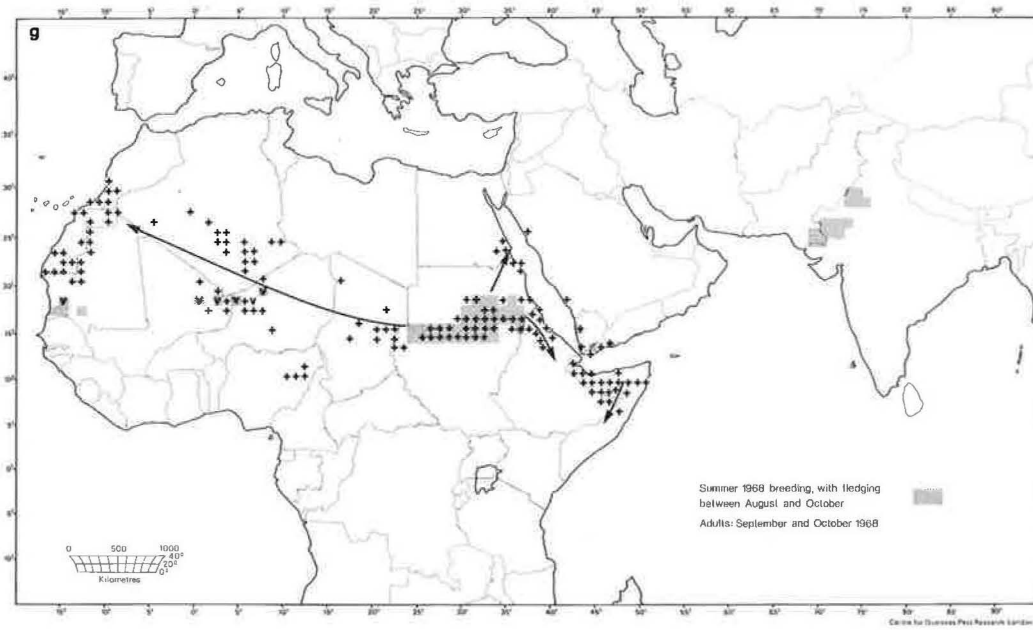
(continued on next two pages).


c
Fledging between
November and January
Winter 1967-68 breeding
Adults: November 1967-January 1968
0 500 1000
Kilometres
Centre for Overseas Pest Research London


d
Winter-early spring 1968 breeding, with
fledging between late January and March
Adults: February to March or April 1968
0 500 1000
Kilometres
Centre for Overseas Pest Research London


e
Spring 1968 breeding, with fledging
between April and June
Adults: April to mid-July 1968
0 500 1000
Kilometres
Centre for Overseas Pest Research London





Developments in the first half of 1967 in the Central and Eastern Regions

In *Arabia,* following winter breeding on the Saudi Tihamah, some possibly considerable populations of scattered young adults were seen in February—March 1967 in the Lith—Qunfidhah area (20°N 40°E, 19°N 40°E). In March, there was an unconfirmed report of a mature swarm at Hasa (30°N 36°E) in Jordan (Fig. 2.15a), but no locusts could be found during special surveys in northern Saudi Arabia and Israel. After this, only small-scale scattered populations or isolated locusts were reported from Saudi Arabia or the south-western Arabian Peninsula until October.

In late March—early April 1967, exceptional rains associated with a large, slow-moving wave in the upper west winds (Bennett 1976; see also Section 3.3.5) fell over south-eastern and southern Arabia, western Somali Republic (North) and adjoining part of Ethiopia. Only low-density, scattered or isolated locusts, however, were reported in the *South-Central Region* throughout the first eight months of 1967 (though following heavy spring rains, grasshoppers (*Phymateus* sp.) were seen in groups in several localities near Hargeisa (9°N 44°E), and were initially reported as 'locust hoppers').

In *southern Arabia,* on the other hand, the breeding which followed the heavy winter and spring rains may have led to the production of considerable populations, for on eleven consecutive nights between 20 May and 1 June immature solitariform locusts were seen flying, isolated or in groups, around the meteorological station at Salalah (17°N 54°E, Fig. 2.15a). Locusts continued to be seen there in June, but their numbers decreased in July.

In the *North-Central Region west of the Red Sea*, only low-density, scattered or isolated locusts were reported from January to autumn 1967, with the important exception of a population found in May in the coastal areas on the borders of Sudan and Egypt between Halaib and Shalatein (22°N 35°E, 22°N 36°E, 23°N 35°E, Fig. 2.15a). Here, late instar hoppers, some of them transiticolor, were present in dense patches within an area of 375 square kilometres. After control operations, surviving young adults were said to have been scattered over some 1,500 square kilometres at a density of 1 in 20 square metres. Even with such an approximate estimate, it appears probable that they numbered several tens of millions. The locusts left the area — probably moving to the summer breeding belt in the interior of Sudan.

The parent generation to these locusts must have laid in late March or early April, but their origin is not clear. The area had received good rains in February–March 1967, and some isolated locusts were observed in it in December 1966 (Bennett 1975). It is not known, however, if they had been numerous enough to give rise to the populations seen in May. Alternatively, the parents could have been some unobserved large populations present in the North-Central Region, or the swarm reported in March from Jordan, if that report did actually refer to an authentic swarm of Desert Locusts.

In the *Eastern Region*, all reports over this period referred to isolated or very low-density, scattered locusts.

Summer–early winter breeding 1967 in the North-Central and Eastern Regions and spread of resultant swarms

The most important development during this period occurred in *southern Arabia*.

On 21 July, an unusual monsoon depression reached the coast of southern Arabia from the Arabian Sea, and heavy and widespread rains fell over a large part of south-eastern Oman — largely coinciding with the area which had received heavy rainfall in March–April 1967 (Fig. 2.15a).

From the few and incomplete reports received from Oman, and the information assembled during a special survey in early 1968 (Popov 1968), it appears that extensive and locally concentrated breeding developed in the south-east of Oman between July and November, and led to the formation of hopper groups or bands in a number of localities in the Sahmah (20°N 55°E, 20°N 56°E), Nafun (20°N 58°E), Huqf (20°N 58°E, 21°N 57°E) and Wahibah (21°N 58°E) areas. To the north, the affected areas extended into the foothills of the Hajar mountains in the Ash Sharquiyah area (22°N 58°E), and in the south included Dhahir (19°N 57°E) and the Umm el Hait area (18°N 54°E) in north-eastern Dhufar (Fig. 2.15b). In view of the extensive area which had received the July rains, it is probable that breeding was even more widespread than the available data suggest. It is also likely that two overlapping generations were produced between late July and December, with the first fledging from September and the second from November. Between September and December large numbers of adults, apparently often in groups and probably also in swarms, were reported in or close to the areas of breeding (Figs. 2.15b and c). Some of these locusts may have left the area already in October, while others emigrated in groups and swarms in December, south-westward to the Somali Peninsula and northward to south-west Iran (see below).

In *western, south-western and central Arabia*, only isolated locusts or low-density scattered populations were reported during summer 1967. Good rains fell over the southern Tihamah and in Asir in July–August, and subsequently some isolated and scattered adults and hoppers were found on the Saudi Tihamah near Gizan (at 16°N 42°E) in September, and some grouping hoppers were controlled in Wadi Hiran (15°N 42°E) in October.

In October, there was an increase in the numbers of locusts in western and central Arabia (with locusts appearing along the Tihamah as far north as Yenbo (25°N)), in western P.D.R. Yemen and in interior Saudi Arabia, and it is possible that immigration continued in November. Most reports referred to mature scattered locusts, but the passage of a swarmlet of gregariform locusts over Najran (17°N 44°E) in southern Asir, and the appearance of groups to east of Aden (at 13°N 45°E) in P.D.R. Yemen, showed that the immigrating populations included some gregarised components (Fig. 2.15b). The origin of these immigrants is now known, but they are likely to have been produced during the summer 1967 breeding somewhere in southern Arabia — either in the south-east, or possibly in interior south-western Arabia, to which the good rains which fell in July–August in Asir (cf. Fig. 2.14) may have extended.

At the time, when immigrant populations were appearing on the eastern coast of the Red Sea and around the north-western Gulf of Aden, the numbers of scattered locusts were increasing on the *western coast* of the southern Red Sea. Only isolated or very low-density scattered adults and a few hoppers had been noted on the coast of Eritrea in September, but the scale of coastal breeding which developed there in the last quarter of 1967 (see below) makes it clear that substantial populations must have invaded the coasts of Ethiopia and Sudan in the autumn of that year. The source of these immigrants is not known, but from the usual seasonal pattern of migrations (Section 6.6) it is probable that they moved in from the summer breeding areas in interior Sudan. The extent of summer 1967 breeding in Sudan is not known; the only indication that locusts had been present there is a report of some scattered locusts in Khartoum Province in September. But substantial populations produced in spring 1967 in south-eastern Egypt (see above) probably bred there in summer; and the eastward migration of their progeny towards the Red Sea may have started from September, when some of them may have stopped to breed in the sorghum cultivations near Atbara (between about 16° and 18°N, and 34° and 35°E, Fig. 2.15b). Here, groups and a few bands of hoppers were found in November over sites totalling some 50 square kilometres (Fig. 2.15c). Fledging began in November, and any young adults surviving after control operations probably also moved towards the Red Sea.

In the *South-Central Region*, where only isolated locusts or very low-density populations had been reported during the eight preceding months, there were three unconfirmed reports of swarms in Somalia in September: (a) near Bulo Burti (3°N 45°E), where no confirmatory evidence of any locusts could be found by the ground reconnaissance party rapidly reaching the area from Mogadiscio; (b) at Lugh Ferrandi (3°N 42°E), where the swarm was subsequently said to have been of *Anacridium*; and (c) in the Eil area (8°N 49°E) in Mijertein, where the report was thought to have arisen because unusually large numbers of *Cyrtacanthacris* were present in the area.

In September, heavy rains fell over the north-western Somali Republic (North) and continued there in October, when the numbers of scattered locusts increased on the north-western coastal plains. The locusts were mature and their numbers apparently increased still further in November. Once again the origin of these populations is not clear. They might have immigrated from north-eastern Ethiopia, or from south-western Arabia, as locusts have been known to do at this season on other occasions (see Section 7.7), or they could have been already present elsewhere on the Somali Peninsula and have moved into areas of good rains.

In addition to these populations, mature laying groups and swarms appeared between 12 and 17 December on the coastal plain and foothills between Berbera and Karin (11°N 45°E), and large scattered populations were seen on the coast near Mait (11°N 47°E) (Fig. 2.15c). Between 10 and 17 December, strong north-easterly winds were sweeping through from the Oman Peninsula across the Gulf of Aden to the Somali Peninsula (Bennett 1975), and there is little doubt that these groups and swarms reached the northern shores of the Gulf of Aden from south-eastern Arabia.

Finally, in the *Eastern Region*, only low-density breeding was observed in the summer areas in 1967. The maximum density of resultant adults, however, reached 12,000 a square kilometre in Barmer district (at 24°N 71°E) in Rajasthan, and in November a 'concentration' of adults was reported near Turbat (26°N 63°E) in south-western Pakistan, indicating that the usual westward movement of locusts to the winter-spring breeding areas (see Section 5.6, westward movements) was in progress (Fig. 2.15c).

From about 23 December, immature scattered locusts, groups and small swarms appeared in a number of localities along some 500 kilometres of the coast of south-western Iran between 29°N 50°E and 26°N 55°E (Fig. 2.15c). It is highly probable that these locusts reached Iran from south-eastern Arabia, for at the time of their arrival strong southerly winds were blowing over the Persian Gulf ahead of a vigorous depression moving over southern Iran (Bennett 1975).

Winter–spring breeding 1967–68 in the Central Regions and spread of resultant swarms

From the preceding account it will be seen that considerable populations, ranging from scattered locusts to swarms, reached the winter–spring breeding areas of the Central and Eastern Regions in the last quarter of 1967. Many of these populations had developed in the sequence of breeding which followed the exceptional rains over southern Arabia in March–April and July 1967, and in some cases the build-up may have started following the November 1966 rains.

The 1967–68 season was again marked by widespread and protracted occurrence of exceptionally favourable breeding conditions in areas around the Red Sea and western Gulf of Aden and over much of the Arabian Peninsula, created by exceptionally heavy rains falling in November 1967 and again in February 1968, associated in both cases with large slow-moving waves in the upper westerlies (Bennett 1976), and by unusually late and abundant rains over Saudi Arabia in April–May 1968 with similar origins (cf. Fig. 2.14). This succession of rainfall led to a further build up of gregarising locust populations through several generations and to the appearance of important and far-ranging populations of swarms (see below).

In describing this breeding it has not been possible in some cases to separate successive generations because young locusts frequently matured rapidly and began to lay while their parents were still alive and breeding in the same areas.

On the *west coast of the Red Sea*, where some isolated hoppers were found in October 1967, the numbers of breeding adults (F_0) increased in October–November, and in November–December hopper groups and bands were seen on the Eritrean coast to north of 15°N and in the Tokar delta in north-east Sudan. Hoppers fledged between November and January, and the new adults (F_1) matured rapidly, forming laying groups and swarmlets which were reported on the coast of northern Eritrea and in north-east Sudan in December–January (Fig. 2.15c).

The hatching of the next generation began from late December, and hopper bands were reported during the following month in the previously infested areas. Fledging began in late January and continued in February and March, when groups and swarms of young adults (F_2 generation) appeared in the infested areas (Fig. 2.15d) but were apparently mostly eliminated by intensive control. The infestations continued longer on the coast of Sudan, where the last of the bands were controlled in April.

In the *Somali Republic (North)*, mating locusts were seen in November 1967 at many points of the coastal plain and foothills from Zeila (11°N 43°E) to east of Berbera (10°N 45°E). Hatching began in November, and in December–January fledglings were seen throughout the infested area, with concentrations of new adults in the Zeila area (Fig. 2.15c).

The groups and swarms which invaded *Somalia* from Arabia in mid December (see preceding sub-Section) began to lay on arrival, and from January to March 1968 scattered hoppers, and groups and bands of mixed instars and fledglings, were reported throughout the coastal areas to the west of 46°E. The bands were likely to have been the progeny of immigrant swarms (F_0), but must have locally comprised the progeny of earlier scattered populations appearing from October. Mixed groups of mature and immature adults and the first young swarms (F_1 to immigrant swarms) were seen from early February (Fig. 2.15d). Maturation was rapid and in the second half of February, and in March, groups and swarms were laying in many localities in north-western coastal areas. Numerous bands of their progeny appeared there and in adjoining parts of the Republic of Djibouti, and of Ethiopia in March and April. Fledging began in April and, in spite of control operations, a number of swarms (F_2 generation) formed in Somalia in April and May (Fig. 2.15e). From late April they began to move west into the Republic of Djibouti and Harar Province of Ethiopia, whence they moved northwards in May through Danakil and the north Ethiopian highlands into Eritrea. In late May and June, some of them spread to interior Sudan, where they converged with swarms reaching Sudan from Arabia (see below and Fig. 2.15e). Not all the Somali swarms moved out to the west and north; a few moved in May to the east and south-east, spreading as far as northern Mijertein in June (Fig. 2.15e).

In *Arabia*, where good rains fell in August 1967 over the southern Tihamah, some local coastal breeding began in September in the Gizan area (16°N 42°E) on the Saudi Tihamah, and in Wadi Hiran area (15°N 42°E) in Yemen, where some hopper groups were controlled in October. The layings and hatchings became more widespread after the arrival of October (F_0) immigrants and in November–December groups, and locally bands, mostly of mixed instar hoppers, appeared in a number of localities along the Red Sea coast between about 14°N in Yemen and about 24°N in Saudi Arabia. At the same time, groups and bands of hoppers were reported in P.D.R. Yemen (at 13°N 45°E). Fledging which was in progress in the Gizan area in November 1967 became more widespread in December and general in January 1968. The young adults (F_1) matured rapidly, and in January there were groups and small swarms of laying locusts in most infested coastal areas (cf. Fig. 2.15c).

Intensive breeding continued in February–March 1968, when there were laying groups and swarms, hopper groups and bands of all instars, as well as groups of fledglings in many localities along the Tihamahs between 14° and about 24°N. Further south, hopper bands were reported in the Subeihi area (12°N 44°E, 13°N 44°E) of P.D.R. Yemen (cf. Fig. 2.15d). About mid March, large numbers of locusts spread from the coastal areas into interior Saudi Arabia, where mature groups and swarms appeared in northern Asir, Hejaz, Qassim and Aridh (Fig. 2.15d). These populations probably consisted of a mixture of the F_1 generation, which had fledged in January, and the rapidly maturing members of the next generation (F_2). Not all the populations left the coastal areas, however, and breeding, with production of further swarms, continued over parts of the Saudi Tihamah until June–July (see Figs. 2.15e and f).

The locusts invading interior Saudi Arabia laid eggs in March and April. Their progeny began to hatch from late March onwards, and from April to early June there were infestations by hopper groups and bands in western and central parts of the country (cf. Fig. 2.15e). Fledging and formation of new swarms (probably mainly of F_3 generation in the later stages) began in late April and continued through May into June; similarly, fledging with formation of some swarms occurred during this period in south-western P.D.R. Yemen.

In the conditions prevailing over much of the Arabian Peninsula following the April–May rains, some of the new locusts rapidly matured and during May and June numerous adult groups and swarms at apparently all stages of maturity, and many of them laying, were reported in and near their source areas and spreading into north-western and northern parts of the country (cf. Fig. 2.15e). Most of these populations became involved in the usual late spring–early summer migration from Arabia across the Red Sea to north-east Africa (see Section 6.14 and Steedman 1976). Thus some scattered formations and groups of maturing and mature locusts reached the coastal areas of Egypt near the Sudan border in late May, while from early June mixed swarms of immature, maturing and mature locusts appeared in the coastal areas of Egypt between Shalatein (23°N 35°E) and Queseir (26°N 34°E), and then spread to the Nile Valley, where they appeared near Edfu (24°N 32°E) and Wadi Halfa on the Sudan border (at 22°N 31°E) by 6 June. In Sudan the swarms moved in a general southward direction through northern, north-eastern and central provinces, as well as westward through Kordofan and Darfur, where some reached the Chad border by 13 June. The westward spread continued in the second half of June, when some swarms reached north-west Niger, north-east Mali and the adjoining part of southern Algeria (cf. Fig. 2.15e).

Late spring–early summer breeding 1968 in the Central Regions and spread of resultant swarms

In *Saudi Arabia*, where favourable breeding conditions created by the heavy April–May 1968 rains persisted into summer, the progeny of the swarms which laid during May–early June were hatching in late May and June in central, western and north-western parts of the country (cf. Fig. 2.15f). The hoppers fledged in late June and July, giving rise to yet one more population of young swarms (F_4). The very last of the hoppers fledged in north-western Saudi Arabia in the Tebuk area (28°N 36°E) in early August, remarkably late for such breeding.

The new swarms emigrated in a general southward direction. In the west they spread through Asir and the Saudi Tihamah and interior and coastal Yemen A.R. to P.D.R. Yemen (Fig. 2.15f). There were also reports of locusts in southern and south-eastern Arabia: a swarm at Salalah (17°N 54°E) on 12 July, and of 'damage by locusts' at Sur (22°N 59°E) about 24 July. These may have moved from north-western or central Arabia with the north-westerly winds blowing towards the ITCZ in the south-eastern part of the Peninsula (see Section 3.3.4 and Fig. 3.17b). On the other hand, the weather over the Persian Gulf and eastern Arabia was unusual in the second half of July 1968 in that the characteristic north and north-west winds were sometimes weak and shallow, and even replaced by winds from between north and east, and it is possible that locusts in south Oman were derived from Iran.

In the western part of the Arabian Peninsula the southward movement continued in early August through Asir and the coastal areas, but from mid August the reports of swarms became restricted to P.D.R. Yemen, where there were further reports of swarms in September when the rest of the Peninsula was clear.

Some late spring–early summer breeding also took place during 1968 in most African countries bordering the Red Sea and Gulf of Aden.

On the *Somali Peninsula*, the few swarms which remained there after the April–May emigration to the west and north matured and laid in May. In late May, bands hatched in the Ethiopian Railway Area (at 10°N 42°E), and in June there were reports of bands in central and eastern Somali Republic (North) (Fig. 2.15f). The escapes from control fledged in late June and July and formed a few swarms. From mid August they were augmented by an invasion of the Somali Peninsula from the north-west (see below — last paragraph of this sub-Section).

In *north-east Africa*, some of the swarms arriving from Arabia in June laid in Egypt in the coastal areas between Halaib and Shalatein (23°N 34°E, 35°E; 24°N 34°E, 35°E), and in Sudan inland from Tokar, and in the Tokar delta (18°N 36°E, 37°E) (Fig. 2.15f). Some hopper bands were reported in both areas and were controlled. No swarms were formed in Egypt but one or two young swarms appeared near Tokar.

Quite heavy late spring or early-summer breeding developed in northern Ethiopia, where some of the swarms arriving from the Somali Peninsula had matured by the time they reached the Eritrean Province in May–June. These laid eggs on arrival in a number of localities in the central Eritrean highlands and on the western plains, and the hatching of their progeny began in June and continued in July, when hopper infestations were reported also from Danakil (at 13°N 40°E) and in the Qoram area (at 12°N 39°E) in Wallo. Fledging began in July and continued in August, and a number of young swarms formed in western and central Eritrea, whence some of them moved to the coastal plain by early August.

In early and mid August, there were some reports of swarms in Danakil, and between 13 and 19 August swarms appeared in the Republic of Djibouti, and there was a marked rise in the number of reports of immature swarms in the western Somali Republic (North). Another wave of swarms apparently arrived in the last ten days of the month, when there were further reports of immature and maturing swarms in the Republic of Djibouti, the adjoining part of Ethiopia, and in western Somalia. Throughout August 1968, the windflow over the southern Red Sea and adjoining areas was typical of the season — i.e., from the north-west, turning to west over the Gulf of Aden. It is highly probable therefore that the swarms invading the north-western Somali Peninsula in August were derived from populations originating in July–August in Eritrea, with a possible addition of some swarms produced in Danakil and Wallo.

Developments in the Eastern Region, January–July 1968

Groups and swarms of immature locusts, invading south-western Iran from Arabia in December 1967 (Fig. 2.15c), were reported there again in January 1968. There is no information on their position in February–March 1968, but judging from the distribution of later reports, they spread further east in southern Iran and possibly into south-west Pakistan, augmenting the concentrations of adults previously reported there in November 1967.

Heavy rains fell over southern Iran and Pakistan in February 1968, and concentrations of breeding adults were reported in the coastal areas of south-west Pakistan (at 25°N 62°E, 63°E) from March, and further inland in Panjgur (26°N 63°E) in April. In the same month, maturing and breeding locusts were found in many localities along the coast of south Iran, from about 52°E to the Pakistan border, as well as further inland in the Iranshahr area (27°N 60°E). As shown by later reports they must have also spread to south Kerman (see below). The appearance of a small swarm near Bandar Abbas (25°N 56°E), and the invasion of south-west Pakistan by two small swarms in April, suggest the presence of considerable populations in southern Iran.

Hatchings began in March, and by April there were groups and bands of hoppers in the coastal areas of south-west Pakistan and further inland at Panjgur; at the same time, hoppers of all instars were reported from the coast of Iran and from Iranshahr (cf. Fig. 2.15e). In the coastal areas, fledging began in April and continued into May, and locally into June. In the inland areas, it probably began in May and continued in June.

During May and June, there were reports of groups and of a swarmlet of young adults in south-western Pakistan, and of concentrations of adults on the coast of Iran. In June, groups of young locusts were seen in Iranshahr, and 'swarming fledglings' in southern Kerman (at 28°N 56°E, 57°E) (Fig. 2.15e).

The usual eastward movement from spring to summer breeding areas (Section 5.14) began from late May, when a swarm appeared at 28°N 68°E in eastern Pakistan. In early June there were some reports of swarms in north-west Baluchistan in Pakistan, and an increase in the density of scattered populations in Rajasthan. By mid July, some swarms appeared in Bahawalpar and south-east Sind in Pakistan and in Barmer district in Rajasthan (Fig. 2.15e).

In the second half of July, more swarms appeared in the coastal areas of south-east Iran and adjoining parts of Pakistan, the number of swarm reports in south Sind increased, and quite numerous swarms reached Rajasthan. These later incursions (Fig. 2.15f), which apparently continued until early August, may have been derived from spring breeding in interior Iran, where it may have been more widespread than reported; or the immigrants may have originated in central and north-west Arabia and moved in across Oman. It is quite possible that they were derived from both sources.

Developments in the Western Region, January–August 1968

Any escapes from the late autumn 1967 outbreak in Niger and Mali, and any low-density populations produced in summer–autumn 1967 in other parts of West Africa, would have moved out in autumn–winter in a general northward direction (Section 8.6). Only isolated locusts or low-density scattered populations were reported in the first quarter of 1968 anywhere in the Western Region, with the exception of northern Mali and Niger (where densities of up to 400 a hectare were recorded in Niger Tamesna in the last stages of late autumn–winter breeding). The densities decreased, however, in both countries in February–March.

During the 1967–68 season, heavy rains fell in November 1967 in southern Morocco, causing floods in the wadis of the Draa region, while in February 1968 there were good rains in central and north-west Mauritania, in Algerian Sahara and in south-west Morocco (Bennett 1975). Thus, in many areas conditions must have been favourable for breeding, but the information on spring 1968 breeding in north-west Africa may be incomplete.

In *Mauritania*, low-density mature adults were reported in the Dhar Adrar area (between about 20° and 23°N, and 11° and 13°W) in March, and the Atar–Akjoujt areas (between about 19° and 21°N, and 11° and 15°W) in April. The widespread distribution of these locusts suggests there were considerable low-density populations over a large area. In March–April, hoppers — again at low densities but locally showing some slight grouping — were present in central and north-west Mauritania (cf. Fig. 2.15e); these fledged in April and in May, when the density of young adults reached locally up to 200 a hectare.

In the *Algerian Sahara*, breeding took place during the same period in Tidikelt (about 26°N 3°E. 4°E), in Wadi Irharhar (about 25°N 5°E, where some pairing adults were seen in February–March), and in Wadi Tahihaout (26°N 6°E) in northern Tassili N'Ajjer (Fig. 2.15e), where it was gregarious, and where some 58 hopper bands, varying in size from 20 square metres to 20 hectares, were controlled in April. The escapes were fledging in May and either they were destroyed or they emigrated.

Further north, on the southern borders of *Morocco*, mature adults at a density of 100 a hectare were found in late March over some 20 hectares in Wadi Daoura (29°N 4°W), and in April mature locusts were reported from a number of localities to the south of the Atlas Mountains between the border of former Spanish Sahara and about 2°W. These locusts were mainly at very low densities, but locally they were more numerous in the lower Wadi Draa (at 28°N 9°W and at 29°N 6°W) and in Maader Khemlia (at 31°N 4°W). In early May, hoppers hatched in the lower Wadi Draa and were sprayed over a small area. In late May, hoppers of all instars were found in Maader Khemlia, where control operations were carried out in June (Fig. 2.15e). Escapes from these areas and any other parts of southern Morocco would have fledged in late May and in June.

There is no information on any *spring* breeding in the former Spanish Sahara, to which it very probably extended. Some early *summer* breeding did take place there, for in late July a one square kilometre band was reported in the central part of the country, and groups of fledglings appeared in August (Fig. 2.15f).

To the south of the Sahara, good rains fell in April–May in northern *Niger* and *Mali*. Adult populations remained low in Mali, but increased in May up to 200 a hectare in Tamesna of Niger — probably due to immigration of scattered locusts from breeding areas in the Algerian Sahara (Fig. 2.15e). In Niger, laying began in May, and in June small bands appeared in north-eastern Tamesna (at 19°N 7°E). Most were controlled, but residual late instars and groups of fledglings were reported there in July.

In the second half of June, maturing swarms appeared in central and north-western Niger, north-eastern Mali and the adjoining parts of southern Algeria (Fig. 2.15e). From consideration of the windflow up to and at the time of their arrival, and of the situation in north-eastern Africa (cf. Case Study 11.4), it appears that these were derived from swarming populations which had crossed the Red Sea from Arabia into Egypt and Sudan.

The invading swarms matured and laid eggs in north-western Niger and north-eastern Mali and apparently left these countries by the end of June, though some swarms continued to be reported in southern Algeria until early July. Dense bands of the hopper progeny of the swarms appeared in Niger and Mali in July (cf. Fig. 2.15f), and in spite of control a few young swarms formed in both countries in August.

Mauritania remained clear of swarms until July, though scattered populations began to appear in the south in late June. From 5 to 7 July, several swarms appeared in the Atar–Akjoujt areas (between 19° and 21°N, and 13° and 16°W–Fig. 2.15e); these swarms were mature and the females in those examined had already laid but were not yet ready to lay again. From examination of the windflow (cf. Case Study 11.4) and from the state of their ovaries, it is probable that they belonged to the population of swarms which was derived from Arabia and had laid in late June in Niger and Mali (see preceding paragraph), but it is also possible that they had originated during the spring breeding in north-west Africa (see above), as must have the scattered populations invading Mauritania in June and July. The swarms spread through western and south-western Mauritania but were not seen to lay; they were heavily attacked by numerous birds and were apparently partly destroyed and partly dispersed, as only scattered populations were reported in August.

Summer breeding 1968 and spread of resultant swarms

It will be seen (Fig. 2.15f) that by July–August 1968 swarming populations had invaded the summer breeding areas of the North-Central Region, where they were most numerous, and also the Eastern and Western Regions. The summer 1968 breeding was not successful, however, in all parts of the summer belt.

In the *Eastern Region*, laying by invading swarms began in July and continued into early August, when the number of swarm reports fell off markedly, with none reported in Rajasthan after 10 August. In late July, hatching began in southern Sind and south-western Rajasthan, and continued there in August, when it occurred also in north-western Rajasthan (Fig. 2.15g). In the meantime, soil and vegetation were drying out due to increasing drought and hoppers in both countries failed to survive to the adult stage in sufficient numbers to form swarms — partly due to control, but probably mainly due to absence of rain (see Section 2.8). The failure of this breeding effectively cleared the Eastern Region of the plague.

In the *Western Region*, following the formation of small swarms of young locusts in north-western Niger and north-eastern Mali in August (Fig. 2.15f), large scattered populations, groups, and small mature swarms were reported in both countries in September–October. Breeding had continued through the summer (cf. Fig. 2.15g), and in October control was in progress against bands of hoppers and groups of adults.

Further west, in Mauritania there was a local infestation by groups of green hoppers in the south in August, and a more widespread infestation by bands of mixed instars in the second half of September (Fig. 2.15g). The rainfall in Mauritania was said to have been deficient in July and August, and it appears probable that these bands were the progeny of scattered locusts and survivors from July swarms, which had become concentrated in limited green areas suitable for breeding. Control was carried out in September and residual populations of young adults formed groups in October.

In the *North-Central Region*, some summer 1968 breeding took place on the Yemen Tihamah (where hoppers were controlled in the Zaidiya area (15°N 43°E) in August) and in P.D.R. Yemen (where there were hopper infestations in the south-western parts of the country in September–October, and further reports of swarms in October (Fig. 2.15g)).

The most serious and extensive summer breeding developed in 1968 in Sudan, where swarms invading the country from Arabia and the Somali Peninsula in June (Fig. 2.15e) laid eggs in July–August throughout the summer breeding belt running from the Red Sea and Kassala Provinces through Northern, Atbara, Khartoum, Kordofan and Darfur Provinces. Hatching began in the last ten days of July and continued into August, and locally to September. In spite of control operations there were escapes, and fledging and formation of young swarms began in the later part of August and continued in September, when there were reports of many young swarms.

Young swarms emigrated from Sudan, partly to the east and partly to west. The eastward movement to the winter breeding areas around the Red Sea began in September, when some swarms moved to the coastal areas in Sudan and the Eritrean Province of Ethiopia, spreading further to the south in the following month. Then in October, some swarms moved north-east to southern and south-eastern Egypt, with a swarm reaching the north-western coast of Arabia (Fig. 2.15g).

Similarly, the westward emigration towards spring breeding areas in north-western Africa began in September, with swarms appearing in eastern Chad near the Sudan border in the last ten days of September and again in early October, and with some swarms reaching north-western Chad by 5 October. By 6–8 October, swarms reached the south-eastern Algerian Sahara, appearing north-west of the Haggar Mountains by the 12th. Further south, some reached south-central Niger by the 10th and moved through Niger Tamesna from the 12th, and Mali Tamesna from the 14th. Still further south, some swarms appeared in north-eastern Nigeria from the 18th.

Further west, swarms appeared in west-central Mauritania from 17 October, and in southern and northern former Spanish Sahara from the 22nd, finally reaching south-western Morocco by the end of the month (Fig. 2.15g). During this rapid movement, swarms spread widely over the Western Region, but by November–December most of them became concentrated in Mauritania, former Spanish Sahara and Morocco. The weather systems in which the westward spread had occurred in 1968 are illustrated in Betts (1976), while Case Studies 17.1 to 17.5 deal with the weather systems during a comparable spread across the continent in September–October 1954.

In the *South-Central Region*, following invasion from the north-west in August 1968 (Fig. 2.15f), the swarms remained without breeding in the northern part of the Somali Peninsula during September. In October, they began to spread further south over the Peninsula (as they usually do at this season) and to mature and lay.

It will be seen from the preceding account that, some 12 months and some four locust generations after the appearance of large scattered populations and swarmlets in the Red Sea and Gulf of Aden areas in October 1967 (or some 18 months and perhaps six locust generations after the probable beginning of population build-up in south-eastern Arabia following the March–April 1967 rains), the plague was widespread over three of the major Desert Locust Regions, with the fourth free of the plague only because of the scarcity of 1968 monsoon rains.

2.7.4 MAIN FEATURES OF PLAGUE UPSURGES AND EXPANSIONS

The outstanding features of the 1949 and the 1967–68 plague upsurges were:

- repeated occurrences of widespread and abundant rains, falling at appropriate intervals for successful breeding by sequences of locust generations, following each other rapidly in the same general areas or in areas connected by movements of adults;
- resultant building up and concomitant gregarisation of locust populations, leading to the production of large numbers of bands and cohesive gregarious swarms.

Examples of such breeding sequences are provided by successions of generations starting in: (a) winter and spring 1948–49 in south-eastern Arabia and continuing in summer 1949 in the monsoon breeding areas of India and Pakistan (Section 2.7.2); (b) spring and summer 1967 in southern Arabia and continuing in the 1967–68 winter and spring seasons on the Red Sea coastal areas of Arabia, and then in the interior of the Arabian Peninsula (Section 2.7.3).

The environmental, behavioural and biological processes involved in plague upsurges are similar to those leading to outbreaks: they involve concentration, multiplication and cumulative gregarisation (Section 2.6). But, for a plague to develop, the factors favouring them (and especially the rainfall favouring successful breeding) have to occur over more extensive areas and recur over longer periods of time.

The *abundant rainfall over extensive areas* had been produced by a variety of mechanisms characteristic of the areas and seasons. In the winter and spring of 1967–68, widespread rainfall over much of the Desert Locust recession area had been particularly associated with deep, slow-moving waves in the upper westerlies (Pedgley 1970a, Bennett 1976, see also Section 3.3.5), whereas some of the heavy and widespread rains over southern Arabia were brought by cyclones moving on to the Arabian Peninsula from the Arabian Sea — e.g., the tropical cyclone of October 1948, and the monsoon depression of July 1967.

The information on the development of earlier plague upsurges is much less complete or absent, but again it points to the importance of repeated abundant rainfall. The early stages of the 1926–27 upsurge (Fig. 2.3) were associated with exceptional rains on the western Red Sea coast in late 1925, and heavy rains in the winter and spring of 1925–26 in the Eastern Region. The building up of populations leading to the 1940 upsurge in the Eastern Region must have begun in the 1939–40 season, but its development was favoured by abundant 1940 monsoon rains in the summer breeding areas of India and Pakistan, and consolidated in the 1940–41 season in Arabia, where heavy rains fell in the south in November 1940 in association with a tropical cyclone, and spring rains were abundant and widespread in the eastern and central parts of the Peninsula (Waloff 1966). Again, the apparently independent upsurge in 1941 in the Western Region developed in a season with repeated spells of heavy rains and floods over different parts of the Sahara between September 1940 and May 1941 (Waloff 1966, 1972).

As to the *kinds and sizes* of populations involved in the initial stages of plague upsurges, there is little information on this important point, and there are different opinions as to their possible antecedents; the alternative hypotheses are discussed in Hemming, Popov *et al.* (1979) and Rainey & Betts (1979).

The build-up in south-east Arabia in the 1948–49 season started about eight months after the last confirmed reports of swarms derived from the preceding plague in the Central Regions — and only 3–4 months after the disappearance of swarms that had formed during the spring 1948 outbreak on the Arabian Red Sea coast. The participation of some swarming populations in this build-up is thus quite possible, though it is not certain (Section 2.7.2). The 1967–68 upsurge followed some five years of recession (Waloff 1976); and the last reports of confirmed recession swarms before the probable beginning of the build-up in southern Arabia in November 1966 or March — April 1967 were in January 1966 (Bennett 1976) — i.e., two or three locust generations earlier. Any later swarm reports remained unconfirmed (Section 2.7.3), and it is quite probable that the populations which multiplied in southern Arabia were initially low-density.

What seems to be particularly significant about plague upsurges is not the kinds of populations which may be involved in their initial stages but the repeated renewal by the rains of widespread conditions favouring successful breeding, with a rapid succession of generations. The resultant continuous increase in locust numbers would almost inevitably lead to gregarisation and to the production of increasing numbers of bands and swarms. Nor does it appear necessary for the initial populations always to differ in their order of magnitude from those which may occur regularly during recessions (cf. Table 2.5). While more investigation is certainly needed on the rates of multiplication in Desert Locust populations, the available data suggest that they may be quite considerable. Thus, Stower (unpublished) has found that congregating Desert Locusts could multiply 100-fold by passing through two successive generations during the winter breeding season on the Red Sea coast of Eritrea, while the multiplication rate between the parent generation and the fourth instar of their progeny observed in 1967 in Tamesna (Section 2.6.2.1) was about 16-fold. Similarly, Joyce (1962), in discussing the build-up of Desert Locust populations on the northern coast of Somalia in the 1956–57 season (following a recession there in 1956), quotes estimates of 4–10 fold increases in each of the three successive generations produced there over the five months of breeding, with the total increase over the season between 100- and 1000-fold.

If, as a first approximation, one accepts a 10-fold increase in each generation, then in a breeding sequence such as that in 1967 and 1968 in Arabia, a moderate population of, say, only two million locusts appearing in southern Arabia (following the probable breeding there on November 1966 rains) might have given rise to perhaps 200 million locusts by October 1967, after passing through two more generations by breeding on the March–April 1967 and July 1967 rains. Even if not more than, say, 10–15 million of these locusts reached the Tihamahs in October 1967, then by the time they had passed through two congregating generations in the coastal areas, and a third generation in the interior of Arabia (Section 2.7.3), the resultant populations appearing in these areas by late May — early June 1968 might have comprised something like 10–15 thousand million locusts.

As to *the location* of areas in which plague upsurges may develop, on the last two occasions (i.e. 1948–49 and 1967) the earlier stages took place in south-eastern or southern Arabia, but the later important breeding sequences continued in the summer areas of the Eastern Region (in 1949) and around the Red Sea and Gulf of Aden and in interior Arabia (in 1967–68). The location of the earlier stages in the 1940–41 upsurge (Fig. 2.3) in the Eastern Region is not known; it is probable that the large scattered populations invading, and forming laying swarms, during the summer of 1940 in the monsoon breeding areas of India and Pakistan developed during the preceding winter and spring in Iran and eastern Arabia (Waloff 1966). In the plague upsurge of 1941 in the Western Region, the populations may have built up in a sequence of generations produced in north-western Niger in the autumn of 1940, in the wadis draining from Ahnet and Tademait in central Algerian Sahara in March–April 1941, and in the wadis on the southern borders of the Atlas Mountains in May–June 1941 (Waloff 1966, 1972). The very incomplete data on the 1926–27 upsurge (Fig. 2.3) suggest that this started both around the Red Sea and in the Eastern Region.

This brief survey shows that, like outbreaks (Section 2.6 and Fig. 2.8), plague upsurges may develop in the central, eastern, and western parts of the recession area. It also shows that in some cases the upsurge breeding sequences may start in one Region and continue in the complementary seasonal areas of another. To foresee a plague upsurge in time, the forecaster will need to have the fullest possible information on locust populations known or suspected to be present in different parts of the Desert Locust area, and on the distribution, magnitude and mechanisms of rains. Special vigilance will be needed when abundant and widespread rains are associated with powerful wind convergence systems capable of concentrating locusts from extensive into smaller areas (Pedgley 1979), and whenever there are sequences of exceptional rains over the same or complimentary breeding areas.

As to the *spread of plagues*, once swarms appear in any numbers, the characteristic seasonal movements (Section 2.4) lead to a rapid expansion from Region to Region. This is well illustrated by the developments in the last two upsurges. Thus, during the 1949 plague upsurge (Section 2.7.2), shortly after the formation of the important population of swarms during the 1949 monsoon season in the Eastern Region and before the end of 1949, swarms re-invaded Arabia and spread to the Somali Peninsula in the South-Central Region (Fig. 2.13e). The progeny of these swarms invaded and bred in Sudan in summer 1950, and before the end of the year the new generation of swarms spread the plague over the Western Region (Figs. 2.13f to h). The spread of a plague between Regions was perhaps even more striking in the 1967–68 upsurge (see Section 2.7.3), in which important developments took place in the more central parts of Desert Locust area. During the period of twelve months from November 1967 to November 1968, there was an incursion by swarms from Arabia into the Eastern Region (in December 1967, Fig. 2.15c), possibly followed by another one in July 1968 (Fig. 2.15f); two invasions of the Somali Peninsula (from Arabia in December 1967 (Fig. 2.15c), and from northern Ethiopia in August 1968 (Fig. 2.15f)); and two incursions from the North–Central Region into the Western Region (in June and in October 1968 (Figs. 2.15e and 2.15g)).

These examples show once again how locust developments in countries widely separated from each other, but connected by locust migrations, depend on each other, and they emphasise the need for forecasters to be continuously aware of the locust situations in all parts of the Desert Locust area.

2.8 TERMINATION OF PLAGUES

As shown in Section 2.7 of this Chapter, once a plague starts in one part or another of the Desert Locust area it usually spreads within one or two years over the other Regions. It may be added that the swarms are able to reach many areas where rainfall is heavier and more reliable than over much of the recession area. The opportunities to breed successfully — and produce more swarms — thus increase during plagues, which in this respect may be said to be self-perpetuating. Yet, after a time, plagues decline and come to an end. Sometimes they terminate in one Region only while continuing in others as, e.g., in 1951 in the Western Region, in 1955 in the Eastern Region, and in 1956 in the South-Central Region during the long 1949–63 plague. Such regional recessions may be brought to an end by local plague upsurges or by invasions by swarms from the neighbouring Regions (Waloff 1976), or both. But eventually the plagues terminate in all the four Regions and major recessions set in. Such declines are usually spread over about two years, and the order in which different Regions become free of the plague varies from occasion to occasion (see Table 2.6).

Table 2.6 Sequences of plague terminations.

1926–34 Plague
- 1932 South-Central
- 1933 Eastern and North-Central
- 1934 Western

1940–48 Plague
- 1946 Eastern
- 1947 North-Central
- 1947 South-Central
- 1948 Western

1949–63 Plague
- 1961 Western
- 1962 North-Central and South-Central
- 1963 Eastern

1967–69 Plague
- 1968 Eastern
- Spring 1969 Western, North-Central and South-Central

The reason why plagues come to an end is not always clear. The rapid ending of the 1967–69 plague has been ascribed to control measures, but in the Eastern Region the major contributing factor was drought, whereas in the South-Central Region it was, at least partly, due to movement of swarms into areas unsuitable for breeding and survival (see below). With regard to the end of the preceding major plague, it has been shown (Rainey, Betts, *et al.*, 1979) that in the Western Region it was brought about by improved control. In other parts of the Desert Locust area, decline of the plague was contributed to by such factors as emigration or drought, in addition to effective control. It can be confidently stated, moreover, that none of the earlier plagues was terminated by control for, even in the 1940–48 plague, insecticides were applied on a scale which was comparatively insignificant in relation to the sizes of the plague populations, while the still smaller scale and often mechanical control applied in earlier plagues could have had no effect on the course of the plagues. It follows that Desert Locust plagues can — and certainly used to — come to an end of their own accord and the reasons for their terminations must be looked for in environmental or some inherent factors.

Among environmental factors, the failure of seasonal rains have, on a number of occasions, led to the termination of plagues in different Regions. The effects of drought could be manifold; e.g., it could lead to the dispersal of swarms (Waloff 1966), or to the failure of locusts to reach sexual maturity, or to the absence of acceptable egg-laying sites, or failure of eggs to develop due to drying out of soil, or failure of hoppers to survive due to lack of food. The latest and the best documented instance of the effects of drought was the failure of the 1968 monsoon breeding in the Eastern Region due to poor monsoon rains. The rainfall requirements for successful breeding (Sections 4.4.1 and 4.7.1) were met in eastern Pakistan and Rajasthan in July only, when the mean rainfall at four representative stations reached 25 mm after six months with little or none. But in August the mean was only 9 mm, followed by none in September and October (Bennett 1976). The July rains were adequate for maturation and laying in July and early August, but in some of the areas the eggs failed to develop and hatch. In other areas, hoppers hatched in large numbers and formed many bands, but none of these survived beyond the third instar, and no swarms were produced in either India or Pakistan. Some of the hopper mortality must have been due to control, which, however, did not extend to all the infested areas, and the major contributing factor was probably the absence of food due to the drying out of vegetation (Bennett 1975, 1976).

Again in the Eastern Region, the previous plague came to an end in 1963 (Table 2.6), when the monsoon rains were late in starting and deficient in amount. In the preceding 1962 monsoon season, only a limited number of swarms was produced, largely due to effective control (Rainey, Betts *et al.*, 1979), and these bred in spring of 1963 in northern Pakistan. Several young swarms were formed, and moved in June–July into Rajasthan. On encountering drought conditions, they became dispersed (as evidenced by widespread occurrence of gregariform locusts among low-density populations), and failed to produce further swarms.

In the South–Central Region, the end of the plague in the 1947–48 season (Table 2.6) was associated with the scarcity of 1947 Short Rains, and consequent failure of the swarms to breed. Again, the 1956 regional recession in that Region followed the scarcity of the 1955 Short Rains. On this occasion the rains favoured maturation of locusts in the northern part of the Somali Peninsula, but many swarms failed to encounter suitable breeding sites during their southward movement over the Peninsula (Section 7.6), and locusts in them cast their eggs on the surface of dry ground. In some localities where eggs were laid they failed to hatch, while hopper bands in the restricted areas suitable for breeding were subjected to heavy predation.

In the Western Region, the plague was brought to an end in 1948 (Table 2.6 and Section 2.7.2) when spring swarms, moving south from Morocco, encountered drought conditions in the summer belt, and apparently dispersed. A regional recession which set in there in 1951 was again due to the scarcity of summer rains and absence of summer breeding.

Another important environmental effect which may lead to an abrupt termination of a regional plague is connected with occasional deviations or anomalies in the seasonal incidence of weather systems that transport the Desert Locust populations from one seasonal breeding area to another (see Section 3.5.5). In some cases such anomalies result in most of the swarms produced in a given Region moving off in an unusual direction and failing to breed. An example of this occurred in 1947 in the North-Central Region, where the plague came to a virtual end in that year (Table 2.6), for few if any of the limited swarming populations produced in the summer breeding areas of Sudan and Ethiopia migrated to Arabia, as they usually do, but instead apparently moved south into the South-Central Region. Similarly, the end of the plague in the North-Central Region in 1962 (Table 2.6) occurred when apparently none of the numerous spring generation swarms produced that year in Arabia and other Middle East countries moved south-west, as they usually do, to the summer breeding areas in north-eastern Africa, but all migrated eastward instead to summer breeding areas in the Eastern Region. (There was no summer breeding in 1962 in Sudan; moreover, only a few local swarms bred in northern Ethiopia, and their progeny was effectively controlled.)

In yet other cases, plagues come to an end in particular Regions when whole regional populations are transported to, and retained in, areas which are unsuitable for breeding and for survival. For example, plagues came to an end in the Eastern Region in 1946 (Table 2.6), and again in 1955, when spring generation swarms moving from the west into the summer breeding areas spread eastward beyond them: into eastern Madhya Pradesh in 1946, and as far as Bihar and Orissa in 1955. The eastward migrations beyond the summer breeding areas are unexceptional and are usually followed by a return westward movement to the latter (see Section 5.14), but in 1946 and 1955 the swarms did not return and they disappeared without breeding. Again, the end of the plague in the South-Central Region in early 1969 (Table 2.6) followed the movement westward into the Ethiopian Highlands of the 1968 Short Rains generation swarms produced on the Somali Peninsula. Such movements are usually followed by an eastward return to the lower ground before breeding during the Long Rains (Section 7.9), but in 1969, apart from reports of an isolated swarm in western Somali Republic (North) in April, there were no confirmed swarms in the Region after February.

Turning next to biotic factors, their possible effects on Desert Locust plague dynamics have been considered by Greathead (1966). After taking into account all the available quantitative data on the effects of natural enemies, he concluded that while these could prevent or delay the building up of local outbreaks in areas of high breeding frequency, they probably did not materially affect large gregarious populations at the height of plagues. Thus, it does not seem probable that declines of Desert Locust plagues are initiated by natural enemies, but the latter can become very important among diminished populations in the later stages of plague declines. For instance, in the case of the regional plague decline on the Somali Peninsula which followed the partial failure of the 1955 Short Rains, the hopper bands appearing in the limited areas which had received adequate rainfall were largely eliminated by birds which were similarly concentrated in areas of localised rainfall (Hudleston 1958).

Finally, a brief reference may be made to what is known about the *lengths* of regional Desert Locust plagues. A statistical analysis (by Green, in Waloff 1976) of the frequency distribution of the lengths of 40 regional plagues, whose durations could be reconstructed from historical records, has shown that if a regional plague persists for more than a year then it is likely to last 6 to 8 years, but unlikely to last any longer. The reason why regional plagues have a tendency to last this period but no longer is not clear, but it has been suggested that this might be due to a hypothetical progressive reduction in the viability of populations passing through a long succession of gregarious generations (Waloff 1976).

3 MIGRATION

To migrate is to move from one place to another. In this Chapter we describe the sequence of activities which results in the MIGRATION of adults from the place where they fledge to the place where they die. The sequence starts with the departure of young *immature* adults from a breeding area and normally ends when these adults mature and breed. *Mature* adults also migrate between successive cycles of mating and laying, usually but not invariably over shorter distances than immature adults. Somewhat infrequently, migrating adults fail to reach areas suitable for breeding. Although such failures are uncommon they can be of crucial importance in breaking the normal alternating sequence of breeding and migration (see Sections 2.4 and 2.8). Sometimes two, or even three, generations occur in succession in the same seasonal breeding area, with the young adults maturing rapidly and not moving far before breeding again.

There are significant differences in the migratory behaviour of gregarious adults, which normally fly by day, and of non-gregarious adults, which normally fly at night, and they are accordingly treated separately.

3.1 MIGRATION OF SWARMS

Swarm migration is the most striking feature of desert locust biology and has been recorded for over 3,000 years (Exodus X, vv. 14 and 19). Only in the last century, however, have the main seasonal patterns been recognised (see Section 2.4). This was achieved in two ways: by analysing and relating occurrence report for many years to major seasonal weather changes (Waloff 1946b, Donnelly 1947, Davies 1952, Fortescue-Foulkes 1953, Waloff 1966, and Chapters 2, 5–8), and by detailed field studies on the behaviour of locusts in migrating swarms and on the speed and direction of swarm displacement in relation particularly to wind, air temperature and sunshine.

In this Section the main features of swarm behaviour and the environmental factors which govern the direction and speed of swarm displacement are described.

3.1.1 INITIAL FORMATION OF SWARMS

As breeding comes to an end the hoppers moult for the last time and the adult stage begins. The final moult is called FLEDGING and the newly emerged adults FLEDGLINGS (Section 4.9). At the time of fledging the wings are soft and crumpled, but within about 30 minutes they expand to their final size and start to harden. At the same time the whole integument, or outer skin, acquiries the pink coloration of the young immature adult of the gregarious phase. At first, fledglings bask, march and feed like hoppers of the gregarious phase (see Section 4.8), but as their integument hardens and their flight muscles develop they start to make short flights. These flights become longer and higher and are undertaken by progressively more individuals. About 3–6 days after fledging, whole groups of adults start to leave the band area. During the next few days, the groups coalesce and start to form swarms which may appear from about one week after the onset of fledging. Some 2–3 weeks after fledging started, swarm formation may be complete and the adults may be a hundred or more kilometres downwind from the breeding area.

There are three points of significance to forecasting in this process of swarm formation.

- Reports of *scattered* fledglings or *groups* of fledglings can be taken as good evidence that breeding has occurred recently in, or close to, the locality mentioned.
- Reports of fledgling *swarms*, however, are likely to refer to a later stage in swarm formation and probably to a locality some distance from the site where the breeding occurred.
- Even the largest swarms start as small swarmlets that grow by coalescence, so that reports of fledgling swarmlets do not preclude the later formation of large swarms.

We now consider the three main aspects of migratory flight: mass departure, displacement and settling. These are most clearly displayed by *immature* swarms since they are not interrupted by breeding behaviour, and most of Sections 3.1.2, 3.1.3 and 3.1.4 refer to such swarms unless otherwise stated.

3.1.2 MASS DEPARTURE

In this Section we consider the main factors which will help a forecaster estimate the time at which a swarm will depart from its overnight roost site and thus help him decide how long a swarm may fly each day.

Swarms usually roost by night on bushes and trees. In the morning they feed and bask in the sun, and gradually begin to fly about over the roosting site. At first a few and then increasing numbers of locusts take off for short descending flights, but, as the morning advances and temperature rises, more and more locusts take off from vegetation and ground for longer flights. The behaviour of gregarious locusts is greatly affected by their reactions to each other, and presently whole groups of locusts flying on a common orientation (though with orientation varying between groups) are to be seen 'streaming' over the roosting site. The streams become larger as more locusts take off and flights become longer and higher. Finally the swarm moves away from the roosting site with the last of the settled locusts rising to join in the streams. This *mass departure* from the roost marks the beginning of diurnal migration which is characteristic of swarms (Kennedy 1951, Waloff & Rainey 1951).

Locusts cannot beat their wings and fly unless their flight muscles are warm enough. In overcast weather with thick cloud, or after sunset, the thoracic temperatures of settled locusts are within 1–2°C of air temperatures, and the lowest air temperatures in the absence of sun at which disturbed and chased locusts can perform low, short flights of a few metres are 19–21°C. But before a swarm can migrate locusts must be able to gain height and fly longer, i.e., their flights must become *sustained*. The lowest air temperatures *in the absence of sun* at which sustained flight has been seen to begin in *immature* swarms is 23–24°C, while with *mature* swarms the air temperature may have to rise to 26°C (Gunn, Perry *et al.* 1948, Waloff & Rainey 1951).

The air temperature limits for flight activity are greatly modified by the effect of sunshine. As locusts bask in the sun, by turning their bodies at right angles to its rays, their body temperatures are raised. It has been shown (Gunn, Perry *et al.* 1948) that in continuous bright sunshine thoracic temperatures of the warmest locusts may exceed those of the air by 10°C within one hour of sunrise. Locusts may thus take off at much lower *air* temperatures in sunny than in overcast weather. Although their rate of loss of heat to cooler air greatly increases as soon as they begin to fly, this rate of loss is partly compensated by the rate of gain of metabolic heat generated by the working flight muscles. According to Weis-Fogh (1956), metabolic heat may raise thoracic temperatures of steadily flying locusts 6°C above air temperature. As the result of these combined effects, immature swarms have been seen to leave their roosting sites, in continuous bright sunshine, at air temperatures down to 17°C in Kenya (Gunn, Perry *et al.* 1948), and apparently even at 14.5°C in Morocco (Rungs 1946). But it was noted that at air temperatures below 23°C flight over roosting sites gradually ceased whenever the sun became obscured.

From their observations in Kenya, Gunn, Perry *et al.* (1948) found that there was a correlation between the temperature (in °C) at mass departure, T, and the maximum temperature of the previous day, P, as follows:

$$T = 0.51\ P + 6.2.$$

They noted that the correlation was not very reliable, the above quoted record from Morocco fitting least well. Waloff & Rainey (1951) obtained a slightly different but much closer correlation, as follows:

$$T = 5.6 + 0.74\ X,$$

where X is the mean temperature (in °C) of the preceding day, i.e. 0.5 (maximum + minimum), but suggested that the correlation was due largely to the diversity of temperature regime of the localities where mass departure was observed and considered that there was no satisfactorily demonstrable effect of the preceding day's temperature on subsequent behaviour of the locusts.

Some observations on behaviour at much higher temperatures, however, suggest that there may be a stronger conditioning effect than was formerly thought. Thus, on the northern coast of Somalia in June 1957, fledgling swarmlets were seen departing from their overnight roosts at air temperatures of 31–38° when the previous day's maximum and minimum temperatures were 42–44°C and 25–30°C respectively (Roffey, unpublished). In the Hadhramaut in May 1956, an immature swarm was beginning to take off when the temperature was 35°C and the previous day's maxima and minima were 39°C and 14°C respectively (Roffey, unpublished). In both cases the Waloff & Rainey equation provides a better prediction than that based on Gunn, Perry *et al.* (1948), and a close prediction for the lower temperatures at which take off was observed in Somalia. On the other hand, the Hadhramaut swarm was taking off at a temperature some 10°C above that predicted by the Waloff & Rainey equation. In this case, however, the distribution of the settled locusts suggested that the swarm had been flying during at least part of the previous night and may have been suffering from fatigue.

Whereas immature swarms *usually* take off in the morning there is evidence that at high temperatures young immature swarms fly only at night: e.g., in Baluchistan in June (Predtechenskii 1938), and possibly in Morocco (Regnier 1931), although it is not clear in the latter case whether the swarms were also flying by day.

These results lead to the general conclusion that *swarms take off at higher temperatures in warmer weather and at lower temperatures in cooler weather*, but it must be borne in mind not only that mass departure will not occur below 23°C unless there is sunshine, but also that other factors may inhibit flight. These include strong winds, rain and fatigue.

Light winds of up to about 4 metres a second do not inhibit the development of flight activity in immature swarms, but stronger winds may do so. Waloff (1972b), studying swarm behaviour in the northern Somali Peninsula during the south-west monsoon (kharif), found that at mean winds of 6 to 10 metres a second which blew there in the mornings, locusts took to the air only during lulls and resettled during gusts, and, in spite of high air temperatures and sunshine, the swarms did not begin to drift away from the roosting sites until some 4 to 6 hours after sunrise, when the lulls became more prolonged.

At low air temperatures, rain may further delay mass departure or prevent it altogether (Waloff & Rainey 1951).

Swarms which have continued flying into the night may delay their departure until they have fed, as in the Hadhramaut example quoted above.

There are two other circumstances when take-off can occur. One is when swarms which have settled completely at around midday in hot weather (See Section 3.1.6) take off again in the afternoon, as temperatures decline (Predtechenskii 1935). The other is when young immature swarms in hot weather take off in the evening and may continue to fly until well into the night (Predtechenskii 1935, 1938).

The net result of these interacting factors is that, over much of the Desert Locust invasion area, swarms leave their roost sites and begin to migrate about two to three hours after sunrise during the warmer months of the year. But in highland areas, and in other areas which experience strong winds or a cool season, mass departure may be delayed until four to six hours after sunrise or it may be totally inhibited by low temperatures, the absence of sunshine, or rain.

3.1.3 SWARM STRUCTURE

Before discussing the direction and speed of *swarm displacement*, i.e., the track of a swarm across land or sea, it is appropriate to describe swarm structure because this is relevant to the speed of swarm displacement and to the interpretation of field reports, and it may help to account for the absence of swarm reports in areas and at times when swarms were likely to have been present.

Desert Locust swarms can exhibit great variability in structure. Those that are flat (tens of metres deep) and low-flying are termed STRATIFORM, whereas those towering upwards (sometimes to over 1,500 metres above the ground) are termed CUMULIFORM (Rainey 1958b). The variability of density of locusts in swarms has been outlined in Section 2.3.1.2.

When there is little or no convective turbulence, swarms are stratiform and low-flying. Stratiform swarms have also been observed in moderate convective turbulence but they have been small, up to a few square kilometres in extent. Very infrequently, distinct horizontal layering has been observed in swarms hundreds of metres above the ground in the late afternoon, when turbulence has been declining.

Swarms in moderate or intense convective turbulence are usually cumuliform and may extend vertically up to close to the limits of the turbulence (Rainey 1958b). Over large parts of the Desert Locust invasion area convective turbulence may reach up to at least 1,500–2,000 metres during the early afternoon in the warmer and drier months of the year, so that high-flying cumuliform swarms are a characteristic feature of Desert Locust migrations.

As Rainey stated (1958b), the detailed structure of cumuliform swarms challenges qualitative description, but he provided many graphic descriptions of their appearance from both ground and air, emphasising that they were everchanging. In fine weather, cumuliform swarms seen from a distance (and in good visibility large cumuliform swarms can be seen at distances of 100 kilometres) often have the appearance of smoke but have usually been distinguishable from smoke by a characteristic fibrous or streaky texture. When viewed from close range they often have a characteristic reticulated structure with swirling veils or near vertical sheets of denser locusts which are constantly disappearing and reappearing. The simplest model of cumuliform swarm structure seems to be of groups of locusts concentrated into the walls of giant colums (see Gunn, Perry *et al.* 1948) in which they fly in nearly vertical sheets gradually changing their orientation. When end on, such sheets appear as the dense streaks; at right angles they appear as the wispy veils. A similar effect, but on a larger scale, has been observed frequently in northern Somalia along the windshift line which develops almost daily there between June and September (Rainey 1958b, Sayer 1962; see also Section 7.3).

Throughout the greater part of a cumuliform swarm the various sheets are oriented in different directions although, as Waloff has shown (1972b), there is a predominance of downwind orientations amongst the higher-flying locusts. As a result of the internal variation in orientation, cumuliform swarms are drifted downwind. There are exceptions to this generalisation; for example, low-flying mature swarms often fly into wind in light winds, but the speed at which they displace and the distance which they travel is much less than for swarms which are drifted downwind.

Because locusts fly or stream in a great variety of directions, forecasters need to realise that reports of locusts flying in a specified direction in a swarm should not be taken to mean that the swarm *as a whole* is moving in that direction.

Around the periphery of a swarm, any individuals or groups of locusts emerging beyond it head back towards the swarm so that the cohesion of swarms is maintained over periods of weeks (see Sections 2.3 and 2.4, also Chapters 5–8). Sometimes swarms fail to maintain their cohesion. Break-up, which may be only temporary, may happen under the following circumstances.

- When swarms contain individuals in different stages of maturation, the earlier maturing individuals form copulating and laying groups, while the later ones may depart as separate swarms (Popov 1954a) (see Section 4.2.2). After the latter have in turn copulated and laid they may resume migration as cohesive swarms.
- When swarms encounter strong winds. Two separate effects of strong winds have been recorded in northern Somalia between June and September (during the 'kharif', or south-west monsoon season). Waloff (1972b) described how individuals in a swarm, instead of departing together from their overnight roost sites, left by very intermittent and low flights during relative lulls in the wind. As the lulls became longer the flights became longer so that a swarm elongated downwind from its roost. Such swarms normally reformed during the afternoon at the wind convergence line that forms on many days near the escarpment. The second effect occurs during the afternoon if swarms encounter strong winds blowing outwards from rain storms (Sayer 1962).

In all types of swarm, a considerable proportion of individuals is usually settled on the ground. Typically, it is the locusts at the leading edge of a swarm which settle first, often in vast numbers and very densely (Gunn, Perry *et al* 1948, Waloff 1958, 1972b). While these locusts are settled (and usually, but not necessarily, feeding), others continue in flight overhead until they in turn settle. Some groups take off throughout the passage of a swarm, but eventually all the locusts which are still settled at the approach of, or during the passage of, the trailing edge of the swarm take off and rejoin the swarm. The whole swarm therefore proceeds in a rolling manner (Gunn, Perry *et al.* 1948, Waloff 1958, 1972b). Only rarely have swarms been seen with no individuals settled beneath them.

It should be noted that as turbulence changes so does swarm structure. Thus, a swarm that is cumuliform and high-flying in intense convection during the middle of the day becomes stratiform some hours later as convection rapidly decreases towards sunset.

3.1.4 **DIRECTION OF SWARM DISPLACEMENT**

Even in biblical days it had been recognised that Desert Locust swarms move with the wind — 'and when it was morning the east wind brought the locusts' (Exodus X, v. 14). Detailed investigations this century have shown why this is so. Waloff (1946b), analysing many years of reports of swarm sightings in relation to seasonal winds, found that the major trends of migrations are *down* the prevailing winds and change with them. Rainey (1951), studying a number of specific long-range migrations, proposed the general hypothesis that major swarm migrations are downwind and take place towards, and with, zones of low-level wind convergence. He also showed that such migrations had survival value, for areas of low-level wind convergence are more likely to receive rain than others (Section 4.11). Subsequently, Rainey (1963) showed that the reason why the long-range migrations were downwind was because the short-term, hour-to-hour displacements were themselves downwind. Although there are some circumstances in which swarms can displace short distances upwind, e.g., low-flying mature swarms flying into light winds, there is now overwhelming evidence that the direction of displacement of swarms, particularly immature swarms, is *downwind*.

The most complete studies on the direction of swarm displacement in relation to wind direction comprise a series of observations on mainly immature swarms in eastern Africa (Rainey 1963). These studies consisted of obtaining successive fixes on positions of swarms, usually from light aircraft, and comparing the direction of displacement of each swarm with the mean wind direction at the time up to the height of the topmost locusts. The results, presented in Fig. 3.1 (Rainey 1963), show that out of the 42 best documented observations 26 swarm displacements were within 10° of downwind. Although these studies were made in eastern Africa, there is no evidence from other parts of the invasion area to suggest that the vast majority of swarms are displaced other than downwind. This finding is of the greatest importance to forecasters. They should also take particular note that the wind direction down which swarms are displaced is the *mean* wind direction up to the height of the topmost locusts and not just the surface wind. Rainey (1963) pointed out that there were only 3 cases out of 49 in which the direction of swarm displacement appeared to be significantly closer to the wind at lower levels than to the mean wind up to the top of the swarm. If only surface wind observations are available to the forecaster, the direction of swarm displacement is likely to be 10°–20° to the right of down the surface wind (due to frictional drag on the wind near the ground—see Section 3.3.2.3).

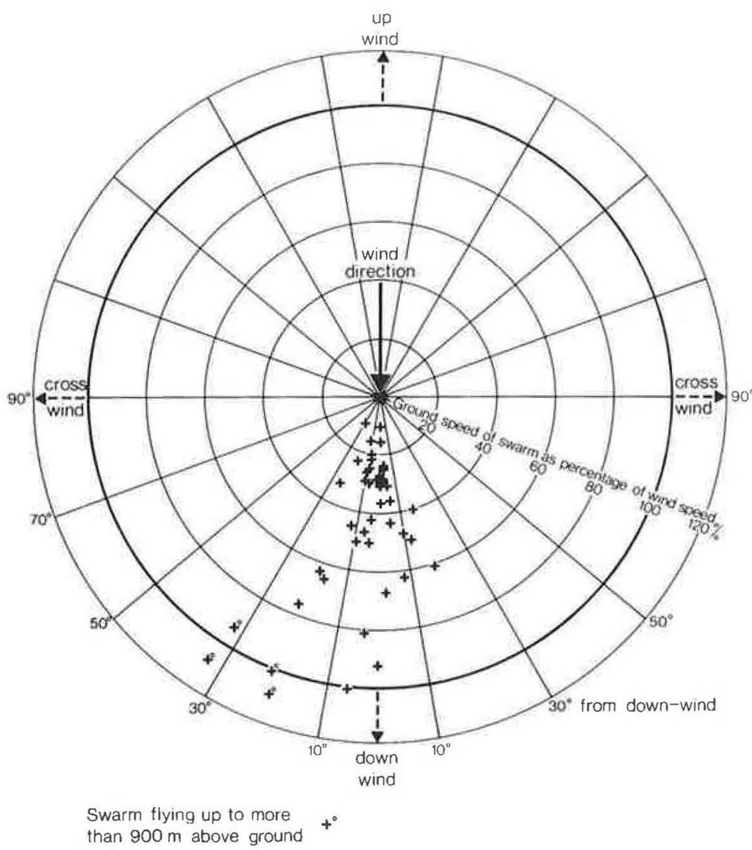


Fig. 3.1 Direction and speed of displacement of individual Desert Locust swarms in relation to the wind: eastern Africa 1951–57 (After Rainey 1963).

Sometimes considerable numbers of locusts may take off and fly over roost sites, yet the swarm *as a whole* does not change position. Circumstances under which swarms do not displace, despite daily flight are (a) when parts of mature swarms are copulating and laying (Popov 1958a), (b) in cold areas where few locusts can fly, e.g. the mountains of Ethiopia, Tanzania, Kenya and Sudan (Rainey 1963 and Section 3.1.8), and (c) when there is no wind (Waloff, personal communication).

Resultant displacements of swarms moving downwind are described in Sections 2.4, 3.1.8 and 3.1.9, in Chapters 5–8, and in the Summaries and Case Studies.

3.1.5 SPEED OF SWARM DISPLACEMENT

The studies in eastern Africa on the *direction* of swarm displacement in relation to wind direction, described in Section 3.1.4, also showed that the *speed* of swarm displacement was related to the mean speed of the wind up to the height of the topmost locusts. Rainey (1963) noted that in none of the 42 observations did the ground speed exceed the wind speed by more than would be expected from errors in measurements, and in most cases the ground speed was less than half the corresponding wind speed (Fig. 3.1). The same data are presented in a different form in Fig. 3.2, from which it may be seen that the swarms travelled at ground speeds of 1.5 to 16 kilometres an hour, with the highest ground speeds occurring at wind speeds of about 12–24 kilometres an hour, intermediate between the recorded extremes (41 and 6 kilometres an hour).

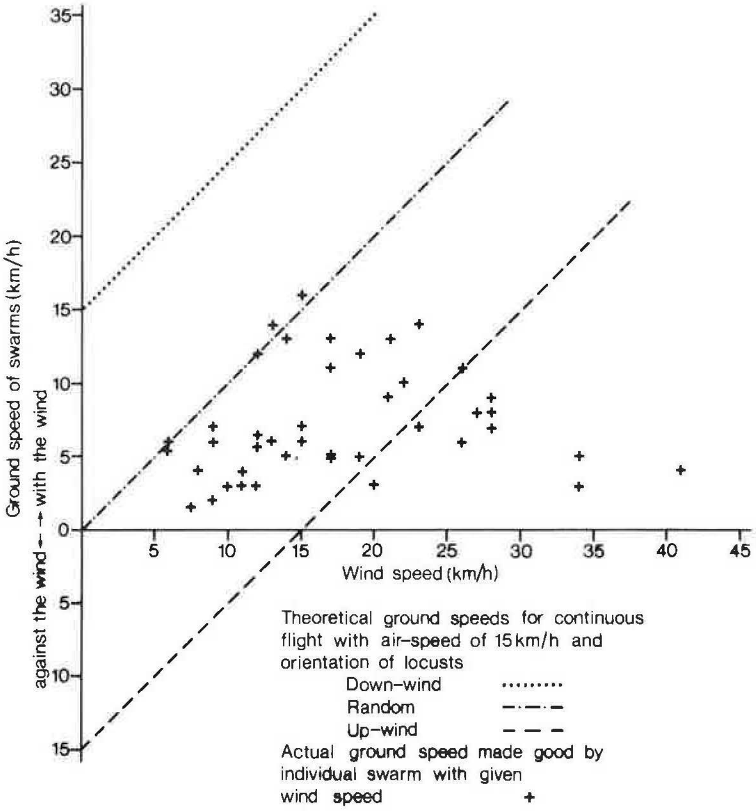


Fig. 3.2 Ground speed of individual Desert Locust swarms in relation to wind speed (after Rainey 1963).

Further examination of Rainey's (1963) data by Draper (personal communication) showed that speed of swarm displacement (or ground speed, D kilometres an hour) was correlated with wind speed (W kilometres an hour) and the maximum height of flight (H metres):

$$D = 0.9071\ W - 0.0199\ W^2 + 0.0049\ H - 3.7373.$$

This relationship can be represented on 3-dimensional axes (Fig. 3.3).

Draper then compared the trajectories of swarms produced in Sudan in August—September 1968, estimated assuming that swarms travelled downwind at the wind speed 900 metres above ground level (Tucker 1976), with trajectories computed using the multiple regression equation. He also assumed that in areas with little or no vegetation (north of 20°N in the example) swarms would settle less than in areas with rather more vegetation, and for such areas he assumed that swarms would displace at wind speed (taken to be the wind at a height of 900 metres). Draper concluded that in areas where speed of swarm displacement may have been reduced by settling (south of 20°N) the regression equation gave generally plausible trajectories, and that for areas with little or no vegetation displacement at wind speed was more acceptable. It should be noted that on some days some swarms were estimated to have displaced at ground speeds of over 30 kilometres an hour, using wind or multiple regres-

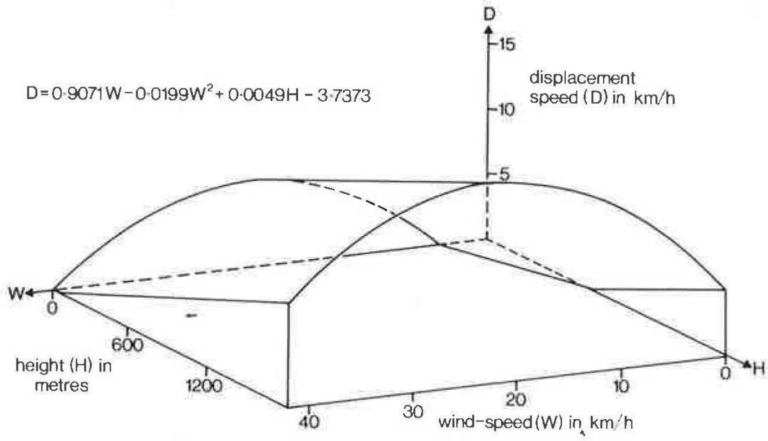


Fig. 3.3 Relation between swarm displacement speed, wind speed and maximum height of flight (after Draper).

sion as appropriate. Some of these speeds were much greater than those attained in the east African examples, and similar speeds must have been attained in some of the movements described in Chapters 5–8 (see also Section 3.1.9, and the Summaries and Case Studies).

The reasons why large and high-flying swarms have higher speeds of displacement than small low-flying ones in the same environment are not fully understood. Waloff (1972b) found that the orientation of groups of locusts flying at lower levels was effectively random except at the edges of swarms (see Section 2.3.1.2), but that at 300–400 metres above ground level the mean orientation was only 13° from downwind. Another reason in many instances is likely to be the normal, but not invariable, increase in wind speed with altitude (see Section 3.3). A third reason, the drag effect created by locusts in rolling swarms settling to feed, has already been noted (see Section 3.1.3).

The effect on immature swarms of vegetation in areas where seasonal rains are beginning is considered in Chapter 4.

Although use of the multiple regression equation and the assumption that it applies only in areas with some vegetation (amount as yet undefined) has so far been very restricted, it appears to offer forecasters a better method of estimating speed of swarm displacement than any other. Forecasters should therefore examine reports of swarms (particularly immature) for estimates of height of flight or for any information which would allow such an estimate to be made (e.g., whether the swarms are said to be cumuliform or stratiform, the occurrence of moderate or high air temperatures, presence of fair weather cumulus cloud) and apply the multiple regression equation for areas where there is known to be some vegetation. If no information about height of flight is available, and it cannot be estimated from other sources, then speed of swarm displacement should be assumed to be at the wind speed. The latter should also be assumed for areas with little or no vegetation and where there is no evidence of rain during the preceding 3–4 months.

3.1.6 **SETTLING**

In the course of the daily migration by rolling swarms, groups of locusts settle and take off repeatedly even when the topmost locusts are hundreds or thousands or metres above ground (see Section 3.1.3). At *low* air temperatures, in the range 20–23°C, when swarms are usually low-flying, the passing of a cloud across the sun causes rapid settling, but when the sun reappears the swarms take off again (Gunn, Perry *et al.* 1948). There is also evidence that swarms may settle in the middle of the day at *high* air temperatures. Predtechenskii (1935) recorded that swarms in Central Asia which took off normally in the morning settled around 1100 hours, when the air temperature was 39°C. *Heavy* rain causes locusts to settle, but flight can continue in drizzle (Waloff & Rainey 1951). The possibility that individuals in swarms may settle more frequently when traversing better-vegetated areas than when traversing areas with little or no vegetation has been mentioned in Section 3.1.5.

Eventually, in the late afternoon or early evening, a swarm usually settles at its overnight roost site. The process of settling has not been studied so thoroughly as take-off and mass departure, but the following seem to be the main features. In the late afternoon, about 1–2 hours before sunset, the maximum height of flight of cumuliform swarms starts to decrease, perhaps due to the rapid decrease in convection which occurs at this time (see Section 3.3.6). The number of locusts flying close to the ground increases, so swarms which were cumuliform in the early afternoon may later become stratiform. The number of locusts settled beneath a swarm increases and eventually all settle at the roost site.

In eastern Africa, swarms have been seen to settle finally for the night at air temperatures ranging from 19 to 23.5°C (Gunn, Perry *et al.* 1948) and from 21 to 29°C (Waloff & Rainey 1951). Settling took place from about two hours before sunset to about half an hour after. It is also possible that decreasing light intensity may induce settling, but its influence has not been separated from the other environmental changes which occur in the late afternoon and early evening.

Sometimes swarms continue to fly after dark. This seems to happen most often with high air temperatures and with flight over the sea. Regnier (1931) stated that immature swarms migrated at night in Morocco, but only when air temperatures exceeded 27°C (although in this case it is not clear whether the swarms were also flying by day). Predtechenskii (1935) recorded night flights (by immature swarms in Middle Asia in July 1929) which were described as intensive at temperatures between 26.5 and 29°C, and weak at temperatures of 24 to 26°C, while temperatures falling below 24°C led to settling. Waloff & Rainey (1951) observed clouds of locusts in flight at heights of up to about 300 metres about half an hour after sunset on the slopes of Mount Kenya, and they suggested that the air temperature at the height at which the locusts were flying was likely to have been rather higher than the 25°C recorded at a height of 1.5 metres (see also Section 3.3.6). Other areas where swarms have been observed flying after dark include: Jordan, as late as 0430 hours in the morning (Bodenheimer 1929); Egypt, where many swarms were recorded settling around midnight in June 1968 (Nahas 1969); Chad, where a swarm was seen in flight at 2300 hours when the temperature was 30°C (J. Castel, personal communication); and Somalia, where part of a swarm was seen flying across the face of the moon at 2300 hours in September 1957 (Roffey 1963).

The best direct evidence of night flight by swarms over the sea was provided by the radar detection of a mature swarm over the Persian Gulf about midway between Bushehr and Kuwait two hours after sunset on 22 March 1954 (Rainey 1955). On this occasion the swarm was not far from land, but much more impressive although less direct evidence of delayed settling has been obtained in studies of calculated trajectories of swarms making long-range flights over water — e.g., from North-West Africa to the British Isles in October 1954 (Rainey 1963), and from Morocco to Portugal in October 1945 (Waloff 1946a). A more recent example was provided by the swarms which reached Gujarat in June 1978. Reports from ships suggest that locusts crossed the northern Arabian Sea on a wide front. They probably came from south-west Arabia or the Horn of Africa and, as on other long-range sea crossings, many settled on the sea and were later washed ashore in the Lasbela district of Pakistan.

3.1.7 DURATION OF DAILY DISPLACEMENT

The *duration* of daily displacement is taken to be the time which elapses between mass departure and final settling. This can be extremely variable for, as has been stated in Sections 3.1.2 and 3.1.6, the times at which both mass departure and final settling occur are very variable and are related to the weather as well as to the physiological state of the locusts, and to whether they are flying over land or sea. Nevertheless, it seems that in warm sunny weather the normal duration of daily displacement is about 9–10 hours, i.e., from about two to three hours after sunrise to around sunset. In cool, cloudy or windy weather the duration may be very considerably reduced, either because mass departure is delayed or because final settling occurs as early as mid-afternoon. The duration of daily displacement in hot weather is more difficult to forecast for, as we have seen in Sections 3.1.2 and 3.1.6, swarms may delay take-off in the morning if they have been flying the previous night, they may settle around midday, they may continue flying after sunset, or they may only take off in the evening. The duration of flight by swarms *at night* is little known.

Forecasters should make themselves aware of the normal duration of daily displacement in their areas by examining swarm reports from earlier years and by referring to the papers quoted in Sections 3.1.2 and 3.1.6.

Although it seems that the normal duration of daily displacement is about 9–10 hours in warm sunny weather, there is good evidence that locusts can fly for very much longer. Thus, the locusts which reached the British Isles in October 1954 were probably airborne for some 60 hours (Rainey 1963); and Waloff (1946a) concluded that the swarms which crossed from southern Morocco to Portugal in October 1945 must have been flying for 24 hours. In the laboratory, Weis-Fogh (1952) found that immature adults normally contained enough fat to fly continuously for about 13 hours, and he calculated that individuals with exceptionally high fat content should be able to fly for about 20 hours. (He also calculated that individual locusts in a migrating swarm might eat up to three times their own body weight of vegetation in a day). He did not imply that locusts normally performed such long continuous flights, and pointed out that in the flight from southern Morocco to Portugal there may have been a good deal of gliding and that many of the locusts may have drowned, as they did later when flying towards the British Isles.

3.1.8 EXTENT OF DAILY DISPLACEMENT

To calculate the extent of daily displacements of swarms, a forecaster needs to know, or be able to estimate, *speed* of displacement, *duration* of displacement and wind *direction*. Methods of estimating speed of displacement have been discussed in Section 3.1.5, and the factors which affect the times at which mass departure and final settling occur, and therefore the duration of displacement, were summarised in Sections 3.1.2 and 3.1.6. In Section 3.1.4 it was shown that, with the exception of very limited displacements *upwind* that are sometimes achieved by mature swarms, displacement is effectively *downwind*. It follows, therefore, that if wind directions are constant in time and space, swarms would always displace in the same direction at any particular place. Wind patterns continually change in time and space, however (Section 3.3.5), and it has been found that the direction of swarm displacement similarly changes in time and space.

Rainey (1963) introduced the concept of CONSTANCY of swarm displacement, which he defined as the ratio of net ground displacement travelled between the first and last observed swarm positions in a series, to the arithmetic sum of all the individual displacements of the same series. He noted that the effective mobility of swarms covered a continuous range, with values of constancy ranging from nearly 100% to nil, i.e., the displacements of swarms during periods of observation ranged from nearly straight lines to complete loops. Rainey considered extent of daily displacement in relation to wind fields in the following four categories.

Progressive systematic swarm displacements

Rainey (1963) found that during periods of effectively constant wind direction, swarms displaced progressively and systematically downwind with a constancy exceeding 75%, and they made displacements of 5–130 kilometres a day. Fig. 3.4 shows the tracks of five swarms which displaced west-south-west across southern Kenya in January 1954 during a period of predominantly north-easterly winds. The uniformity of direction of displacement was maintained despite flight over terrain ranging in altitude from less than 200 to over 2,000 metres. The only marked deviation from west-south-west occurred when the most northerly swarm reached the Rift Valley, where upper winds were not known but where surface winds suggested that the north-east winds did not reach. During the period of these observations the swarms achieved daily displacements of 10–70 kilometres. Rainey described and figured other examples of swarms displacing with a high constancy of direction. There appear to be almost no other comparably detailed published data from other parts of the Desert Locust invasion area, but a single swarm of mixed maturity measuring 6 square kilometres, tracked in Pakistan during June 1976, was found to have displaced 66, 51 and 48 kilometres on successive days as it moved eastward along the Kolwa valley, and altogether displaced 388 kilometres in 6 days. From five successive reported positions, this swarm was found to have a constancy of direction of displacement of 97%. The India Daily Weather Reports for the period show a persistent low pressure area over Quetta with consequent westerly winds over the Kolwa valley.

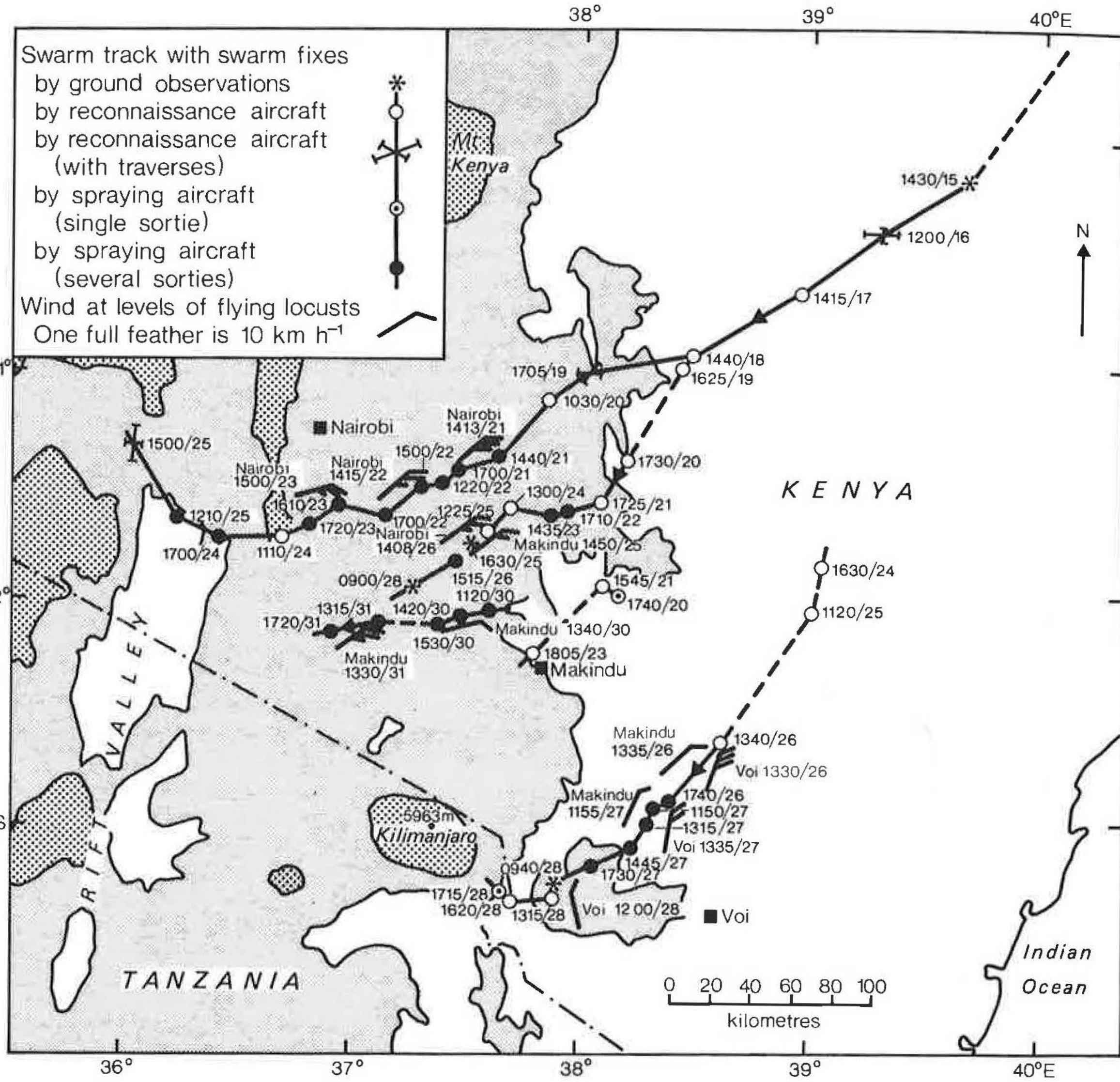


Fig. 3.4 Swarm displacements in a quasi-uniform wind field in Kenya, January 1954 (after Rainey 1963).

Simple changes in direction of swarm displacement

Rainey (1963) illustrated two examples of simple changes in direction of swarm displacement associated with corresponding changes of wind. Fig. 3.5 shows that the successive tracks of a swarm in southern Kenya were very similar to corresponding wind changes over a period of nearly 26 hours. Fig. 3.6 shows the successive positions of a swarm in northern Somalia in alternating winds. The swarm had settled near Borama on the night of 25–26 September and was located near Touligagto at 1315 on 26 September. At Hargeisa, a change in surface wind, from south-westerly to northerly, was noted at about 1330; and between 1618 and 1745 the swarm displaced on a track of 193°, representing a change of at least 90° from its track earlier in the afternoon. On the next day there was a similarly large change in direction of swarm displacement from eastward to south-south-westward when a north-easterly wind developed in the afternoon. In this example the net displacement on 27 September was 58 kilometres, whereas the sum of the individual displacements between successive positions was about 97 kilometres, so the constancy of swarm displacement was about 60%. Similar changes of track are a regular occurrence along or just south of the escarpment in northern Somalia during the south-west monsoon season between June and September (Sayer 1962).

Complex changes in swarm displacement

Rainey (1963) provided a number of examples of complex changes of direction of displacement causing swarms to recross their previous tracks so that their effective displacement for the intervening period was nil. Fig. 3.7 shows the successive positions and track of an immature swarm in western Sudan and the winds in which it was flying. The main features of this example are westward movement by the swarm on 9 and 10 June, when winds were generally from the east, followed by a rapid eastward movement by the swarm on 11 June, when winds had become a fresh westerly. By 1635 on 11 June, it was only 5 kilometres from its position at 1650 on 9 June, having displaced a total of 150 kilometres during the intervening period, corresponding to a constancy of only 3%.

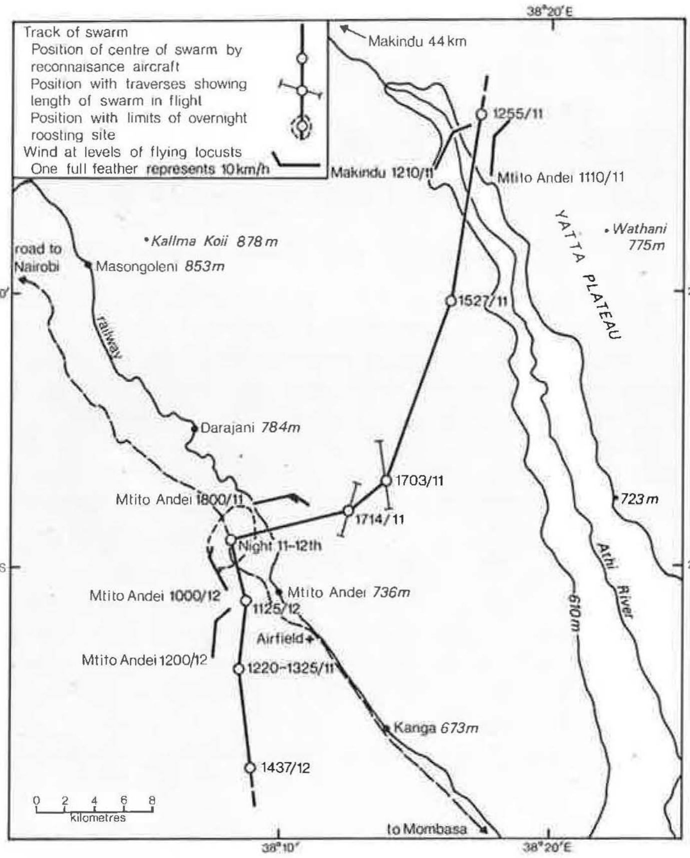


Fig. 3.5 Effects of hour-to-hour changes in wind direction on the displacement of a swarm in Kenya, February 1955 (after Rainey 1963).

A much more complex track was followed by a swarm from late February to late March 1955 in north-east Tanzania and southern Kenya (Fig. 3.8). Between 24 February and the evening of 5 March, the swarm achieved almost zero net displacement, though displacing every day, whilst it was experiencing variable winds in the eastern Usambara Mountains. Then between 6 and 11 March it moved rapidly for about 300 kilometres north-north-west across lowland plains during a spell of south-south-east winds to the northern slopes of Mount Kilimanjaro, where it remained for a further 14 days, apart from a three-day movement over the neighbouring lowlands. Other complex changes of swarm displacement are described by Rainey (1963, pp. 40–51).

Quasi-stationary flying swarms

Finally, Rainey (1963) gives a number of examples in which, despite conspicuous flight, the displacement of a particular swarm over a period of one or more days has been less than the corresponding linear dimension of the swarm, so that the ground positions occupied on successive days have overlapped and the swarm as a whole has

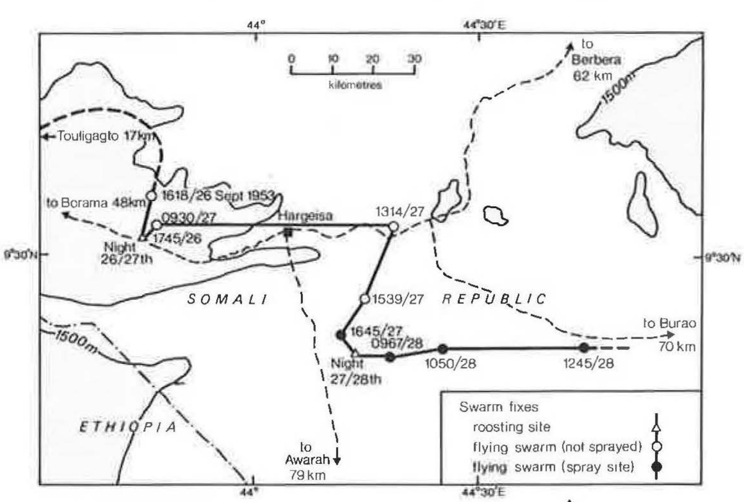


Fig. 3.6 Displacement of a swarm in alternating wind directions in Somalia, September 1953 (after Rainey 1963).

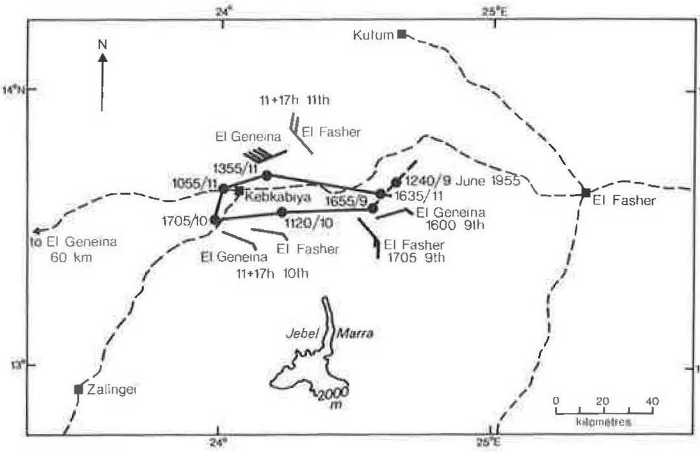


Fig. 3.7 Displacement of a swarm with a reversal of wind direction in the vicinity of the Inter-Tropical Convergence Zone in western Sudan, June 1955 (after Rainey 1963).

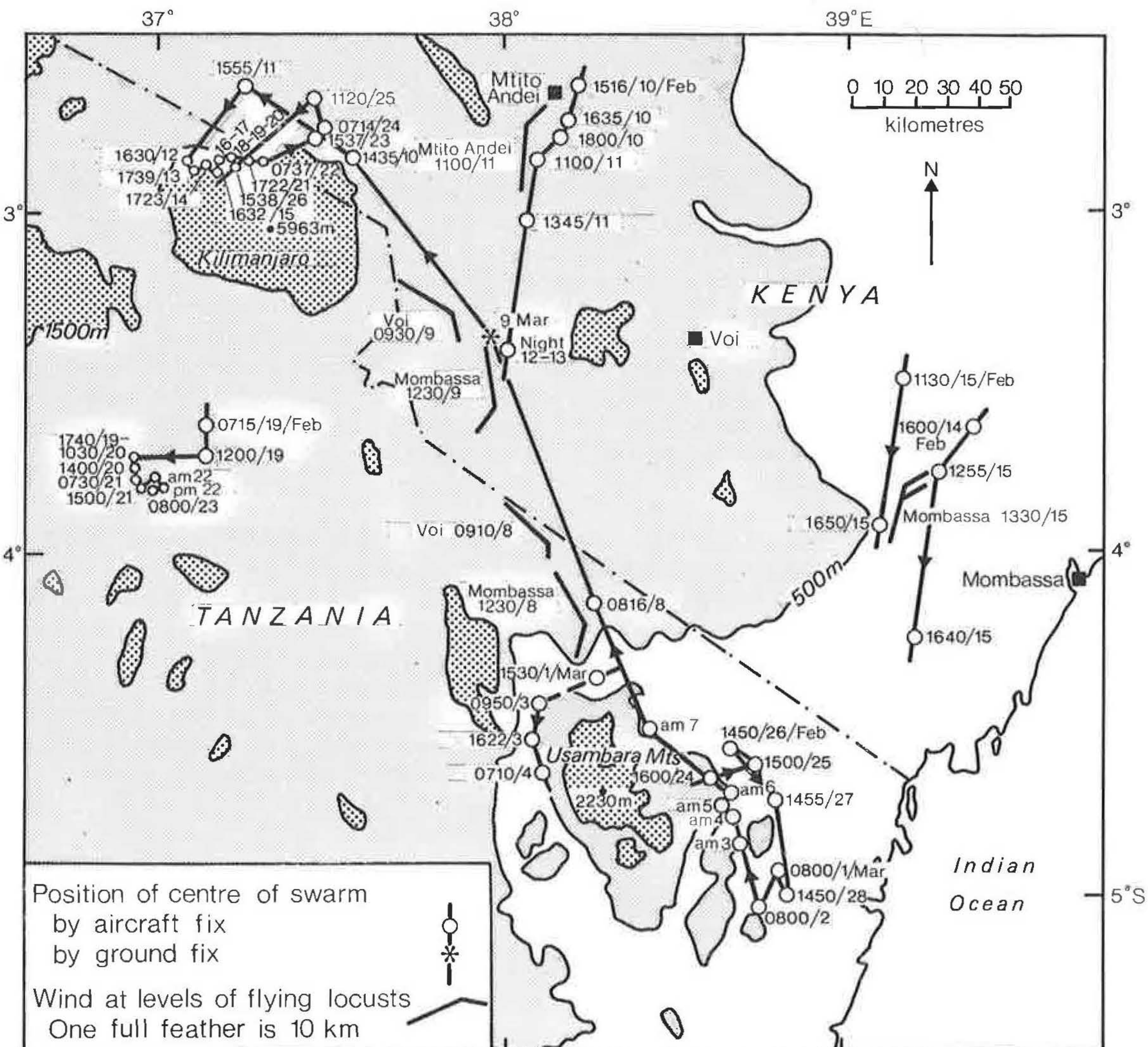


Fig. 3.8 Effects of topography and of the seasonal movement of the Inter-Tropical Convergence Zone on swarm displacements in southern Kenya and northern Tanzania, February and March 1955 (after Rainey 1963).

remained almost stationary. The examples quoted came from Ethiopia, Tanzania, Kenya and Sudan, and Rainey contrasted such effective immobilization, although associated with mountains or escarpments in all cases, with the due general inhibition of flight activity associated with low temperatures, as may occur in Morocco and Iran during the winter months.

Summarising, swarms achieve greatest net displacements when winds blow persistently from the same general direction, at moderate speeds and in warm weather, and lowest net displacements in changing wind fields and in cool weather. In the next Section some examples of longer-range displacements are presented.

3.1.9 RATES OF DISPLACEMENT DURING LONG-RANGE MIGRATIONS

The normal result of successive daily displacements is that each swarm leaves the area where it was bred and migrates downwind to another area where it in turn breeds. In Section 3.1.8 examples are given which show that, because wind direction and speed change in time and space (see also Sections 3.3.4 and 3.3.5), the displacements of individual swarms or groups of swarms can range from almost straight lines for periods of days to sharp bends or even complete loops within one or two days. No swarm has been tracked consistently for longer than about a month, and only rarely for this long (Gunn, Perry *et al.* 1948, Rainey 1963), so evidence on rates of net displacement during long-range migrations, which may last two to four months (Section 2.4), comes from biogeographical analyses of swarm sightings during such migrations.

Table 3.1 summarises the results of some of the biogeographical analyses which are presented as Summaries or Case Studies in Chapters 5–8 of this Manual, and which are illustrated in Volume II. The examples include migrations both *within* Regions and *between* Regions, and by swarms of differing maturities. It needs to be stressed that the distances and durations quoted in the Table are approximations. There are three main reasons for this. First, with few exceptions (e.g., cultivated areas in Rajasthan), even in areas where many reports of swarms are received, only some swarms are reported on any one day (see Rainey 1963). Thus, the swarm positions used in these analyses do not necessarily refer to the swarms which have displaced furthest, although, because the first swarms to arrive in a previously free area attract attention, the swarms first reported are likely to have been amongst the first to arrive in an area. Second, the dates of the start and the end of the migration may not be known exactly; for this reason some of the analyses presented in the Case Studies are not quoted in Table 3.1. Third, in estimating the total net distance displaced it has normally been assumed that the distance between the start and finish of a migration was a straight line, unless there is clear evidence that the migration has taken a different route, e.g., from the South-Central Region to the Eastern Region in January—February 1952. It should be recognised, therefore, that the *total* distance displaced by swarms may have been considerably greater than the *net* distance displaced, particularly when there is evidence of changing wind patterns (see Sections 3.3.5 and 3.3.6). It should also be stressed that the numbers of examples of migrations between Regions and within Regions presented in Table 3.1 do *not* represent the frequency with which such migrations occur. Nevertheless, the absence of any example of a movement from the Western Region to the South-Central Region, and the presence of only one example of a movement from the Western Region to the North-Central Region, seem to reflect the relative rarity of major eastward migrations from the Western Region into the North-Central and South-Central Regions (see Section 2.4).

In spite of the above qualifications, the following main points arise from the examples presented in Table 3.1.

- There is great variability in the average daily rate of net displacement of swarms, which can range from under 5 kilometres a day in the cool weather of winter-early spring in Iran to nearly 200 kilometres a day during bursts of rapid displacement in warm weather and a more or less consistent wind direction. As a result, the greater part of a migration between the breeding areas of two successive generations may be completed within a small proportion of the time elapsing between the two corresponding breeding seasons (see also Rainey 1963).
- Very long distances may be traversed by swarms produced both in summer and in spring (see examples 3, 7, 19, 21, 40; and 37, 38, 42, respectively) and sometimes also by swarms of the winter generation (example 30).
- The most rapid migrations usually take place over the desert and semi-arid areas of the invasion area (where vegetation cover is normally minimal; see Section 3.1.5).
- Whereas most of the long-range displacements of swarms are made by *immature* swarms, *maturing* and *mature* swarms can also make long-range displacements and may achieve similar rates of net displacement to those of immature swarms.

3.1.10 END OF MIGRATION

Migration by immature swarms normally ends when they reach areas where rain has fallen and they mature, copulate and lay for the first time. After the first laying, mature swarms frequently resume their migration so that second and third waves of laying may take place several hundred kilometres downwind of previous laying, as frequently occurs, for example, in the Somali Peninsula during the Short Rains, and in north-west Africa and the Middle East in spring. Somewhat infrequently, immature swarms fail to locate areas suitable for successful breeding, either because the seasonal rains are so deficient that the female locusts are unable to detect suitable laying sites or the vegetation is inadequate to sustain the hoppers, or because the swarms are taken out to sea.

Table 3.1 Examples of average rates of displacement of Desert Locust swarms during long-range migrations.

Region	Reference no.	Migration	Approximate period	Maturity I Immature M Mature	Distance (km)	Approximate Duration (days)	Approximate average rate of displacement (km/day)	Reference C Case Study S Summary (See Chapters 5–8)
Within Eastern Region	1	Indo-Pakistan summer breeding area to south-east Iran (Jask)	5 Oct – 17 Oct 1950	I	1,200	12	100	S1
	2	Indo-Pakistan summer breeding area to south-west Iran (Fars)	20 Sept – 23 Oct 1952	I	1,900	33	58	S3
	3	Indo-Pakistan summer breeding area to south-west Iran (Khuzistan)	1 Oct – 24 Nov 1960	I	2,300	55	42	C4.4 and C4.5
	4	Tharparkar to Gujarat	23 Aug – 2 Sept 1961	M	550	20	27	C5.2
	5	Tharparkar to Uttar Pradesh	20 – 30 Nov 1961	I	330	10	33	C5.4
	6	South-west Madhya Pradesh to Assam	1 Oct – end Dec 1960	I	1,600	90	18	C4.2 and C4.3
	7	South-west Madhya Pradesh to Bangladesh via Karnataka	20 Sept – end Dec 1960	I	2,600	100	26	C4.2 and C4.3
	8	Rajasthan to Bengal	15 Jan – 16 Mar 1951	I	1,550	60	26	S1
	9	Northward migration in eastern Iran, Pakistan and India	1 Jan – 27 Jan 1951	I	350 – 400	27	13 – 15	S1
	10	Northward migration in eastern Iran and northern Pakistan	1 Feb – 3 Mar 1951	Maturing	450	31	15	S1
	11	Northward migration across Iran (Hari-Rud route)	Feb – May 1929	M	1,600	120	13	Predtechenskii (1938)
	12	Northward migration across Iran (Sabzawar route)	Feb – May 1929	M	1,150	120	10	Predtechenskii (1938)
	13	Northward migration across Iran (Sabzawar route)	Feb – May 1930	M	1,000	120	8	Predtechenskii (1938)
	14	Northward migration across Iran (Urmia route)	Mar – May 1930	M	925	90	10	Predtechenskii (1938)
	15	Mekran of Iran to Jiroft and Saravan (continuation of 24)	Jan – Mar 1959	Maturing	100 – 200	60	1.7 – 3.3	S9
	16	South-east Iran and Baluchistan to north-east Iran and Afghanistan (continuation of 24)	early April – early May 1959	M	800	30	27	S9
From Eastern Region to North-Central Region	17	Indo-Pakistan summer breeding area to Oman and United Arab Emirates	5 – 17 Oct 1950	I	1,600	12	133	S1
	18	Indo-Pakistan summer breeding area to Qatar	5 Oct – 17 Nov 1950	I	1,800	33	55	S1
	19	Indo-Pakistan summer breeding area to Jordan (continuation of 2)	20 Sept – 3 Dec 1952	I	3,200	74	43	S3
	20	Indo-Pakistan summer breeding area to western People's Democratic Republic of Yemen	15 Sept – 20 Oct 1952	I	2,900	35	83	S3
From Eastern Region to South-Central Region	21	Indo-Pakistan summer breeding area to northern Somalia	10 Nov – 1 Dec 1949	I	2,800	21	133	
From North Central Region to Eastern Region	22	Southern Iraq and north-eastern Saudi Arabia to Pakistan (Mekran)	7 – 8 Nov – 20 Dec 1958	I	1,850	43	43	S9

Table 3.1 Examples of average rates of displacement of Desert Locust swarms during long-range migrations (continued).

Region	Reference no.	Migration	Approximate period	Maturity I Immature M Mature	Distance (km)	Approximate Duration (days)	Approximate average rate of displacement (km/day)	Reference C Case Study S Summary (See Chapters 5 – 8)
Within North-Central Region	23	Northern Ethiopia to Sudan (Darfur)	? 9 May – 29 May 1954	M	1,700	21	80	C11.2 and C11.3
	24	Sudan to Egypt (Sinai)	23 Sept – 29 Oct 1958	I	1,050	36	29	S9
	25	People's Democratic Republic of Yemen (and perhaps northern Ethiopia) to south-west Iraq	5 Oct – 7 Nov 1958	I	1,950	33	59	S9
	26	Kuwait, Neutral Zone and possibly south-west Iraq to central Iraq	14 Jan – 28 Feb 1959	M	450	45	10	S9
	27	Northern Saudi Arabia and Iraq to south-east Turkey	1 April – 2 May 1959	M	500 – 850	32	15 – 27	S9
	28	Jordan, Israel to Lower Egypt	13 April – 11 May 1959	M	450	28	16	S9
From North-Central Region to South-Central Region	29	Eastern Sudan and Western District of Eritrea (Ethiopia) to northern Somalia	20 Sept – 20 Nov 1958	I	1,600	60	27	Section 2.3.1.2
From South-Central Region to North-Central and Eastern Regions	30 a	Somalia and eastern Ethiopia to Saudi Arabia (Asir)	5 Jan – 2 Feb 1952	I	1,150	32	36	C10.1 and C10.2
	30 b	Saudi Arabia (Asir) to northern Saudi Arabia (near border of Iraq)	2 – 8 Feb 1952	I	1,150	6	190	C10.3
	30 c	Neutral Zone and northern Saudi Arabia to south-west Iran, Bahrein and eastern Saudi Arabia	14 Feb to 25 – 29 Feb 1952	Maturing	550	11 – 15	42 – 50	C10.4
	30 d	South-west Iran to Pakistan	1 – 31 Mar 1952	M	900	31	29	S10
					3,750	91	42	
Within South-Central Region	31	Northern Somalia to north-east Kenya	27 Sept – 27 Oct 1950	Maturing	960	30	32	Rainey 1951
	32	Northern Somalia to north-east Tanzania	1 Oct – 7 Nov 1961	I and M	2,000	38	53	C13.3 and C13.4
	33	Northern Somalia to Kenya (Turkana) — continuation of 29	10 Feb – 24 Mar 1959	Maturing	1,800	42	42	Joyce 1962
	34	South-west Somalia to northern Tanzania	24 Dec 1961 – 12 Feb 1962	I	500	50	10	C13.5
	35	Northern Tanzania to southern Sudan	1 Apr – 20 May 1955	Maturing	1,700	50	34	C14.3 and C14.4
	36	Kenya to north-east Somalia	1 Apr – 11 May 1955	M	2,000	41	49	C14.2
North-Central Region to Western Region	37	Western Saudi Arabia to Niger	5 May – 22 June 1950	I	3,350	48	70	Rainey 1951
	38	Northern Saudi Arabia to north-west Niger	12 May – 4 June 1954	I	3,300	24	137	C11.2 and C11.3
	39	Southern Egypt to central Niger	5 – 6 June – 17 June 1968	I	2,500	12	200	S11
	40	Sudan to Morocco	12 Sept – 22 Oct 1968	I	3,800	40	95	Betts 1976
From Western Region to North-Central Region	41	Algeria (Ahaggar) to Egypt	10 Oct – 17 Nov 1954	I	2,100	38	55	C17.4 and C17.6
Within Western Region	42	South-west Morocco to north-east Mali	24 May – 9 June 1954	I	1,500	16	94	C11.5
	43	Northern Mauritania to south-west Mauritania	7 June – 27 June 1954	I	800	20	40	S11
	44	North-west Algeria or south-east Morocco to north-east Mali	21 – 23 May – 9 June 1954	M	1,700	17 – 19	90 – 100	C11.5
	45	North-west Chad to Algeria (Ahaggar)	18 – 25 Sept 1954	M	1,100	7	160	C11.1
	46	Senegal to Guinea	14 – 22 Feb 1955	I	500	8	62	C17.9
	47	Guinea to southern Mali	22 Mar – 6 Apr 1955	I	220	15	14	C17.10

Although such events are uncommon they can result in heavy mortality in regional populations. Thus, the high level of swarming populations in the South-Central Region between 1950 and 1955 was broken abruptly in October—December 1955, when only light, patchy rainfall occurred in the Ogaden, adjacent areas of Somalia and in north-eastern Kenya. As a result, most hopper infestations were controlled by the end of the third instar and only a few small swarms were produced in December 1955 and January 1956. These apparently dispersed and did not breed as swarms, thus breaking the alternating chain of swarm migration and breeding in that Region which had continued for five years. Yet during June—September 1955 the total area of swarms in northern Somalia had been assessed at some 3,700 square kilometres (Joyce 1962), one of the highest regional swarm coverages ever recorded.

3.1.11 DURATION AND EXTENT OF SEASONAL MIGRATIONS

A result of the cumulative daily displacements is that many, if not most, swarms achieve net displacements of at least 1,000 kilometres, and displacements of 3,000—4,000 kilometres in a single generation are not uncommon. A discussion of the usual seasonal migrations is given in Section 2.4, and more detailed accounts are presented in Chapters 5—8. From these accounts it will be clear that, whereas there are many *regular* patterns of seasonal migration, there are considerable differences from year to year. These arise from differences in the source breeding areas, in the timing of the start of the migrations, in the direction of the winds in the course of the migrations, and in how long the migrations continue.

3.2 MIGRATION OF NON-GREGARIOUS ADULTS

In marked contrast to the migration of swarms, *non-gregarious* adults migrate *at night.* Night flight is of particular significance during recessions or the early stages of outbreaks and upsurges, when the great majority of adults are likely to be at low densities (see Section 2.2).

The commonest evidence of adults flying at night is their arrival at outdoor lights. They may also be observed taking off after sunset or flying across the face of the moon, and they have been studied using vertically directed lights (Roffey 1963, Waloff 1963) and by radar (Schaefer 1976). Indirect evidence of night flight may be provided by the finding of low-density adults in areas previously known to be clear (Roffey & Popov 1968).

Flights by non-gregarious adults during the day have been recorded, but these are short and either made by mature males seeking females with which they mate (Roffey & Popov 1968) or caused by some disturbance, e.g., a passing bird, camel or human.

3.2.1. TAKE-OFF

Systematic visual observations (Roffey 1963, Waloff 1963) and radar studies (Schaefer 1976) have shown that non-gregarious adults start to take off spontaneously about 20 minutes after sunset, when light intensity is decreasing most rapidly. The behaviour of these locusts thus contrasts strongly with locusts in swarms, which normally settle as light intensity decreases around sunset. Radar studies have shown that the rate of take-off reaches a *peak* about 15 minutes after starting, at which time it is normally too dark to see take-off with the naked eye. With image intensifiers such take-off can be observed.

Scattered locusts take off after sunset into wind and frequently circle as they climb, but their subsequent track is downwind (see Section 3.2.2). Spontaneous take-off appears to be inhibited at air temperatures below about 20—22°C, and at wind speeds above about 7 metres a second. Air temperature near the ground at sunset over considerable parts of the invasion area during the cooler months are too low to allow take-off. These areas include large parts of north-western Africa, northern Arabia and the Middle East, as well as Iran and Pakistan (except for the coastal strip). Air temperatures at around sunset at many synoptic meteorological stations are available operationally; but if they are not, then a rough approximation is

$$\frac{T_{max} + T_{min}}{2}$$

where T_{max} is the day's maximum temperature
T_{min} is the minimum temperature the following morning.

A set of monthly maps showing isotherms of EFFECTIVE NIGHT TEMPERATURE was prepared for the whole of the invasion area (Cochemé 1966b). Effective night temperature was defined as $m + \left(\frac{M-m}{4}\right)$, where M is the long-term monthly mean of daily maxima and m is the long-term monthly mean of daily minima. It is normally below the temperature at sunset so the maps tend to underestimate the areas where take-off can occur. An important source of error in using the maps can arise during spells of weather warmer than average. During such spells temperatures may be 5—10°C above the monthly mean and therefore allow substantial night migrations to occur when monthly *mean* temperatures indicate it would not happen. For example, scattered locusts were seen at Al Jawf in northern Saudi Arabia on 2 March 1968, following three days and nights of strong and warm southerly

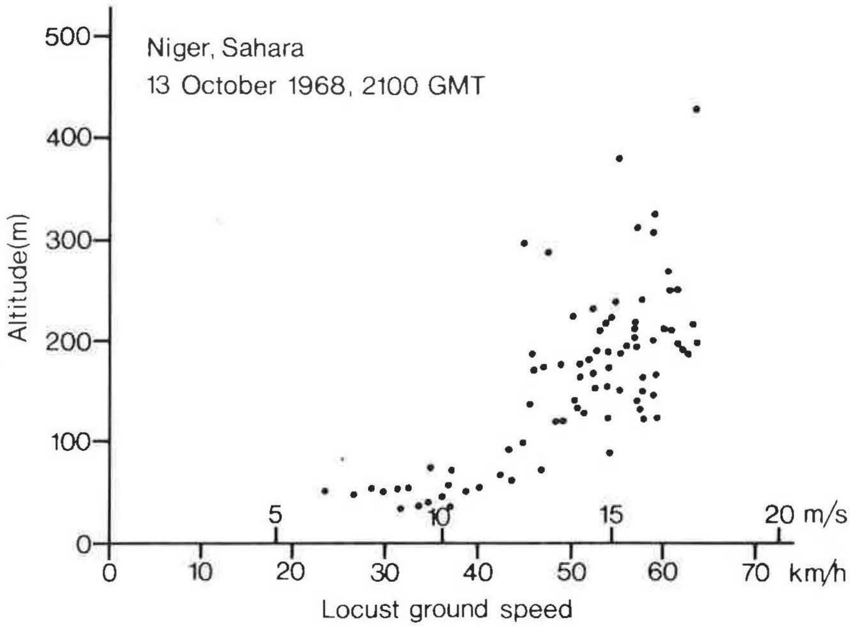


Fig. 3.9 Ground speeds of individual night-flying Desert Locusts in relation to height (after Schaefer 1976).

winds (on the second of which large numbers of adults were seen in the beam of an Aldis lamp about 100 kilometres north of Jeddah), whereas the appropriate map of effective night temperature suggests that night flight would not occur at Al Jawf until May. Errors may also arise during the spring when average temperatures are rising rapidly, and during the autumn when they are falling rapidly. Whenever possible, forecasters should attempt to obtain or deduce *actual* temperatures at sunset and not accept values based on long-term means.

The proportion of individuals in an area which take off each evening appears to be very variable. It seems to depend on the physiological state of the individual locust, i.e., on its age and maturity; on the state and extent of the vegetation, i.e., whether there are large or small areas of vegetation which are green or drying out; and on the air temperature and the wind speed at the time of take-off. Symmons (in Popov 1968) estimated that about 30% of the immature adults took off each night in an isolated area of about 36 hectares of *Schouwia* and *Tribulus* in Tamesna in Niger. In another study, in a plot of 3.2 hectares on the coastal plains of northern Ethiopia, 74–100% of the adults moved out of the area on successive days (Roffey & Stower, unpublished), although, in this case, disturbance during the day may have accounted for the apparently higher rate of emigration.

At present no fixed guide can be given to forecasters about the proportion of non-gregarious locusts which take off and migrate each night, but current data suggest that these locusts do not vacate their breeding sites together. Rather, there seems to be a gradual departure, which may extend over several weeks, as hoppers of different ages fledge and commence their migration. If laying in the breeding area is possible, however, many if not most of the new generation adults remain there, mature, lay and give rise to another generation (see Section 4.10.1).

3.2.2. DISPLACEMENT

The most complete data on the direction and speed of displacement of night-flying, non-gregarious locusts was obtained by radar in Tamesna of Niger in September–October 1968 (Schaefer 1976). These data showed that, after upwind take-off flight, the adults oriented almost exclusively downwind, with only occasional individuals heading into light winds. The data thus provided additional evidence that night-flying, non-gregarious adults are displaced downwind (Rao 1942, Roffey 1963, Waloff 1963).

Speed of displacement was also studied by radar. Fig. 3.9 shows that ground speeds ranged from about 7 to 18 metres a second on an evening when winds were strongest at heights of over 200 metres (Schaefer 1976). On this occasion, as on many others, the ground speed of locusts increased rapidly with height in the lowest 200 metres of the atmosphere (see Fig. 3.9).

The radar observations showed that the Desert Locust can fly at heights of up to about 1.8 kilometres. Although no individual locusts were tracked for periods of more than about two minutes, the continued passage of adults at heights hundreds of metres above the ground, and the virtual absence of settling in the early part of the evening, suggested that the locusts detected by the radar were part of an over-flying population, some individuals of which were flying for up to 10 hours a night, and it was calculated that the average duration of flight in Tamesna was 4 hours a night. Thus some locusts were capable of displacing up to 400 kilometres in a single night and many would have displaced 100 kilometres.

In Tamesna, conditions for night flight were very favourable and it is possible that on some nights most locusts were in flight: temperatures at sunset, 30°C or more, were well above the minimum threshold for take-off; surface wind speeds were below 4 metres a second; and the annual vegetation was drying out (Roffey 1969). In cooler, windier weather, and in areas with luxuriant annual vegetation, a much smaller proportion of locusts can be expected to take off, and smaller displacements are likely, but further work is required to confirm these suggestions.

Forecasters need to be alert to the possibility of night-flying locusts reaching areas where surface air temperatures inhibit take-off. This can happen if there is a temperature inversion, when locusts can climb into air which is warmer than at ground level and can reach areas beyond those suggested by the maps showing an effective night temperature. Similarly, metabolic heat generated by wing flapping may enable locusts to continue flying when surface air temperature is too low for take-off. As a result, locusts have sometimes been recorded coming to lights at temperatures below that at which take-off normally occurs (Guichard 1955, Roffey 1963).

Since both day-and night-flying locusts are displaced downwind, both types of population have the same seasonal *patterns* of migration. But because of lower night temperatures the *extent* of displacement by night-flying locusts is usually considerably less. Fig. 2.1 shows the difference in area which is reached by swarms during plagues (the invasion area) and that reached during recessions (the recession area), whether the adults are non-gregarious and night-flying or are day-flying swarms. These differences were discussed in Section 2.5.

3.2.3 SETTLING

There are few direct observations of settling by night-flying locusts. The commonest evidence that night-flying is in progress is the appearance of locusts at outdoor lights. In areas where no locusts have been seen during the day despite careful searching, such appearances are probably good evidence of migration, particularly if there is a sudden influx of locusts to lights some hours after sunset. The appearance of isolated individuals at light only one or two hours after sunset, however, may mean no more than that they have been disturbed from an area close to the light, whereas the occurrence of even small numbers later in the night may be evidence of arrival from much further away.

Daytime observations on the distribution of non-gregarious adults indicate that such locusts flying at night are able to detect areas of green vegetation, which provide food and shelter (see Section 2.6). It appears that after a variable period of sustained flight, probably depending mainly on air temperature, night-flying locusts settle in areas of green vegetation. It is not known whether locusts which have settled once during the night take off again the same night, but when surface air temperatures are below the minimum threshold it seems unlikely that there is renewed take-off.

On one occasion during the radar observations in Tamesna, a small proportion of the population which had been flying over the radar site during the night continued to fly after sunrise (Roffey 1969). Forecasters should appreciate that camp lights are often switched off 3 – 4 hours after sunset and that significant migrations may take place later in the night and therefore not be recorded.

3.3 WEATHER MAPS

It has been shown that the *direction* of displacement of both day-flying swarms and night-flying solitarious locusts is downwind (Sections 3.1.4 and 3.2.2), and that flight and hence daily *duration* of displacement is strongly affected by temperature (Sections 3.1.7 and 3.2.2). It is therefore of great use to a locust forecaster to know what winds and temperatures may have been, or are likely to be, met by flying locusts. With such knowledge, attempts can be made: (a) to back-track locusts to their likely sources using known winds and temperatures from the recent past; (b) to forecast movement in the light of what the winds and temperatures might be in the near future.

Because winds and temperatures are continually varying in both time and space, locust forecasters need a way of depicting the variations over the area, and for the period, of movement. Aviation weather forecasters have much the same kind of need, so locust forecasters can use the ways that have been developed in aviation weather forecasting. The main way is to use a time series of synoptic weather maps. A synoptic map shows the weather over a given area at some given time, either in the past or in the future (forecast map). It can be used to estimate the wind and temperature at any place in the area for that time. Because winds and temperatures vary with height, weather forecasters prepare maps for several internationally agreed heights; those of most direct use to locust forecasters are 'the surface' (nominally 10 metres above the ground), and 850 and 700 millibars (about 1.5 and 3 kilometres above sea level). Greater heights are not of direct use to the locust forecaster because temperatures there are almost always too low for flight; nevertheless they can be of great value when assessing the likelihood of rains suitable for breeding (see Section 4.11.2). With a time series of synoptic weather maps at the internationally agreed heights, winds and temperatures can be estimated for any place, height and time — including places along the track taken by the locusts.

Synoptic weather maps used in weather forecasting show not only wind and temperature but also other *meteorological parameters* such as clouds, rain, visibility and atmospheric pressure, only some of which are useful to locust forecasters. Such maps are therefore more detailed than need be for locust forecasting, but because they are the ones most likely to be used by locust forecasters their method of construction is outlined in this Manual

(Section 3.3.3). The weather maps used as illustrations in this Manual, however, have been simplified to show the weather parameters of most direct use in understanding locust movement — winds and temperatures. There are many examples in Volume II.

3.3.1 USEFULNESS OF WEATHER MAPS

Forward-tracking of locusts can be of great value in adding precision to *warnings* or *forecasts* of the timing, speed, direction and extent of invasions, and the timing and extent of breeding. *Warnings* will be of recent or imminent likely movements or breeding, perhaps related to some known or expected change in the weather, and they can be issued before locust reports have come from the area concerned. *Forecasts* will be of likely movements or breeding over a given longer period, say several weeks or months ahead. The preparation of forecast weather maps for so far ahead is not yet feasible, but experience of usual changes for the time of year, for both locusts and weather, can be drawn upon to help decide among a choice of possible movements or breeding sites.

Back-tracking of locusts can be of great value in making *the best possible assessment of the current locust situation,* which is so essential before making a forecast. It can help answer questions such as:

what is the most likely source of the locusts?

are there likely to have been unreported sources?

are there likely to have been unreported invasions (from known or other sources)?

what is the real size of an invasion likely to have been (bearing in mind the likely sizes of source populations and the extent of under-reporting)?

when was the earliest possible date of egg laying (and hence hatching and fledging)?

After making an assessment of the current locust situation, similar questions need to be asked about the changes that are likely to take place in the currently known or likely populations.

Many of the Case Studies in this Manual give examples of how answers to questions of the above kind can be got with the help of weather maps. It follows that the locust forecaster must know something of how atmospheric behaviour affects locust movement. He is not expected to be a meteorologist, but he should know enough to be able to use synoptic weather maps, to recognise on them the patterns of wind and temperature known to affect locust movement, and to understand the advice given by meteorologists about those patterns (see Section 3.3.4). Likewise, the meteorologist whose advice is being sought should know enough about locust behaviour to be able to understand the questions put to him by the locust forecaster concerning the time and place of breeding and movement. To help both locust forecaster and meteorologist in the use of weather maps for locust forecasting, Section 3.3.5 introduces the kinds of weather systems that affect locust movement (and they are discussed in more detail in the Regional chapters 5 to 8), but for a greater understanding of the nature and causes of these weather systems the locust forecaster should consult standard textbooks and perhaps selected papers from the technical journals (with guidance from a meteorologist).

Apart from tracking the movement of flying locusts, weather maps are also used to help assess where locusts might be brought together, and thereby be controlled more easily. Locusts can be brought together because they land in a preferred area after having been brought there on the wind, or because they become concentrated whilst airborne in convergent winds. CONVERGENCE is said to happen wherever there is an overall inflow of wind into an area. Inflow near the ground must lead to an upward flow, perhaps leading to clouds and rain (Section 4.11.2). If flying locusts are carried with the upward flow their aerial density stays much the same, but if for some reason there is an upper limit to which locusts fly (due, say, to temperatures at greater heights being below the threshold for flight — see Section 3.1.2) then they must come closer together. The evidence is not clear whether wind convergence alone is able to crowd scattered airborne solitarious locusts into swarms, but there is no doubt that convergence can bring swarms closer together and stretch them upwards. For example, a slow-moving CONVERGENCE ZONE between two wind streams can be one where swarms gather. Since it may also be a zone where rains fall (Section 4.11.2), and hence where breeding may take place, the locust forecaster should watch for any convergence zone that may appear on the weather maps. Sometimes maps of convergence are prepared routinely; but, even if not, some general idea of the synoptic pattern of convergence can often be deduced by meteorologists from a simple inspection of weather maps, and a sequence of maps will show how the pattern of convergence changes with time.

3.3.2 CONSTRUCTION AND AVAILABILITY OF WEATHER MAPS

3.3.2.1 Weather observations

A weather map for some fixed time in the past is built up from a set of observations made more or less simultaneously at a network of meteorological stations. Almost every country in the world has a meteorological service that maintains such a network, keeping constant watch on the weather and recording observations at agreed times, usually hourly or 3-hourly throughout the day and night. Each observation contains details of a fixed set of meteorological parameters — air temperature, air humidity, air pressure, wind, visibility, cloud (amount, type, height) and weather (rain, thunder, dust storm, etc). Observations are reported rapidly by telephone, radio or

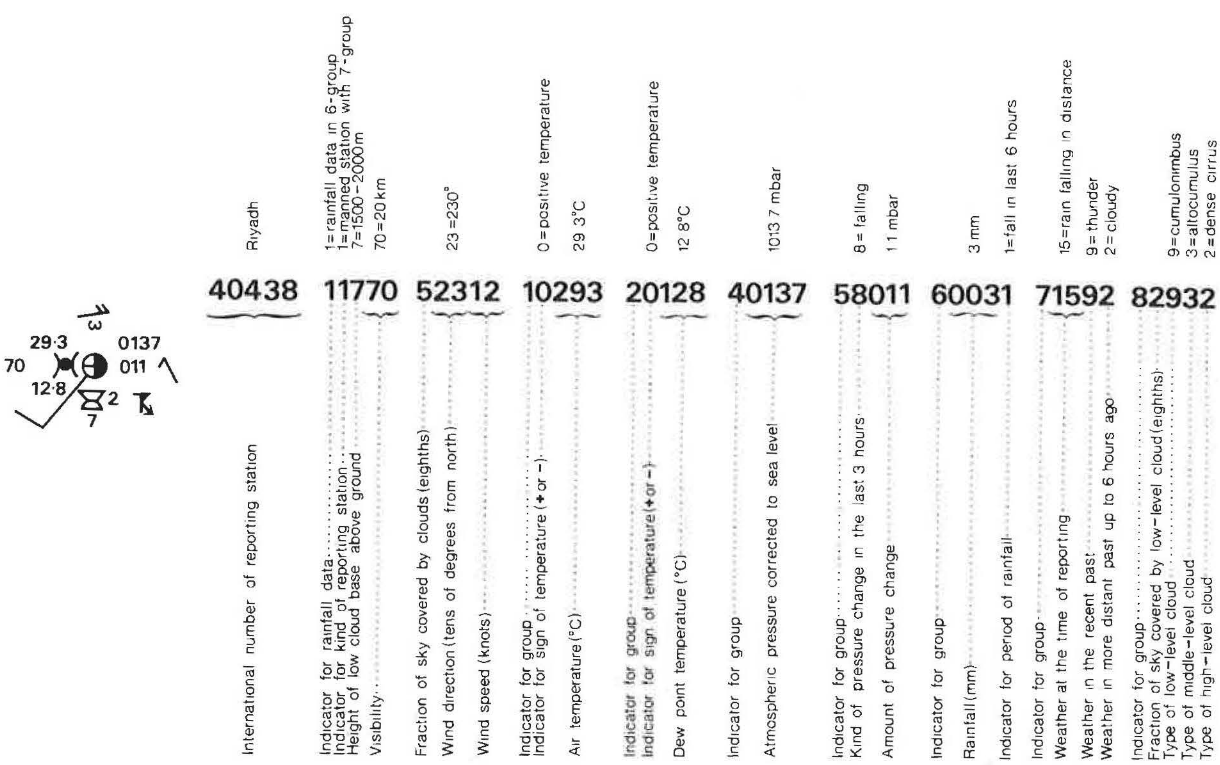


Fig. 3.10 Example of a coded weather observation — as transmitted, and as plotted on a weather map. The code shown is the one in use since January 1982.

telex to collecting centres for distribution, nationally and internationally, to analysis centres where weather maps are drawn for use in aviation weather forecasting. Observations on a national scale are usually exchanged within 1 hour, on a continental scale within 3 hours, and on a global scale within 6 hours. To avoid difficulties that would arise from the use of many languages, the observations are reported in numerical code, and can be understood in all countries. There is a very elaborate system of rapid, world-wide communications for these observations, supported by all countries and co-ordinated by the World Meteorological Organization (WMO), a specialised agency of the United Nations. In most countries there are places where data can be made available from this world-wide network. Hence, the Desert Locust forecaster has access to this vast and continual flow of observations, usually through the weather forecast offices at international airports, where weather maps on a continental scale are drawn every 3 or 6 hours. For a list of weather observing stations, see WMO publication 9, volume A, and for details of the communications system see WMO publication 9, volume C. (Additional weather information in locust reports can also be very useful — see Section 9.3.4.)

At weather analysis centres, observations for a given time are plotted either by hand or by machine, on a base map that shows the positions of the stations. Around each position the data are plotted using an internationally agreed system of numbers and symbols. Fig. 3.10 is an example of a coded weather observation, and the form it takes when plotted. The arrangement around each 'station circle' is the same in all countries, so a meteorologist, no matter what his nationality, can read a weather map from any part of the world. So, too, can a locust forecaster after some practice. Fig. 3.11 explains the commonest symbols seen on weather maps. (For a full list, and for detailed instructions on the preparation of weather maps, see WMO publication No. 305 and handbooks of national meteorological services.) Of particular interest to locust forecasters are the symbols for *wind*. Wind has both *direction* and *speed*, and the wind symbol is an 'arrow' drawn along the wind direction, with 'feathers' increasing in number with wind speed. Fig. 3.12 shows the range of these symbols most likely to be met on a weather map of the Desert Locust invasion area. WIND DIRECTION is that *from* which the wind is blowing, expressed as degrees from north, and it is reported to the nearest 10°. WIND SPEED is reported to the nearest knot, or nearest metre a second (1 knot is very nearly 0.5 metre a second or 1.8 kilometres an hour), but plotted to the nearest 5 knots except that speeds of 1–2 knots have no 'feather', and a calm is shown as a circle drawn around the position of the observing station. (For many examples, see the weather maps with the Case Studies after Chapters 5–8.)

After the observations have been plotted, various *analyses* are made for use in aviation weather forecasting. Those of greatest interest to the locust forecaster are of temperature and wind. Temperatures are conveniently represented by a set of ISOTHERMS — lines drawn through places with the same temperature. Because there are both horizontal and vertical variations, an analysis of temperatures near the surface becomes complex in mountainous country, where it is therefore more difficult than over flat country to estimate temperature at a place where there is no observation. A way of avoiding this difficulty, at least in part, is to use isotherms of temperature corrected to some standard height, such as sea level, using a fixed variation of temperature with height (LAPSE RATE — see also Section 3.3.6). Weather maps in this Manual show only uncorrected temperatures.

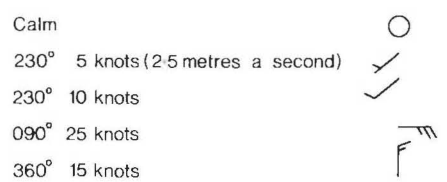
Fig. 3.11 Meanings of commonest symbols seen on weather maps.

Wind analysis must show both direction and speed. Two analysis systems are widely used: one emphasises the wind reports, whereas the other emphasises a relationship between wind and *atmospheric pressure*. In practice, both systems can be used together to give the best wind analysis.

3.3.2.2 Wind analysis

Wind *direction* can be represented on weather maps by STREAMLINES — lines drawn parallel to the wind direction. Those drawn on the weather maps in this Manual show only the broad-scale wind patterns; smaller-scale patterns have been largely ignored on the grounds that there are too few observations to show them clearly. Wind *speeds* can be represented by ISOTACHS — lines drawn through places with the same wind speed. Isotachs have not been drawn on the Case Study maps because of the difficulty in drawing patterns free from unwanted and probably partly spurious detail over land.

Fig. 3.12 Examples of symbols for winds used on weather maps.



3.3.2.3 Pressure analysis

Atmospheric pressure is measured at most meteorological observing stations. It can be represented on weather maps by ISOBARS — lines drawn through places with the same pressure. Because pressure always decreases upwards, isobar patterns have little use unless pressures are corrected to some standard height — usually sea level. Sea level pressure is almost always in the range 980–1030 millibars over the Desert Locust invasion area. This range is small, but differences of only 1 millibar between places 100 kilometres apart are significant. Hence, pressure is measured with a precision barometer that can be read to within 0.1 millibar, or about 0.01% of sea level pressure. Because pressure decreases upwards at the rate of about 1 millibar in 10 metres, a precision of 0.1 millibar means that the height of the barometer above sea level must be known to within 1 metre. In some highland areas, pressure corrections to sea level are large and unreliable. In such areas, pressures are used to calculate the height of some standard pressure surface, usually 850 millibars, and instead of isobars, *contours* of the pressure surface can be drawn.

Isobars are usually drawn at intervals of 2 millibars (as in this Manual) or 5 millibars. They form patterns like those of contours on a topographic map (Fig. 3.13). Centres of low pressure are called DEPRESSIONS or LOWS (shown

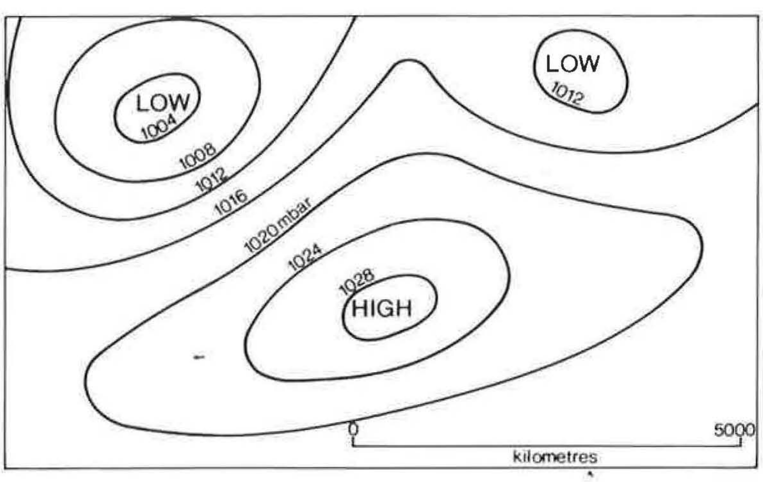


Fig. 3.13 Part of a pattern of isobars on a northern hemisphere weather map showing lows (L) and a high (H).

as L on the Case Study maps), whereas centres of high pressure are HIGHS (shown as H). TROUGHS (often extending outwards from lows) and RIDGES (from highs) have obvious relationships to topographic contour patterns (Fig. 3.14). The terms *deepening* and *filling* are used with lows having falling and rising central pressure, respectively. Corresponding terms for highs are *weakening* and *intensifying*. Similar patterns are formed by contours of the 850 millibars pressure surface drawn on surface weather maps for highland areas.

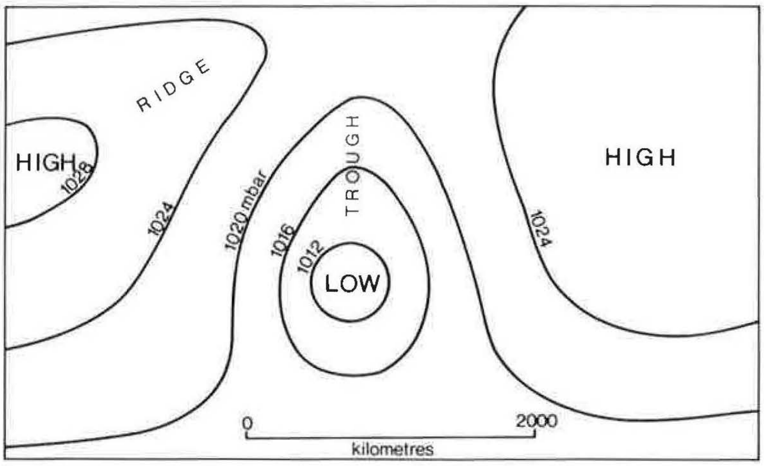
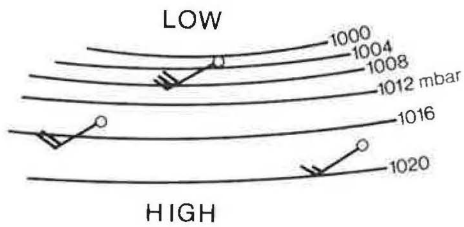


Fig. 3.14 Part of a pattern of isobars on a northern hemisphere weather map showing a trough and a ridge.

Patterns of isobars and winds are related, so the former can be used to help deduce the latter. Above the frictional drag of the rough ground (at heights greater than about 1 kilometre), and wherever the isobars are straight and parallel to the equator, and pressure does not change with time, then the wind blows parallel to the isobars with lowest pressure on the left facing downwind (in the northern hemisphere; on the right in the southern). Thus, in Fig. 3.15 the pattern of isobars corresponds to a west wind. Moreover, the wind is strongest where isobars are closest; in Fig. 3.15 the strongest winds are therefore in the north. Near the ground, the wind is slowed by frictional drag and turned a little towards low pressure (Fig. 3.15). The relationship between isobars and wind systems becomes more complex where the isobars are curved, not parallel, or moving. This Manual is not the place to discuss such complexities, but it should be said that winds sometimes blow almost from high to low pressure, as can be seen on some of the Case Study maps. On those maps, the broad-scale streamlines have been drawn from the wind observations but ensuring that the angle of crossing the isobars varies in a smooth and systematic way across the map. Streamlines are not always drawn routinely on operational weather maps at aviation forecast offices.

Fig. 3.15 Part of a pattern of isobars on a northern hemisphere weather map showing westerly winds, strongest in the north. Friction at the ground causes winds to blow a little towards low pressure.



The *observations* upon which wind analyses are based are made at only a few places; hence the *analyses* can represent only approximations of the real wind systems, for they are based on assumed variations in the wind between observing stations. The same applies to temperature. Much depends on the size of the area over which an observation is representative. If the area is small (because, e.g., there are local topographic effects, or a short-lived atmospheric disturbance happens to be over the station at the time of observation), there is the risk of over-weighting the value of the observation. A smoothed pattern must be drawn, but knowing that superimposed smaller-scale patterns are not represented. Resulting errors are reduced with a denser network, but they are increased when some expected observations are missing (e.g., through failure of communications). No two analysts will produce quite the same analysis from a given set of observations, because each uses, knowingly or not, his own assumptions about variations between stations.

Weather maps prepared at aviation forecast offices are usually available within three hours of the time of observation and are therefore of great value in operational locust forecasting. Some countries publish daily maps, but the time lag varies from days to months, so they are of use only after the event rather than operationally, and then only as long as they show the detail needed.

In addition to those stations used for preparing weather maps, most countries have networks of *climatological stations* (particularly *agro-meteorological* stations) where weather observations are made often only once or twice a day. Their observations are not usually gathered quickly but are sent weekly or monthly to collecting centres for checking, analysis and storage, and can be consulted there for research studies. Such networks, and the even denser networks of raingauges that exist in most countries, may come under an authority different from the national meteorological service — often government departments of agriculture or water resources.

3.3.3 TRAJECTORIES

Wind maps can be used to estimate the TRAJECTORY, or cross-country track, of airborne locusts moving downwind. A trajectory is not a straight line but a more or less complex curve whose shape is strongly affected by the winds and temperatures met by the locusts in flight. To calculate a trajectory, the following are needed: flight height, flight speed and flight duration. On a given occasion, these will not be known, but they can be estimated as follows. *Flight height* is likely to be in the lowest kilometre of the atmosphere (Section 3.1.3); hence the direction of locust movement will be some mean value for that layer, and perhaps a little to the right of the surface wind direction (northern hemisphere). *Flight speed* will be some fraction of the mean wind in the layer (Section 3.1.5). *Flight duration* will be no longer than that part of the day when air temperature at flight height is above the threshold for flight (Section 3.1.7). *Daytime* movement can be taken as down the surface wind (or 10–20° to the right) and at about the surface wind speed. *Night-time* movement (Section 3.2.2) is not easily related to surface winds, which often become light at night near the surface (Section 3.3.6), and is best related to winds at heights of a few hundred metres above the ground. These upper winds are measured once or more a day at some places by means of balloons. In the absence of night observations, upper winds can be estimated by interpolation between the daytime wind patterns of preceding and following days. Such estimates are best made by meteorologists. A trajectory is built up by adding daily sections, each perhaps 50–200 kilometres long (Section 3.1.8). Each section will have errors due to errors in the wind analyses and to false assumptions about flight behaviour. Errors are cumulative, and after a few days can become unacceptably large. Precise trajectories are not justified in areas with doubtful wind analyses, but daily displacements can often be estimated usefully to within 30° for direction, and 50% for distance moved.

3.3.4 WIND SYSTEMS

Any weather map shows a more or less complex pattern of winds (see, for example, those accompanying the Case Studies), and a series of such maps, say one each day, will show how the pattern changes with time. The changes are progressive, although they may not be clear in areas where there are few observations, and where meteorological analysis must rely heavily on continuity and the orderly evolution of wind systems from one map to the next. That implies experience and understanding of the behaviour of wind systems. Such understanding is valuable to the locust forecaster, so a brief introduction is given in this Section.

Weather maps and everyday experience show that the atmosphere is disturbed by innumerable and continually changing eddies on a great variety of space and time scales — from seasonal monsoons down to fleeting gusts and even smaller. The air is continually being churned up by these eddies, which are basically a form of *convective stirring* set in motion because some parts of the earth are warmer than others, although the eddies are modified by the roughness of the ground. When the locust forecaster is considering movements over distances of hundreds or thousands of kilometres, he is most interested in the largest wind systems, so emphasis in this Manual is put on them.

Any weather map for the whole world will show the presence of a great number of more or less circular eddies with diameters of a few thousand kilometres. Streamlines show the *instantaneous* windflow around the centre of an eddy: either in the same sense as the turning of the earth on its axis (when the eddy is known as a *cyclone*), or in the opposite sense (*anticyclone*) — see Fig. 3.16. In the northern hemisphere, winds in a *cyclone rotate anti-clockwise*, but those in an *anticyclone rotate clockwise*. Cyclones and anticyclones are common between latitudes about 40° and 70° in both hemispheres, each lasting a few days, sometimes a week or two, and their centres move

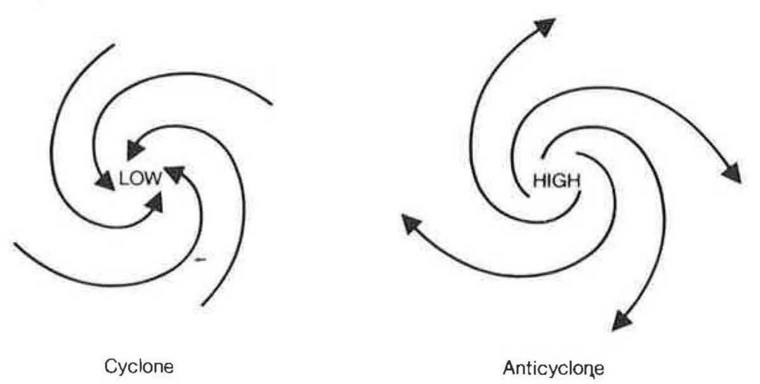


Fig. 3.16 Patterns of schematic streamlines in northern hemisphere cyclones and anticyclones.

generally from *west to east*, at speeds up to 50 knots (80 kilometres an hour) but sometimes faster. Some eddies are weak, and when embedded in a broad-scale airstream they take the form of WAVES in otherwise more or less straight flow. Between latitudes about 10° and 40°, anticyclones are more common than cyclones; some are large and very persistent — the SUBTROPICAL ANTICYCLONES centred near latitude 30°. On their poleward sides, winds are dominantly westerly — the MIDDLE-LATITUDE WESTERLIES (responsible, for example, for the eastward spread of swarms in winter across the Mediterranean countries of North Africa — see Chapter 8) but disturbed from day to day by innumerable passing cyclones, anticyclones and waves with a periodicity, very roughly, of a few days. On their equatorward sides, winds are mostly from the east — the TROPICAL EASTERLIES or TRADE WINDS (responsible, for example, for the westward spread of swarms in winter and spring across south-west Asia and the Sahel countries of West Africa — see Chapters 5, 6 and 8) — also disturbed by passing waves and cyclones, some moving *from east to west* but others (the equatorward ends of middle latitude cyclones and anticyclones) moving *from west to east*, i.e., against the dominant wind. Some westward-moving low-latitude cyclones are very powerful, with winds as much as 200 kilometres an hour. These are the hurricanes of the Atlantic Ocean and the typhoons of the Pacific Ocean. Those forming over the Indian

Table 3.2 Wind systems often present on weather maps. Letters refer to Fig. 3.17.

a northern winter

principal wind systems

A	subtropical anticyclone
B, D	southern extensions of eastward-moving middle latitude cyclones
C	southern extension of an eastward-moving middle latitude anticyclone
E	tropical easterlies ('harmattan' of West Africa)
F	tropical easterlies (north-east trade winds of the northern Indian Ocean)
G	tropical easterlies (south-east trade winds of the South Atlantic Ocean)
H	inter-tropical convergence zone (ITCZ) between E and G
I	northerly winds behind B
J	I turning through north-easterlies into tropical easterlies
K	southerly winds ahead of B
L	eastward-moving windshift line between I and K — a cold front marking the change at any given place from rising temperature ahead to falling temperatures behind.

distortions due to highlands

M	northerly winds behind D, distorted to blow parallel to the edge of the Iran highlands, and turning to east over Arabia when passing to the north of the highlands of Asir and Yemen
N	tropical easterlies distorted almost to northerlies over Sudan by the highlands of Ethiopia
O	north-westerly winds channelled by mountains bordering the northern Red Sea (and crossed by tropical easterlies from Arabia)
P	south-easterly winds channelled by mountains bordering the southern Red Sea
Q	Red Sea convergence zone (RSCZ) between O and P
R	Oman convergence zone (OCZ) in the lee of the Hajar mountains of Oman
S	convergence zone in the lee of the highlands of Ethiopia
T	tropical easterlies distorted to north-westerly, parallel to the edge of the Tibet highlands
U	G turned to westerly winds over the basin of the Zaire river
V	African rift convergence zone (ARCZ; also called the Zaire air boundary) between U and F

b northern summer

principal wind systems

A	subtropical anticyclone
B	seasonal cyclone centred over Pakistan
C	tropical easterlies
D	tropical easterlies (south-east trade winds of the South Atlantic Ocean) turning to F
E	tropical easterlies (south-east trade winds of the southern Indian Ocean) turning to G
F	monsoon of West Africa
G	monsoon of the Horn of Africa and northern Indian Ocean, spreading to India and Pakistan
H	inter-tropical convergence zone (ITCZ), between C and F over West Africa, between O and G over Arabia and Pakistan
I	westward-moving wave in F
J	westward-moving cyclone at the intersection of I and H
K	westward-moving cyclone in G
L	westward-moving windshift line, followed by easterly squall
M	windshift line (trade front) between cool trade winds around A over the sea and hot continental easterlies, C

distortions due to highlands

N	part of northerly winds between A and B channelled between the highlands of Turkey and Greece, and following into C
O	another part of the northerly winds, distorted to blow parallel to the edge of the Iran highlands, meeting G at the ITCZ over Oman
P	north-westerly winds channelled by mountains bordering the length of the Red Sea
Q	Afar convergence zone (ACZ) between P and G
R	D turned to westerly winds over the basin of the Zaire river
S	African rift convergence zone (ARCZ) between G and R
T	Kenya Highlands convergence zone (KHCZ), on the leeward (north-west) side where two branches of E come together

Ocean occasionally affect the Desert Locust invasion area (Sections 5.3 and 6.3), and are easily seen on meteorological satellite pictures by their spiral bands of cloud (Section 4.11.2). Close to the equator, the tropical easterlies of opposite hemispheres come together as the INTER–TROPICAL CONVERGENCE ZONE (ITCZ), where swarms tend to gather during the summer. Over land in summer, the ITCZ moves poleward beyond latitude 10°, and winds on its equatorward side become westerly. These EQUATORIAL WESTERLIES are also known as MONSOONS, a word derived from the Arabic for 'season' and applied to the seasonal change of wind between winter tropical easterlies and summer equatorial westerlies. During summer, both the subtropical anticyclones and the belt of middle latitude cyclones and anticyclones tend to be shifted polewards about 10°. During the *northern* summer, the monsoon reaches about 20°N over Africa; but over Asia, where the subtropical anticyclonic belt is interrupted by a seasonal cyclone over Pakistan, the whole of the continent south of the Tibet highlands is reached by the monsoon.

From this greatly simplified description of the global surface wind patterns it follows that the Desert Locust invasion area, lying between about 40°N and 10°S, is dominated by the subtropical anticyclones, the tropical easterlies and the monsoons of Asia and Africa. Superimposed on these are the smaller and shorter-lived cyclones, anticyclones and waves that bring much of the day-to-day changes of wind. Furthermore, the great highland areas distort these wind systems by sideways deflection and by channelling along valleys, and they cause local con-

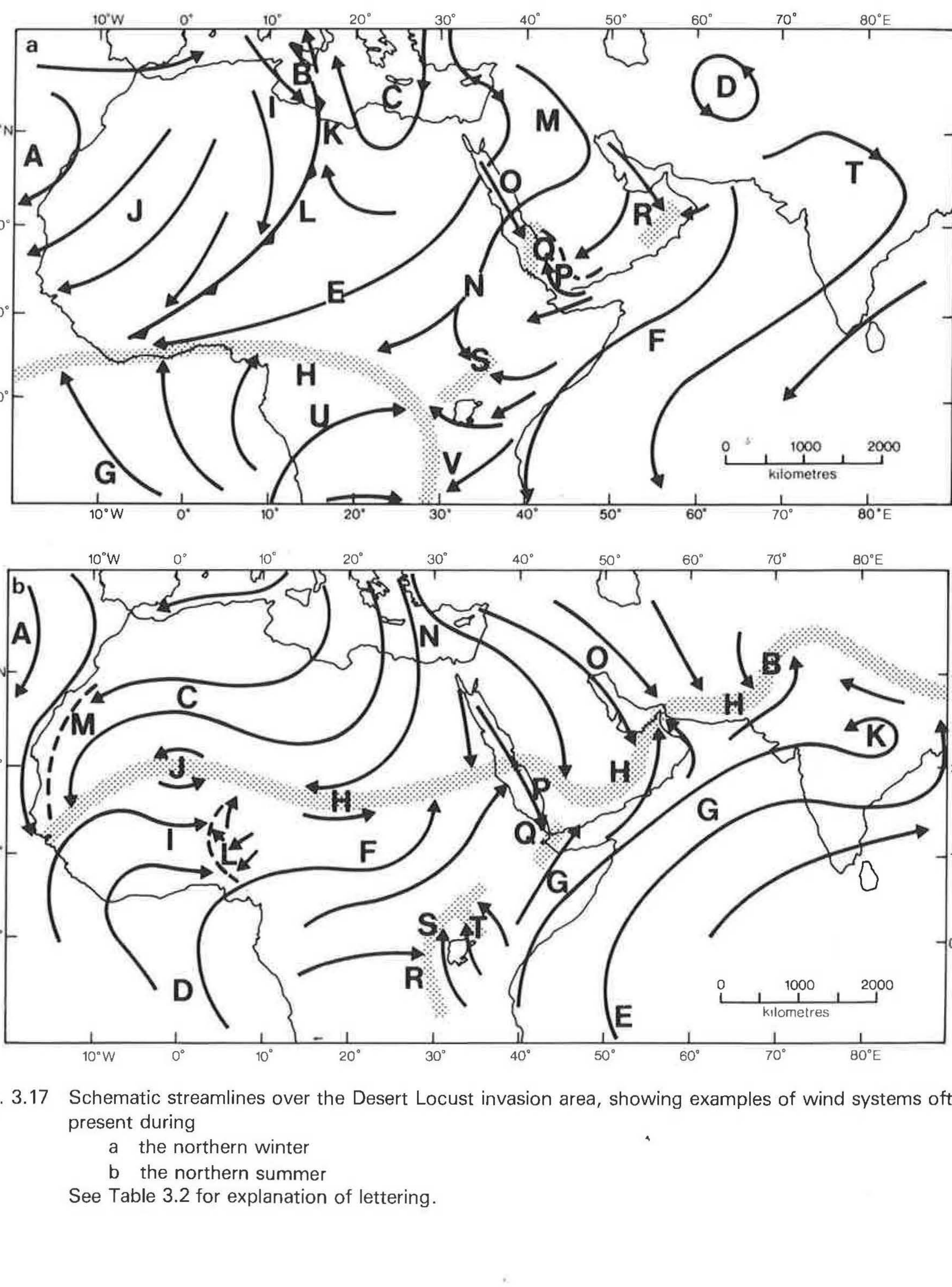


Fig. 3.17 Schematic streamlines over the Desert Locust invasion area, showing examples of wind systems often present during
a the northern winter
b the northern summer
See Table 3.2 for explanation of lettering.

vergence zones to form. In addition, along some coasts there are semi-permanent *coastal windshift lines* separating cool winds over the sea from hot winds over the land blowing towards the sea. Examples occur along the coasts of north-west Africa (the 'trade front') and of south-east Arabia.

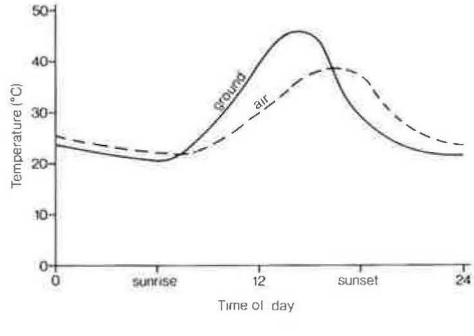
Day-to-day changes in *temperature* are associated with the movement and development of cyclones, anticyclones and waves. For example, the southerly winds to the east of a middle latitude cyclone (in the northern hemisphere) tend to be warm for the time of year, whereas the northerlies to the west tend to be cool. Often the change over from southerlies to northerlies is sudden and takes place at a WINDSHIFT LINE that moves progressively across country, sometimes for thousands of kilometres. The windshift line is also a COLD FRONT, making a change from a spell with a few days of rising temperatures in the southerlies to one of falling temperatures in the northerlies. Because cool-season swarms tend to be displaced most in the warm southerly winds they can move northward in short spells of such winds more than they move southward when there are cool winds from the north.

It is convenient to summarise this very brief account of wind systems by reference to two schematic maps showing systems that are often present over the invasion area in winter and summer (Figs. 3.17a and b, and Tables 3.2a and b). Many examples of these systems can be seen in the Case Studies, together with discussions of their effects on swarm movement.

3.3.5 DAY-TO-NIGHT WEATHER CHANGES

For most of the year over the Desert Locust invasion area, it is well known that the weather changes more from day to night than from day to day. The difference between the warmth of the day and the coolness of the night is due to an excess of heating over cooling by day, and the reverse at night. The atmosphere is heated by the sun, but largely indirectly — the ground is heated first. At night, of course, there is no heating, but cooling (through loss of invisible radiant heat to space) goes on day and night. From about sunrise, the heating exceeds cooling so ground and air temperatures rise, but during the afternoon cooling starts to exceed heating so ground and air temperatures start to fall (Fig. 3.18). As a result, lowest air temperature often occurs about sunrise, and highest air temperature about mid afternoon. The change of temperature from day to night (DIURNAL RANGE) is commonly 10–20°C (but more in very dry desert air) and can strongly affect daily flight duration (Section 3.1.3.3). By contrast, temperatures of the sea and of the air above it change very little from day to night.

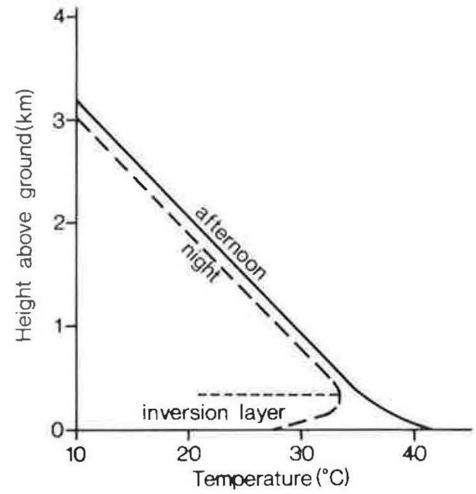
Fig. 3.18 Schematic diurnal variation of air and ground temperature in cloudless weather.



Heat from the warm ground is taken aloft mostly by *convective mixing* — a continual churning of the atmosphere as rising blobs and columns of warm air are replaced by sinking cool air — reflected in the fitful gustiness of an otherwise light wind. The depth of the mixed layer grows as surface temperature rises and may reach 2–3 kilometres by mid afternoon, and even 5 kilometres in the hottest places. In this mixed layer, highest air temperatures are close to the ground and there is a decrease upwards at a rate (LAPSE RATE) of about 10°C a kilometre. The temperature at any height in the layer, and hence the greatest height at which locusts may be flying (Section 3.1.3.1), can therefore be estimated from the surface temperature. At greater heights, the lapse rate is smaller, often 6–8°C a kilometre. At night, with falling temperature near the ground, there is often an *increase* in temperature upwards, especially with light winds and clear skies. Such an upward increase is known as a TEMPERATURE INVERSION. Highest temperature within a night-time inversion often occurs at some hundreds of metres above the ground (Fig. 3.19), and may enable high-flying locusts to migrate at night when surface temperatures are too low.

Wind as well as temperature usually varies from day to night. The reason is that wind near the ground tends to be slowed by ground roughness. By day, convection mixes the slowed air through a deep layer of the atmosphere, but at night the lowest few tens of metres can be slowed to near calm. Thus, night-flying locusts aloft may move faster than expected from surface winds. Where the large-scale wind *strengthens* upwards through the lowest few kilometres of the atmosphere (as it often does in the middle latitude westerlies), daytime convective mixing brings down faster air, and surface winds tend to be strongest at the time of deepest convection—mid afternoon. By contrast, where the large-scale wind *weakens* upwards (as it often does in the tropical easterlies and the monsoons), daytime convective mixing first brings down the fastest air from heights of a few hundred metres (just above the night-time temperature inversion), but by afternoon the weaker winds from greater heights are brought down, so surface winds are strongest during the morning. Such morning winds may be too strong for locust take-off, which is delayed to the afternoon. At night, whilst winds near the ground weaken to near calm those at a height of a few hundred metres may strengthen, and by so much that a mechanical mixing sets in, and fast-moving air is brought down and leads to a sudden and unexpectedly strong night wind. Where there is also a variation of wind *direction* upwards, surface wind changes from day to night can be very complex.

Fig. 3.19 Schematic variation of temperature with height in cloudless weather, day and night.



On most coasts, except in the coolest months, there is a day-to-night cycle of wind changes: from mid morning to early evening, a cool wind tends to blow from sea to land (the *sea breeze*) at a speed of about 10 knots (5 metres a second), and then at night it tends to reverse and blow from land to sea (the *land breeze*). The sea breeze is about 1 kilometre deep, and its leading edge is a windshift line that may move some tens of kilometres inland by sunset. Day-flying locusts may be kept by the onshore winds from moving out to sea, whereas the night-time land breeze may be too cool for flight. Many sea breezes are shown on the 1200 GMT weather maps of the Case Studies. Similar day-to-night changes also often occur over sloping ground, with *up-slope (anabatic) winds* blowing from about mid morning into the evening, and *down-slope (katabatic) winds* at night. Day-flying locusts may therefore become trapped in highland areas by upslope winds. Upslope winds along an *escarpment* may form a daytime convergence zone with an opposing larger-scale wind—the northern Somali Peninsula is an outstanding example of where this occurs.

It is clear that daytime rather than night-time surface winds can be used to estimate winds at heights where locusts are flying but where there are no direct observations; allowances must be made, however, for the possibilities of coast and slope winds. Moreover, mid afternoon surface temperatures can be used to estimate temperature at any *time* of the day (if the average day-to-night diurnal range for the month is assumed), and at any *height* in the convective layer (even at night above the inversion). For most of the invasion area, the 1200 GMT weather map is the best choice for making these estimates; otherwise 0900 or 1500 GMT could be used in the east and west, respectively, but there may be fewer observations at those times. Only 1200 GMT maps are used for the Case Studies in this Manual.

4 BREEDING

Breeding is the sequence of activities which results in the production of a new generation of adults. It starts with the arrival of immigrant adults in an area where rain has fallen, or which has received run-off, and finishes with the departure of young adults at the end of the breeding period. Usually there is only one generation in each breeding period but under some circumstances there may be two or even three generations (see Sections 2.4 and 2.5, and Chapters 5–8). The timing of seasonal breeding and the distribution of the seasonal breeding areas are summarised in Sections 2.4 and 2.5, and in more detail in the Regional Chapters 5–8. There are examples of the timing and extent of breeding in the Summaries and Case Studies. Maps showing the frequency of gregarious hopper infestations in each degree square are given at the beginning of Volume II.

Most of the information presented in this Chapter refers to breeding by *gregarious* locusts; differences in the breeding by *solitarious* locusts are described in Section 4.10. Volumes I and II of *Grasshoppers and Locusts* (Uvarov 1966, 1977) contain valuable summaries on many aspects of breeding and a very large number of references to original research.

Before describing breeding activities, it is appropriate to outline the main ecological requirements for breeding, because one of the main tasks which confronts a forecaster is to predict where, when and on what scale breeding is likely to occur.

4.1 ECOLOGICAL REQUIREMENTS FOR BREEDING

Rainfall is the most important requirement for breeding, because it creates, directly or indirectly, an environment suitable for all processes which together constitute breeding; these are *maturation, egg laying, egg development* and *hopper development.* It provides water in the soil which the eggs need to absorb in order to complete development (see Section 4.5) and which the desert vegetation, on which the hoppers feed (see Section 4.7.1), requires for germination or regeneration. Over most of the Desert Locust invasion area there is only one, usually relatively short, rainy season so that in many places breeding is confined to a few months of the year (Section 2.4 and Chapters 5–8). There are some areas, however, where breeding may occur for many months; although their extent is small in comparison with the Desert Locust invasion area, they are important in the initiation of plagues (see Section 2.7).

Topography influences where and when breeding occurs since upland areas often receive more rain than surrounding lowlands (see Sections 2.6 and 3.1), and run-off can result in suitable breeding sites in wadi beds tens of kilometres downstream of areas where rain has fallen.

Soil type influences the selection of sites where laying takes place as females prefer to lay in sandy or silty soils (see Section 4.4). The type of soil also influences the time it will retain enough moisture for laying and egg development to take place (see Section 2.6.2.1).

The *vegetation* of an area influences where swarms settle prior to laying, the distribution and density of egg pods (see Section 4.4.2) and the behaviour of hopper bands (see Section 4.7).

Finally, *temperature* determines the *rate of egg development* (Section 4.5.2), and it is the most important factor in determining the *rate of hopper development* (Section 4.7.4).

4.2 MATURATION

This term describes the sequence of changes which occur when *sexually immature* locusts become *mature*. These include changes in colour, behaviour and the reproductive organs. The changes are more or less correlated but there are sexual and individual variations. Forecasters need to be aware of the changes in order to be able to judge from field reports when locusts are maturing, and to predict when and where breeding may commence. Although adult locusts usually begin to mature a day or two after they reach areas where rain has recently fallen, swarms can exist in rainy areas without maturing. The precise factors which result in locusts maturing are not fully known; Carlisle, Ellis & Betts (1965) noted that the egg development and colour changes which take place during maturation occurred just before the onset of the seasonal rains in the Somali Peninsula and suggested that it was the scent of bursting buds of aromatic desert shrubs which caused adults to mature. Over the Desert Locust invasion area, the period between fledging and the onset of maturation is very variable and is discussed in Section 4.2.4.

4.2.1 CHANGES IN COLOUR

The commonest evidence in field reports that swarms are beginning to mature is that instead of being described as pink, red, reddish-brown or brick-red they are reported as 'red and yellow', 'yellowing' or 'of mixed maturity'. This is because gregarious locusts turn yellow as they mature. Any swarm which is reported as yellow can be regarded as mature. There are marked differences between the sexes: males become bright yellow but females become only dull yellow. The first area to become yellow is normally the base of the hind wing. Next, traces of yellow appear on the upper sides of the rear abdominal segments, and at this stage males are usually ready to copulate and are therefore regarded as mature. Colour characteristics of the extreme phases, *solitaria* and *gregaria,* are illustrated in the *Desert Locust Pocket Book* (Centre for Overseas Pest Research 1978), and in the frontispiece of Uvarov (1966).

Males usually mature slightly earlier than females so that it is normal for maturing swarms to contain both pink (or red) and yellow individuals and a range of intermediates. It should be noted that in some areas and seasons, for example in the Somali Peninsula during the summer, swarms may contain males which have yellow hind wings and partially yellow abdomens but which are reproductively immature.

Forecasters should be aware of the possibility that swarms of mixed maturity can also be produced by the joining up of fully mature swarms with immature swarms.

In low-density populations, the colour changes which occur at maturation are less pronounced than in swarming populations.

4.2.2. CHANGES IN BEHAVIOUR

When swarms reach areas which are suitable for breeding their predominant behaviour changes from migratory flight to reproductive activities so that migration is temporarily arrested. The change is not immediate but takes place over several days as the number of adults which are fully mature increases. These form numerous feeding, marching, copulating and (later) laying groups, while the less mature individuals undertake further flights near to where copulation starts. Swarms often therefore break up as they mature, but frequently rejoin when they resume their migratory flight between successive cycles of copulation and egg laying.

4.2.3. CHANGES IN THE REPRODUCTIVE ORGANS

At the same time as the changes in colour and behaviour occur, there are changes in the reproductive organs. These are most easily recognised in the ovaries of the females. In immature females, the largest rudimentary egg in each ovariole is about 1 millimetre long, transparent, thread-like and contains no yolk. As the female matures, yolk is deposited in the egg, which increases in length and diameter until, when it is fully grown, it is about 7 millimetres long and 1 millimetre in diameter. Several systems have been evolved which relate egg development to the maturity of the individual (Phipps 1949, Norris 1954). One which is widely used in West Africa is presented in Table 4.1. It should be noted that the relationship between egg development and adult maturity only applies to females about to lay *for the first time.* Because females lay more than one egg pod (see Section 4.4.4.), mature individuals are sometimes reported as containing no eggs. These will have only just laid and will not have had enough time to deposit noticeable quantities of yolk in the next batch of eggs. Information on ovarian development is particularly valuable in assessing the state of maturity of females in low-density populations, when other evidence maturity, e.g., colour change, may be lacking. The presence of red bodies at the base of each ovariole is evidence that a female is mature, though not necessarily that it has laid (Uvarov 1966). Field reports seldom refer to changes in the male reproductive system.

Table 4.1 Stages in egg development in relation to the maturity of females about to lay for the first time.

Stage	Length of largest egg (mm)	State of largest egg	Maturity
0	1	no yolk visible	Immature
1	1	yolk visible	Maturing
2	2	each egg visible	Maturing
3	2–4		Maturing
4	5–7		Mature
5	7–7.5	eggs released into oviduct ready for laying	Mature

4.2.4. RATE OF MATURATION

The rate of maturation is very variable and is complexly related to the amount, area and timing of rainfall, soil, topography, vegetation and temperature.

The extreme cases are provided on the one hand by the continuance of conditions favourable for maturation after the first generation of hoppers has fledged. Under such conditions the young adults mature and lay within about three weeks of fledging (Rao 1942), e.g., in the summer breeding areas of West Africa (Tamesna in Niger and Mali), in India and Pakistan, and in spring breeding areas around the Red Sea and the Gulf of Aden. In some exceptional years there may even be three generations in rapid succession, e.g., northern Somalia 1956–1957. Such circumstances may permit very rapid increases in population, and have been particularly associated with outbreaks and plague upsurges (Kennedy 1939, Waloff 1966, Roffey, Popov & Hemming 1970, and Sections 2.6 and 2.7). The other extreme occurs when swarms which have been produced on the summer rains in West Africa move south with the retreating ITCZ and remain immature throughout the dry season, maturing only with the arrival of the following year's monsoon rain some nine months later (see Sections 2.4 and 8.9).

Much more frequently the duration of the immature adult stage is two to four months. For examples, see Section 2.4, Chapters 5–8, and the Summaries and Case Studies.

Locusts reaching an area which has received widespread and heavy rain usually mature and start to lay within about a week, providing it is not too cold, i.e:, at temperatures above about 17°C (Popov 1954a). Because migrating swarms often reach an area of widespread rainfall nearly simultaneously or, alternatively, there is widespread and heavy rain in an area already occupied by swarms, there have been many occasions when laying has begun within a few days over very extensive areas. Carlisle, Ellis & Betts (1965) provide examples from most of the major breeding areas and in most months.

Forecasters need to know that there are certain areas, however, where although sufficient rain has fallen, at least locally, to promote maturation, this is nevertheless delayed for reasons which are not always clear. The following are the most important of these areas.

- The 5,000 kilometres long belt south of the Sahara, within which immature swarms can start to accumulate from mid May, but in which laying is usually delayed until early July (Rainey 1963). The delay in this area is probably due to the absence of widespread and heavy rain in the areas reached by swarms until early or mid July in most years. However in some years, as in 1968, locusts can mature and lay as early as April.
- The northern Somali Peninsula; immature swarms which are regularly concentrated along the marked windshift line between June and September usually remain sexually immature even though they are often engulfed by heavy afternoon showers. In this area the delay constitutes an unsolved puzzle (see Rainey 1963).
- North-West Africa; immature swarms from summer breeding areas south of the Sahara normally reach south-west Morocco in October, but fail to mature until late January or February. In this area it is probable that low temperatures delay maturation.
- Middle East; swarms reaching Egypt, Jordan, northern Arabia and Iran from October to December may remain immature for two or three months, although in some years swarms mature and lay in December.

4.3 COPULATION

Copulation is the process by which males fertilize females. To do this the male pounces on the female and sits on her back, clasping her firmly by the first two pairs of legs. Even when copulation is over, gregarious males usually remain on the females while the latter are laying. Reports of locusts pairing may therefore refer to copulating or laying or both. Once copulation has been reported in an area it can be assumed that laying will commence very shortly, usually within hours, and in the same locality. Copulation has been recorded at air temperatures down to 17°C (Popov 1954a).

4.4 EGG LAYING

4.4.1 LAYING BEHAVIOUR AND ECOLOGICAL REQUIREMENTS FOR LAYING

Within hours of the commencement of copulation the females start searching for suitable egg laying sites. Once some females have located suitable sites by trial probing of the soil they are joined by others and eventually groups of laying pairs form. These may comprise hundreds of pairs.

The initial selection of laying sites starts with marching females seeking warmer and more open sites. Site selection is then influenced by the properties of the soil. A dry, soft sandy surface is preferred to a moist compact one. The amount of water in the topmost 6 centimetres of soil is unimportant, but at greater depths there is selection in favour of soils with higher moisture contents. Unless the whole egg pod can be embedded in moist soil, usually at a depth between 5 and 15 centimetres, egg laying will not take place (Popov 1958a). Popov found that the equivalent of 15–20 millimetres of rain 24–48 hours before laying provided the most acceptable conditions for laying, and Magor (1962), in a biogeographical study of field reports of laying, concluded that approximately 20 millimetres of rain in a short period, or its equivalent in run-off, will provide sites suitable for laying, in most but not all circumstances. Thus, somewhat larger amounts of rain may be required to provide sites suitable for laying by females arriving several days or even weeks after the rain has fallen. Also, female locusts do not lay in very clayey, very stony or saline soils (Popov 1954a, 1958a).

The total period for laying by a swarm ranges from 7 to 30 hours (Popov 1958a). At the end of laying, the pairs separate and the swarm usually leaves the laying site. Because swarms tend to split up as they mature (see Section 4.2.2), it is normal for each swarm at successive layings to give rise to several EGG FIELDS, all laid within a day or two of one another, and usually within a few kilometres of one another. Reports of single egg fields may mean that there are other egg fields in the area which have not been seen.

If soils are suitable for laying in only a small part of the area of the settled swarm, females may make many trial probes before they find a suitable site. Sometimes no suitable sites are found and the females, which can retain fully developed eggs for about three days, then lay on the surface of the ground, or on bushes or trees (Popov 1958a). If there are many reports of such behaviour in a seasonal breeding area it is probable that breeding will be generally unsuccessful. This happened, for example, in eastern Africa in late 1955 and led to the disappearance of large swarming populations for the first time for five years (see also Section 3.1.10).

Estimating the size of an egg field is a time-consuming task unless the swarm was seen whilst laying. Experienced observers can recognise the disturbed soil surface, and the size of the egg field can then be estimated by foot traverses through the kinds of soils and vegetation that were selected by the females for laying. Strong winds or rain, however, can remove the surface disturbance, and it then becomes necessary to dig and seek pods at depths of 10–15 centimetres.

4.4.2 EGG POD DENSITIES

The density at which egg pods are laid varies greatly. Highest densities, which may reach 1000 in a square metre, tend to occur at sites where only a small proportion of the area is suitable for laying, e.g., in a wadi bed surrounded by dry soil. At the other extreme, egg pod densities may average only one or two in a square metre if a swarm lays in a very uniform habitat that provides, in effect, one large favourable laying site (Popov 1965). Egg pods are usually laid, however, in groups of tens or hundreds, at densities of 200 – 500 in a square metre. Because groups of pods may be separated from one another by several metres, *average* egg pod densities *throughout* an egg field may be no more than about 5 in a square metre (Stower, Popov & Greathead 1958).

4.4.3 NUMBER OF EGGS IN AN EGG POD

The number of eggs laid in each pod depends mainly upon the phase and the age of the female (Ashall & Ellis 1962). Whereas pods laid by females at low densities, or by swarms which had solitarious antecedants, contained an average of more than 95 eggs (see Section 2.2), pods laid by continuously swarming populations contained an average of less than 81 eggs. Females from swarms laid significantly fewer eggs at the second laying than at the first, and if a third laying occurred there was a further reduction in the number of eggs in a pod. Swarms originating in different areas lay significantly different numbers of eggs in a pod, which suggests that the differences could be related to the time taken to reach maturity, rapidly maturing females laying more eggs in a pod than older females. The number of eggs in a pod also decreases in seasons of low rainfall and poor vegetation growth.

4.4.4. NUMBER OF LAYINGS

Analysis of field reports of layings in eastern Africa showed that there were two main waves of laying on almost equal scales, followed by a third on a much smaller scale (Popov 1958b). The interval between successive layings was 6 to 11 days, depending upon temperature. The reduction in scale of the third laying is due to death. Females usually die sooner than males, so that reports of mature swarms with high proportions of males relate to old swarms which are nearly at the end of their life.

4.5 EGG DEVELOPMENT

4.5.1 THE MOISTURE REQUIREMENTS FOR EGG DEVELOPMENT

Laboratory studies have shown that eggs of the Desert Locust need to absorb approximately their own weight of water in order to complete their development (Shulov 1952, Roonwal 1954, Hunter-Jones 1964). Eggs in the field are normally able to absorb sufficient water from the soil within a few days of laying, so that about 20 millimetres of rain in a short period (or its equivalent in run-off) will provide adequate moisture for eggs to complete development. But if the eggs do not absorb enough water to continue development in the first few days after laying, it has been found in the laboratory that they may remain dormant for up to about 3 months and then resume development if they are wetted (Shulov & Pener 1963). In the field, dormant periods of 60 days have been recorded (Popov 1965).

4.5.2 DURATION OF EGG DEVELOPMENT

Providing Desert Locust eggs have absorbed enough water to complete development, the duration of egg development depends upon *soil temperature.* Field and laboratory data show that the duration decreases as the temperature increases (Rao 1942, 1960, Hunter-Jones 1966, Wardhaugh, Ashour *et al.* 1969). Expressed in another way, the *rate of egg development* increases as temperature increases. At constant temperatures in the laboratory, this increase is from 2% a day at about 20°C to about 9% a day at temperatures of 35 – 40°C (Hunter-Jones 1966).

Thus, providing the temperature of the soil is known, the daily rate of development can be calculated, and the start of hatching estimated as the day after development is complete. In practice, forecasters are unlikely to have access to *soil* temperatures at or near laying sites. They should therefore attempt to obtain the most relevant *air* temperatures: the *mean daily* air temperatures (normally taken as the *average* of the daily maximum and the daily minimum temperatures) recorded at the meteorological station nearest to the laying site. These temperatures can be corrected roughly for any difference in altitude by adding (subtracting) 1°C for every 200 metres that the station is above (below) the egg field.

The relationship between the *mean daily* rate of egg development and the mean daily air temperature has been examined using field *experiments* (Wardhaugh, Ashour *et al.* 1969). The data are of limited forecasting value, however, because they were obtained at two sites in Saudi Arabia, and they do not provide the complete range of temperatures or the variation in other environmental conditions which Desert Locust eggs may experience in the field. Symmons, Green *et al.* (1973, 1974) used *field reports* of incubation periods from different parts of the Desert Locust invasion area. Their data covered a range of mean air temperatures between 12 and 34°C, and incubation periods between 10 and 65 days.

J. Draper (personal communication) has suggested that the relationship is unsatisfactory at low temperatures and has proposed another* based on the work of Pradhan (1945) (Fig. 4.1). If air temperatures are available near the egg field, Draper's relationship can be used. As a guide, Table 4.2 has been prepared giving percentage development and incubation period at different temperatures, and the error range which might be expected (calculated from the 95% confidence limits).

Table 4.2 Variation of daily percentage egg development and incubation period with mean daily air temperature.
Ranges are calculated from the 95% confidence limits.
Figures marked * are corrected for the minimum known incubation period (9 days).

Mean daily air temperature (°C)	daily percentage development		incubation period (days)	
10	1.0	0.7–1.4	99	70–139
11	1.2	0.9–1.7	83	60–116
12	1.4	1.0–2.0	70	51– 97
13	1.7	1.2–2.3	60	44–82
14	1.9	1.4–2.7	51	38–70
15	2.3	1.7–3.1	44	33–60
16	2.6	1.9–3.5	39	29–52
17	3.0	2.2–4.0	34	25–46
18	3.3	2.5–4.5	30	22–41
19	3.8	2.8–5.1	27	20–36
20	4.2	3.1–5.7	24	18–32
22	5.1	3.8–7.0	19	14–26
24	6.1	4.5–8.3	16	12–22
26	7.0	5.2–9.6	14	10–19
28	7.9	5.8–10.7	13	9–17
30	8.6	6.3–11.0*	12	*9–16
32	9.1	6.7–11.0*	11	*9–15
34	9.4	6.8–11.0*	11	*9–15

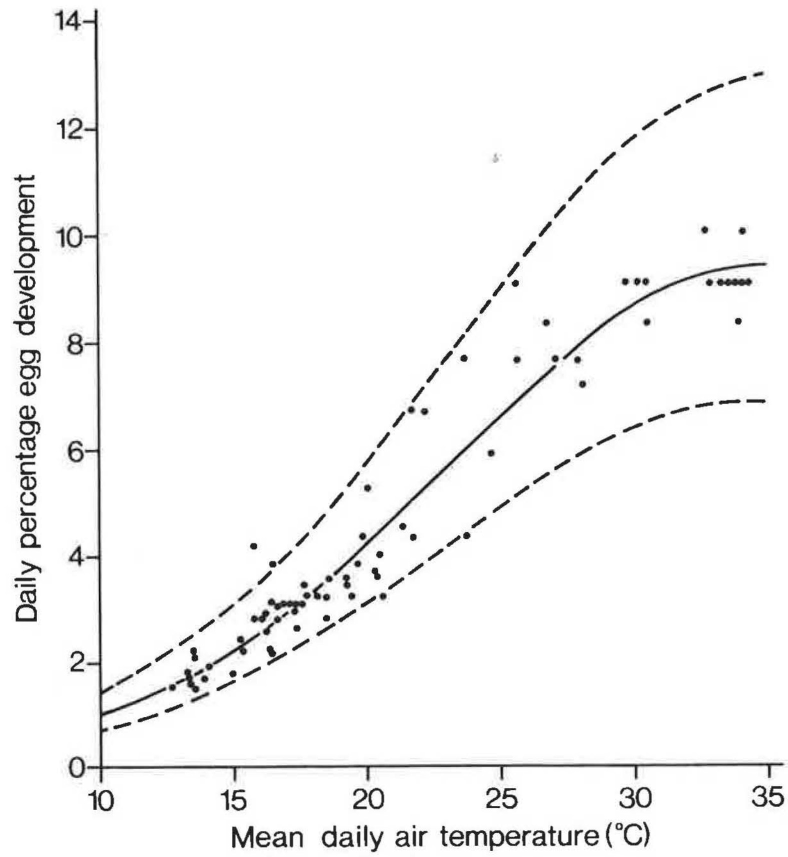


Fig. 4.1 Variation of daily percentage egg development with mean daily air temperature (after Draper, personal communication). Pecked lines show 95% confidence limits.

*The relationship between daily percentage development and mean daily air temperature is expressed by the equation:

$$y = 9.416e^{-0.00357\,(35.019-t)^2}$$

where y is the daily percentage development
t is the mean daily air temperature (°C)
e is the Naperian constant, 2.718.

On many occasions daily air temperatures will not be available and use should be made of development maps prepared by Symmons, Green *et al.* (1973), based on *mean monthly* air temperatures. Use of these maps has suggested that they are unreliable for forecasting *long* incubation periods (in the winter and spring breeding areas, particularly in the cooler months). Estimates made using these maps, however, will probably be adequate for forecasting, provided the incubation periods obtained do not exceed 50 – 55 days. It should be noted that, because the maps are based on mean *monthly* air temperatures, spells of weather warmer than average during the forecasting period will lead to incubation periods which can be considerably shorter than average, whereas spells of weather colder than average will lead to incubation periods which can be considerably longer than average. The error ranges given in Table 4.2 for different incubation periods will also be generally applicable to estimates derived from the development maps.

As a further aid to forecasters when air temperatures are not available, summaries of egg development periods recorded in the field have been prepared (Tables 4.3 – 4.8). These summaries are based on data from field reports up to 1966 at the Centre for Overseas Pest Research and extracted by K. G. Wardhaugh, E. Betts and Z. Waloff. The summaries consist of the arithmetic means and ranges of incubation periods for each month in each of the major seasonal breeding seasons. The month in which the egg incubation period is listed is the month in which *laying* occurred. For occasions where laying and hatching were reported for two or more days, the values in the tables are the intervals between the *first* day of laying and the *first* day of hatching. The months for which there are 10 or more recorded incubation periods in each season and area are marked with an asterisk(*), as these will probably provide a better guide to likely incubation periods than months for which there are fewer records. Where there are no recorded incubation periods for a particular area and month, forecasters should be guided by periods in adjacent months and areas.

These Tables should be used in conjunction with the development maps, and in place of the maps when incubation periods exceed 50 – 55 days. Care should be taken when using Tables 4.3 – 4.8 because large ranges in the observed incubation periods probably reflect differences in environmental conditions within a breeding area, and the resulting mean values may be suspect when the number of observations is small (less than 10).

There are likely to be many reports of laying and associated hatching in national and regional locust offices which have not been used in preparing Tables 4.3 – 4.8. Forecasters will find it helpful to assemble these reports and revise the periods shown, particularly for those areas and months where the data used were sparse.

Apart from major variations in durations of egg development due to temperature, there is also variation within a given egg field. Thus, it has commonly been observed that hatching from a single group of egg pods extends over 2 – 3 days when the average incubation period is 12 – 14 days (Ellis & Ashall 1957, Stower, Popov & Greathead 1958). This variation of some 15 – 20% is probably due to slight variations in egg pod depth, soil temperature, soil moisture, and perhaps genetic make-up. At lower temperatures, the period over which hatching occurs may be even more protracted: in the Hasa area of Saudi Arabia the first hatchings once occurred 72 days after laying, and hatching was noted for six days.

The following example shows how Tables 4.3 – 4.8 can be used. Suppose hatching was reported from Somalia on 9 November at a place 200 metres above sea level. Table 4.3 gives 12.8 (say 13) days for the egg incubation period; hence the most likely egg laying date was 9 November minus 13 days, i.e., 27 October. (Additionally, Table 4.9 gives 37.8 (say 38) days for the hopper development period; hence the most likely fledging date would be 9 November plus 38 days, i.e., 17 December.) For further examples of the use of these Tables see Section 10.4.

Table 4.3 Egg incubation periods recorded in the summer breeding areas in Africa, Arabia, Pakistan and India. Arithmetic means and ranges, in days. *denotes means based on 10 or more records.

Area	Altitude (metres)	June		July		Aug.		Sept.		Oct.	
India	0 – 500	12.0	12	12.2*	10 – 21	13.3*	10 – 20	13.3* –	9 – 17	17.2	13 – 36
Pakistan	0 – 250			11.7*	10 – 16	12.7*	9 – 17	10.7*	9 – 13		
Arabia	0 – 1500	15.5	15 – 16			11.3	10 – 12	12.5	10 – 15	11.0	9 – 12
Ethiopia,	0 – 900	15	15	16.0*	12 – 21	12.4	10 – 18	11.7	11 – 12		
Somalia,	900 – 1500	17	17	17.3*	10 – 23	15.0*	10 – 20	11.3	10 – 12		
Kenya	>1500			17.6	13 – 23	17.5	14 – 20				
Sudan, Chad, Niger, Mali, Mauritania, Senegal	0 – 1250	12.5	9 – 16	12.6*	9 – 14	13.9*	9 – 25	13.5*	9 – 23	17	17

Throughout this vast area mean air temperatures during the summer breeding season exceed 25°C almost everywhere except in the highlands of Ethiopia. Daily maximum temperatures are commonly 30 – 40°C, and at night temperatures rarely fall below 20°C. Eggs develop rapidly and hatching generally occurs 10 – 14 days after laying. At higher altitudes, durations tend to increase but rarely exceed more than 20 days. There is a significant lengthening of incubation periods for eggs laid in October in India, when mean air temperatures are decreasing.

Table 4.4 Egg incubation periods recorded in the Long Rains and Short Rains breeding areas in eastern Africa. Arithmetic means and ranges, in days. *denotes means based on 10 or more records.

Altitude (metres)	Feb.	Mar.	Apr.	May	Oct.	Nov.	Dec.
0–300			13.7* 11–19	13.8* 10–17	13.7* 9–18	12.8* 9–17	14.0 14
300–600		11.3 10–13	14.1 12–16	12.6 10–17	13.0* 10–18	12.8* 10–16	12.3* 11–15
600–900	17.0 15–19	10 10	13.9* 10–18	13.6* 10–16	13.5* 11–18	13.0 10–16	13.3 13–14
900–1500	18.5 15–22	16.4 16.4	14.7* 11–20	13.9* 9–20	13.0 12–17		
1500–2000			14 14	16.4 13–20			

Mean air temperatures during both the Long Rains and Short Rains breeding seasons exceed 25°C over a large part of the area, despite considerable differences in altitude. The great majority of incubation periods throughout the area lie in the range 10–14 days. Slightly longer incubation periods have been recorded at higher altitudes, but they rarely reach 20 days.

Table 4.5 Egg incubation periods recorded in coastal areas around the Red Sea and Gulf of Aden. Arithmetic means and ranges, in days. *denotes means based on 10 or more records.

Jan.	Feb.	March	Apr.	May	June
15.1* 12–29	13.7* 11–22	14.7 13–16	11.5 10–15	(no records)	15 15

July	Aug.	Sept.	Oct.	Nov.	Dec.
15 15	12.5 12–16	11.5 10–16	12.0 9–17	11.6* 9–18	14.0* 9–25

These areas are characterised by high mean air temperatures, which may exceed 33°C during the summer. During the winter, mean air temperatures around the southern end of the Red Sea and the Gulf of Aden fall to 23–25°C, but night minimum temperatures rarely fall below 20°C. Incubation periods are usually in the range 11–15 days. North of about 20°N, minimum temperatures frequently fall below 20°C in the winter months and longer incubation periods have been recorded, but these rarely exceed 20 days.

Table 4.6 Egg incubation periods recorded in the winter–spring breeding areas in Arabia and the Middle East. Arithmetic means and ranges, in days. *denotes means based on 10 or more records.

Area	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Oman and United Arab Emirates	15.7 15–16	30 30	20.0 13–24	17.3 16–19	13.7 11–16	16 16		
Arabian peninsula S of 25°N			22.6 15–33	31 18–38		15.1 9–23	11 11	
Saudi Arabia N of 25°N			54.0* 39–84	29.3* 23–40	24.7* 15–41	17.0 11–25	16.5 15–18	
Kuwait			56.8 53–59	38.5* 21–51	26.4 18–38	21.0 12–30		
Iraq			55 55	31.5 31–32	23.0 17–32	28 28		
Jordan		41.2 29–51	44.0 41–47	32.0* 21–53	28.0* 20–40	27 27		
Israel				34 34	26.0 22–28	21.3 14–26		
Lebanon							23.9* 20–29	24.7* 24–25
Syria					26 26	24.2* 15–33	15 15	
Turkey						28.5* 15–38	22.3* 14–38	18.2* 17–19
Egypt (except south-eastern desert), Sinai				37.3 27–43		24.5 24–25		

Over most of this area, mean air temperatures are below 15°C during January, which is normally the coldest month of the year. Daily maximum air temperatures rarely exceed 20°C, and frosts are common at night. Eggs may develop for only a few hours during the warmest part of the day, and during particularly cold weather development may cease altogether. As a result, durations of egg incubation may exceed 60 days. The longest duration recorded, 84 days, occurred following laying in early January 1960 in the Hofuf area of eastern Saudi Arabia.

Incubation periods at different altitudes have not been given separately for each month and area because, although incubation periods increase with altitude, swarms only lay at lower altitudes in the earlier and cooler months and at higher altitudes and latitudes in the later months. As a result, the duration of incubation periods for each month and area at different elevations show no more variation than those within each altitudinal level.

Table 4.7 Egg incubation periods recorded in the winter-spring breeding areas in the Eastern Region and the U.S.S.R. Arithmetic means and ranges, in days. *denotes means based on 10 or more records.

Area	Altitude (metres)	Dec	Jan	Feb	Mar	Apr	May	June
Iran, Afghanistan	0–250	33.3 15–63	20.0 18–22	16.7 14–28	16.8 14–26	15.7 15–17		
	250–1000		25 25	30.3 25–37	25 25	12 12	19.5 13–26	
	>1000						16.3 10–19	
Pakistan, India	0–250			25.0*14–31	25.2 16–39			
	250–1000			25.0 16–32	25.0 14–36	17.0*9–26	15.4 14–17	14 14
USSR	0–250					18 18	17.0 14–21	14.5 14–15

In the coldest months, egg laying is restricted to coastal areas of southern Iran and the Mekran of western Pakistan, and egg incubation periods are very variable. As temperatures rise in the spring, laying occurs further north and at greater elevations, and development periods shorten, but remain very variable. By May, laying has ceased in coastal and low-lying areas, and most development periods are in the range 14–21 days.

Table 4.8 Egg incubation periods recorded in the winter-spring breeding areas of North-West Africa. Arithmetic means and ranges, in days. *denotes means based on 10 or more records.

Country	Altitude (metres)	Jan	Feb	Mar	Apr	May	June
Morocco	0–500	29.2 16–43	35.6* 23–50	29.6* 19–49	24.5 20–27	18.3 10–23	15.7 10–17
	>500		37.7 27–53	35.7* 19–51	30.7 28–31	18.0 11–25	19.0 17–21
Algeria	0–500		44.5 39–48	35.0* 29–42	24.1* 18–31	19.9* 13–33	10 10
	500–750			38.9 27–55	30.9 21–37	22.4 16–35	
	750–1000		51.3 43–62	42.3* 34–58	33.3* 16–48	22.0* 18–31	20.2 20–21
	>1000		54.0 50–58	39.7 26–56	38.8* 27–49	24.6 16–33	
Tunisia	0–750		38.7 29–54	30.2 21–46	30.6 20–43	19.5 16–25	14.0 14
Libya	0–750	61.2 51–70	47.0* 35–60	33.2* 17–39	27.4* 22–32	17 17	

In January, which is normally the coldest month, laying is restricted to the western coast of Morocco and to the Jefara coast of north-west Libya. As temperatures rise, egg laying can become widespread and it occurs at greater altitudes. Field data show very clearly in this area that incubation periods increase with altitude, and decrease as spring progresses. During the cooler months, there is usually very considerable variation in recorded development periods for each area and altitudinal zone, so that it is preferable to calculate periods from temperature data for the current season.

4.5.3 EGG MORTALITY

Eggs die from a wide range of causes. Greathead (1966) gives a brief summary and provides references to more detailed studies.

Among the more important and regular causes of egg mortality are:

- desiccation, mould and bacteria, which may amount to 10% (somewhat rarely it may be much higher if eggs are unable to absorb sufficient soil water and are not subsequently wetted);
- inviability, which is frequently about 10%;
- predation — there are many different species of predators and their effect is highly variable, among the most important being the flies *Stomorhina lunata* and *Systoechus* species, and various beetle larvae including *Trox* and *Mylabris,* leading to losses of 10–40%, but sometimes totally destroying an egg field.

4.6 HATCHING

Hatching usually occurs within 2 or 3 hours of dawn, but hoppers may hatch at any time of the day from pods which have been disturbed by digging. Usually all viable eggs from a single pod hatch on the same day, but different pods within a group may hatch over 2–3 days. When egg incubation periods are long, hatching may occur over several days.

On emergence from egg pods laid by gregarious females, hatchlings are pale green or fawn but within a few hours they become black.

4.7 HOPPER DEVELOPMENT

4.7.1 ECOLOGICAL REQUIREMENTS FOR HOPPER DEVELOPMENT

The most important ecological requirement for hopper development is *rainfall* because it allows growth of vegetation that provides both food and shelter for the hoppers. While hoppers do feed on, and shelter in, *perennial* grasses, herbs and shrubs, much of the food is provided by the *ephemeral* grasses and herbs which germinate following the onset of seasonal rains. Extensive germination of ephemerals occurs only after about 25 millimetres of rain has fallen. The life cycle of ephemerals usually takes 6–8 weeks but is partly temperature dependent (Kassas 1966). The period from laying to fledging in the Desert Locust is frequently 40–50 days (see Sections 4.5.2 and 4.7.4). As a result, over much of the Desert Locust invasion area the amount of rain which is necessary for egg development is also adequate to provide sufficient vegetation for the hoppers to complete their development. However, more than 25 millimetres of rain may be required for successful breeding in the very hot summer breeding area (Bennett 1976).

During the sequences of successive generations of successful breeding which are characteristic of plague upsurges, unusually heavy and widespread rain appears to be necessary only in the early stages. Subsequently, the most important factor is the occurrence of adequate rain at suitably timed intervals (see Section 2.7).

4.7.2 THE GROWTH OF HOPPERS

Hoppers eat approximately their own weight of fresh vegetation per day (Davey 1954), and the weight of hoppers increases more or less continuously throughout hopper life (see Table 4.9). The external form of a hopper, however, only changes at MOULTS. The period between two successive moults is called an INSTAR. At moults the old outer skin is cast off and replaced by a new soft skin which has developed under the old. The new skin stretches before it hardens, thus allowing the hopper to grow in size (see Table 4.9).

Table 4.9 Ranges of body weight and length for gregarious Desert Locust hoppers (after Davey 1954).

Instar	Weight (mg)		Length (mm)	
	males	females	males	females
First	10–54	10–56	6–14	6–13
Second	40–140	44–150	10–20	13–20
Third	90–308	110–366	18–27	18–27
Fourth*	226–326	224–360	25–36	25–38
Fifth	496–1694	606–2342	35–48	35–49

*weights at beginning of instar only.

Gregarious hoppers have *five* instars, but individuals in low-density populations often have *six* instars; the extra instar occurs between the normal third and fourth instars.

Apart from an increase in size and weight, the main external changes that occur as hoppers grow are the development of wing buds and the external genitalia. Wings start as rearward projections from the second and third segments of the thorax. At the end of the third instar (in five-instar forms) or the fourth instar (in six-instar forms) the wing buds turn on their axes so that the outer surfaces become the inner, and the rudiments of the front wings are covered by those of the hind wings. Wing-reversal clearly differentiates younger hoppers from older ones.

There are also changes in the pigmentation of the compound eyes that provide a sure method of determining the instar of a hopper. These are most noticeable in solitarious hoppers. In the first instar, a single longitudinal darker stripe appears and one extra stripe is added at each moult. Thus, second instar hoppers have two eyestripes, third instars three, etc. This continues up to the last moult (fledging) so that adults have either 6 or 7 eyestripes. Since the extra instar only occurs in low-density populations, adults with 7 eyestripes have been bred at low densities. Because only a proportion of individuals in low-density populations have an extra instar, however, the density at which adults with six eyestripes bred has to be deduced from other evidence, e.g., colour and morphometrics (see Section 2.2).

4.7.3 COLOUR CHANGES DURING HOPPER DEVELOPMENT

The colour patterns of Desert Locust hoppers are very complex and display great variation. The most comprehensive study is that by Stower (1959), upon which this simplified summary is based. Colour characteristics of the extreme phases, *solitaria* and *gregaria,* are illustrated in the *Desert Locust Pocket Book* (Centre for Overseas Pest Research 1978) and in the frontispiece of Uvarov (1966).

Essentially, colour patterns arise from two main components: a *ground colour,* which is normally some shade of green in individuals bred at low densities, but which is red, orange or yellow in gregarious individuals; and a *dark* *pattern,* which is usually strongly developed in gregarious populations but usually absent among individuals at low densities.

There are many intermediate colour types, which can be used to decide whether population density is increasing or decreasing. In addition, hoppers produced at high temperatures tend to be light in colour, and solitarious individuals in the last two instars may be brown instead of green.

Thus, individuals bred at low density are green in the first three instars, and green or brown in the last two instars (in individuals having six instars the extra instar is green). In gregarious populations, the first two instars are predominantly black, in the third they are red or orange and black, while in the fourth and fifth they are yellow and black. In many transient populations, black and green hoppers are recorded: they are frequently an indication of an increase in population density and represent one aspect of the process of gregarisation.

4.7.4 DURATION OF HOPPER DEVELOPMENT

Most studies of factors which affect the duration of the hopper stage have been conducted in the laboratory and have been largely concerned with the effect of temperature and relative humidity. In the field, however, hoppers are able to regulate their body temperatures to a very considerable extent (Stower & Griffiths 1966) by moving about in response to changes in the microclimate. As a result there is far less variation in the duration of the hopper stage than in the egg stage.

In the laboratory, it has been found that at constant temperature there is a linear relationship between temperature and the *rate* of hopper development between 24 and 38°C, being about 1.5% a day at 24°C and 5% a day at 38°C (Dudley 1961). The corresponding *durations* of hopper development were found to be 66 days and 20 days.

Field studies on hoppers in cages similarly showed that there was a linear relationship between mean daily air temperature during development and the rate of hopper development (see Fig. 4.2, from Wardhaugh, Ashour *et al.* 1969). Symmons, Green *et al.* (1974) found that the relationship could be expressed as follows:

$$Y = 0.222\,T - 3.166$$

where Y is the percentage development per day, and T is the mean air temperature in degrees Celsius.

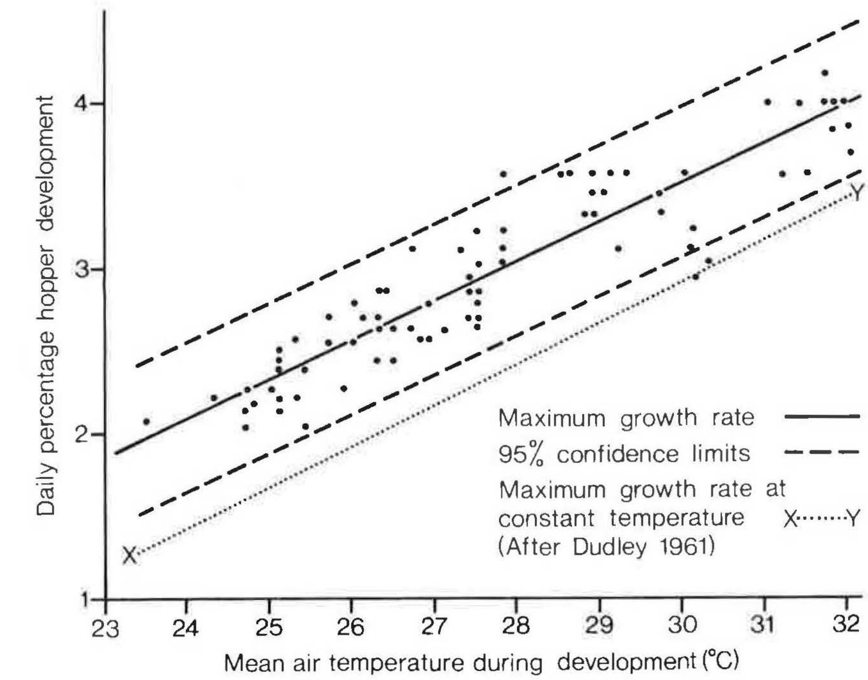


Fig. 4.2 Variation of daily percentage hopper development with mean daily air temperature (after Wardhaugh *et al* 1969).

The results show there is considerable variation in the rate of development at any given mean temperature. Thus at a mean temperature of 32°C the percentage development a day can range from 3.5 to 4.5 at the 95% level of confidence, the corresponding duration of development being from 29 to 22 days. At lower mean temperatures there is even greater variability. Thus, at a mean air temperature of 25°C, the percentage of development a day can range from 1.9 to 2.8, giving corresponding hopper development periods of 53 to 36 days. Because of the variability of hopper development periods at any given mean temperature and because they used long-term mean temperatures, the maps of hopper development produced by Symmons, Green *et al.* (1973, 1974) should be used only as a rough guide to hopper development periods.

Table 4.10 Hopper development periods recorded in the field. Arithmetic means and ranges, in days. *denotes means based on 10 or more records.

Area	Altitude (metres)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Summer breeding areas													
India and Pakistan							32 32	33.0 27–36	27.3 26–29	43 30–95			
Arabia							37 35–41		34.3 31–37	38.2 35–42			
Ethiopia, Somalia, Kenya	0–900								41.9* 34–52	32.8 30–37			
	900–1,500								40.1 36–49				
	'1,500								46.7 44–50				
Sudan, Chad, Niger, Mali, Mauritania and Senegal							31.0 30–32		34.3* 28–46	32.0 31–33			
Long Rains and Short Rains breeding areas													
Ethiopia, Somalia, Kenya	0–300				30.5 27–34	42.5 39–46					37.5 32–40	37.8 36–42	
	300–600				46 46	37.3 32–42					33.5 33–38	37.5* 31–45	36.0 35–37
	600–900				34.0 29–37	32.8 26–38					38 38	39.7 38–45	
	900–1,500			40.0 36–44	40.5* 36–47	35.0 27–38	30 30					38 38	
	'1,500				40.5 38–42	35.5 33–38	31 31					41 41	
Coastal areas around the Red Sea and Gulf of Aden													
Saudi Arabia, Yemen Arab Republic, People's Democratic Republic of Yemen, Dhofar, Somalia, Ethiopia, Sudan, south-eastern desert of Egypt		37.3 32–46	35.9 32–39	31.5 26–36	32.1* 24–39	28 28		33.7 31–39	27 27	31.7 28–36	48 48	34.7 28–42	37.9 36–43
Winter-spring breeding areas in Arabia and the Middle East (except southern and western coasts of Arabia)													
Saudi Arabia, Yemen Arab Republic, People's Democratic Republic of Yemen, Oman, United Arab Emirates, Kuwait, Iraq, Jordan, Israel, Egypt (except south-eastern desert), Sinai, Lebanon, Syria, Turkey			40.6* 35–57	37.1* 27–49	33.5 28–43	35.5 25–45							47 47
Winter-spring breeding areas in the Eastern Region and the USSR													
Iran, Afghanistan, Pakistan, India, USSR				40.0 32–44	34.8 31–43	34.0 34	34.2 28–49						
Winter-spring breeding areas in North-West Africa													
Morocco, Algeria, Tunisia, Libya				42.9 33–48	43.4 33–49	35.4 30–41							

In view of the difficulty of predicting hopper development periods even when maximum and minimum temperature data are available, Table 4.10 has been prepared to show the means and ranges of hopper development periods which have been recorded in the major breeding areas month by month. The data have been extracted by K. G. Wardhaugh, E. Betts and Z. Waloff from field reports up to the end of 1966 held at the Centre for Overseas Pest Research. They are arranged in the same order as the Tables of egg development periods (see Section 4.5.2). It has been necessary to group the data for some of the breeding areas as there are far fewer records of total periods for hopper development than for egg development. This is because in areas where hatching is observed the hoppers are usually controlled before fledging occurs, while most records of fledglings come from areas where hatching was not observed. There is also less certainty about relating records of fledging with hatching from a particular egg field even when the dates of both are known because hopper bands march. Thus, in an area where there are many egg fields it is often not possible to judge whether fledglings were produced by a particular egg field or from an adjacent egg field which may have been laid several days before or after. Months for which there are 10 or more recorded durations are marked with an asterisk. If there are no records for a particular month in which hatching is reported, forecasters should be guided by development periods in adjacent or similar areas or months.

The following are the main points shown by Table 4.10.

- In the summer breeding belt, which extends from north-west India to Senegal, most hopper development periods lie in the range 30 – 39 days, with a distinct peak (40% of the available records) in the range 30 – 34 days (Wardhaugh 1964). Longer development periods occur in the mountainous areas of Ethiopia amongst hoppers which hatch in August, almost certainly due to overcast skies and low temperatures. There is also evidence of a significant increase in hopper development periods at the end of the summer breeding season: there is one record, for example, of fledging occurring on 1 – 5 January from hoppers reported in the last week of September in the Punjab in Pakistan.
- There is very considerable uniformity in the duration of hopper development in the Short Rains breeding area in eastern Africa: 63% of the records fall in the range 35 – 39 days, despite variations in elevation from less than 100 to over 1500 metres. It allows forecasts of fledging dates to be made with considerable precision (see Section 4.7.4.1). There is a rather wider spread of hopper durations during the Long Rains breeding season, but again little systematic increase in hopper duration with increase in altitude.
- Hopper development periods are usually short in the coastal areas around the Red Sea and the Gulf of Aden in the warmer months of the year, and longer in the cooler months. 71% of the records lie within the range 30 – 39 days. The shortest hopper development period, 24 days from hatching in April 1955 on the southern Tihamah of Saudi Arabia, occurred in this area.
- In the northern winter-spring breeding areas of North-West Africa, Arabia, the Middle East, and the Eastern Region, the duration of hopper development may vary from 25 days to about two months and is more variable than in the hotter breeding areas. The longest period, 57 days from hatching in February 1957 in the interior of the Hejaz in Saudi Arabia, was recorded in these areas. Even longer durations almost certainly occur, for in North-West Africa there are four records of intervals exceeding 70 days between hatching and the occurrence of fledgling swarms. The dates of the occurrence of fledgling swarms may not refer to the first appearance of fledglings but may refer to a somewhat later stage in swarm development (see Section 3.1.1). Toward the end of spring breeding, hopper development periods are as short as in the southern breeding areas. The increased variability of hopper development periods in the northern breeding areas is consistent with the wider range of temperatures that the hoppers experience (Wardhaugh 1964).

The 'heat unit' approach to estimating hopper development periods has been used by Venkatesh *et al.* (1972) and by Singh & Venkatesh (1972). It was calculated that the total heat needed by hoppers in order to complete development was 8640 degree (Celsius) – hours above 17.2°C. The estimates of the minimum and maximum hopper durations, however, exceed very considerably the values recorded in the field, being 19 days for hoppers hatching in the Bikaner area of India between mid May and late June, and 128 days for hoppers hatching in late October, respectively.

4.7.4.1 Durations of individual instars

Both in the laboratory and the field, it has been found that the durations of individual instars are not the same, the fifth instar usually being significantly longer than earlier ones.

The most comprehensive information on the duration of each instar comes from the Short Rains breeding area in the Somali Peninsula. Analysis of many hundreds of records (Hemming, J. M. E. & Rainey, unpublished) shows that the average duration (in days) of successive instars is as follows:

first	6
second	7
third	6
fourth	7
fifth	10
Total hopper development period	36 days

There was some variation in these figures, even in adjacent populations. Thus, in two populations near El Rago in the Ogaden of Ethiopia, in which hatching occurred less than a week apart, the duration of the first instars in one population was 8 days, in the other 6 days. In these populations, as in others, durations were longer in cool, overcast weather, but shorter in hot, dry weather (P. E. Ellis, personal communication).

Similar relative durations of individual instars have been recorded from other areas. Thus, Predtechenskii (1935) recorded the following mean durations for successive instars in Turkmenistan in June-July 1929: 6, 5, 5, 6 and 10 days, giving a mean hopper development period of 32 days (the range was 28 – 37 days). Stolyarov (1964) recorded the following durations for successive instars, also in Turkmenistan, in 1962: 7 – 9, 5 – 7, 5 – 6, 6 – 8 and 11 – 12 days, giving a mean hopper development period of about 38 days, although the most rapid was completed in 34 days. These examples refer to hopper development in months and areas when there was little change in mean daily temperature between hatching and fledging. When mean daily temperatures are increasing in the spring the *relative* duration of the fifth instar may be less than that of the first instar; conversely, at the end of the summer breeding season (when mean daily temperatures are decreasing) the *relative* duration may be very much greater.

When the full development period differs from the values quoted, the duration of each instar can be calculated by using the same proportions. It then follows, if locusts of a given instar in a report are assumed to have developed to half way through the period for the instar, that the percentage of full development can be estimated:

instar reported	first	second	third	fourth	fifth
percentage development	10	25	40	60	85

The following example shows how these figures can be used. Suppose third-instar hoppers are reported from Somalia on 24 November at a place 200 metres above sea level. Table 4.9 gives 37.8 (say, 38) days as the mean full hopper development period; hence $38 \times {}^{40}/_{100}$, i.e, 15.2 (say, 15) days would have passed since hatching; and a further (37.8 – 15.2), i.e., 22.6 (say, 23) days would be needed for fledging. Hence the most likely fledging date is 24 November plus 23 days, i.e., 17 December. With an egg-incubation period of 12.8 (say, 13) days (Table 4.3), the most likely egg-laying date is 24 November minus (13 + 15) days, i.e., 27 October.

When temperatures are changing quickly during the full development period, the proportions given above will need to be modified by the forecaster in the light of known or likely temperatures.

4.7.4.2 Estimation of fledging dates

Information about probable durations of incubation, of total hopper development, and of individual hopper instars allows forecasters to estimate when fledging is likely to occur in an area.

For areas where average air temperatures are known, Figs. 4.1 and 4.2 should be consulted to estimate daily rates of egg and hopper development, respectively. If hopper reports give the instar which is present, Fig. 4.3 should be examined to estimate the dates of fledging from the beginning of the second, third, fourth and fifth instars, respectively. 'Heat units' have also been used by Singh & Venkatesh (1972) to calculate the period from the beginning of the second, third, fourth and fifth instars to fledging.

The scanty information on development periods in low-density populations is summarised in Section 4.10.

4.7.5 HOPPER MORTALITY

There has been little quantitative work on the natural mortality of hoppers in the field, but many examples of mortality have been recorded.

Lack of sufficient rain is undoubtedly the major cause of hopper mortality. Although the Desert Locust is well adapted to breed in areas receiving sparse and erratic rains, falls may be adequate to allow egg laying but inadequate to promote sufficient growth of the vegetation to provide food and shelter habitats. The almost complete extinction of the large regional population during the Short Rains breeding season in the Somali Peninsula in late 1955 has already been noted (see Section 4.4.1). Ashall & Ellis (1962) recorded hoppers dying beneath the shrubs where they sought shelter during the heat of the day, and they attributed death to desiccation. Bennet (1976) suggested that the failure of the monsoon generation in Rajasthan in 1968 was in part due to rainfall inadequate to allow development of ephemeral vegetation.

A very wide range of parasites and predators has been recorded attacking Desert Locust hoppers, but their overall effect is probably insignificant at the height of a plague. They may hasten the decline of small populations, however, and may delay upsurges in areas where there are semi-permanent breeding areas, e.g., along the Red Sea coasts (Greathead 1966).

Forecasters should also take note that even with apparently favourable breeding, very large numbers of hoppers die, particularly in the first instar. This appears to be due to inadequate reserves of food and water at hatching (Albrecht 1962), but it is possible that some of the high mortality recorded among young hoppers may be due to their inability to find suitable food.

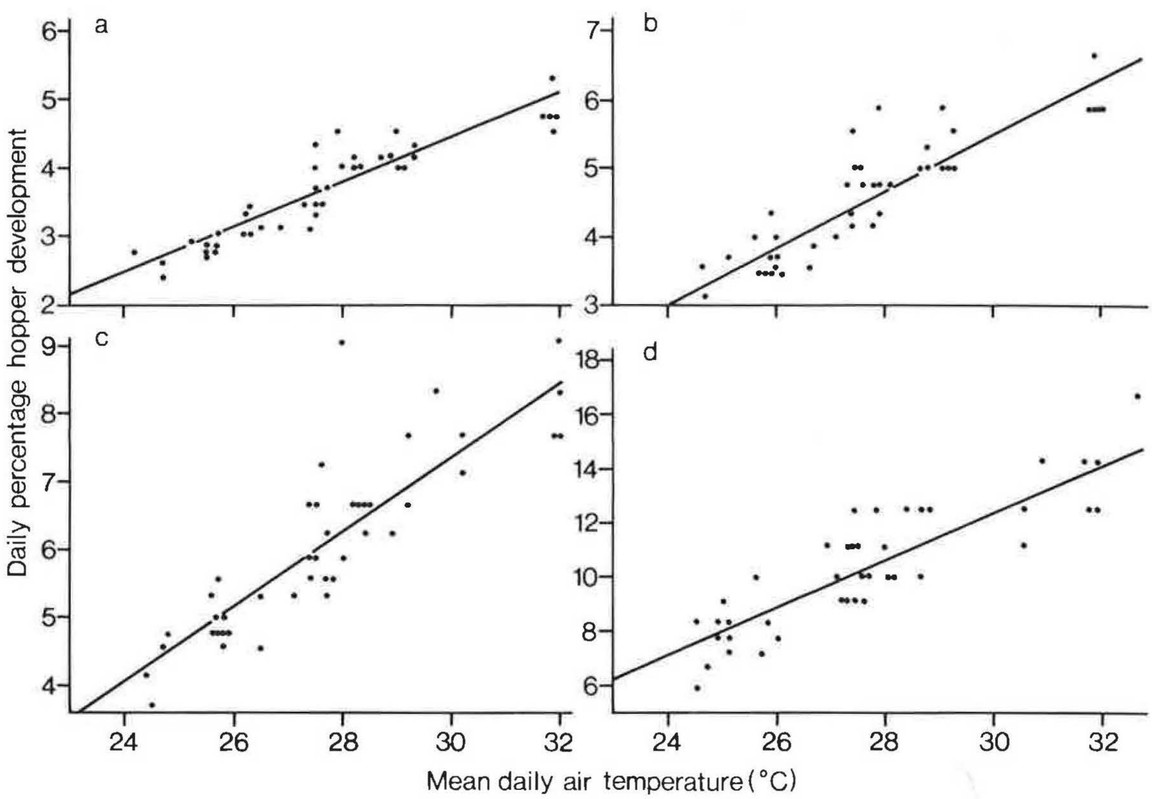


Fig. 4.3 Rate of hopper development and mean daily air temperature, from first appearance of
a second-instar hoppers
b third-instar hoppers
c fourth-instar hoppers
d fifth-instar hoppers
to first appearance of fledglings (after Wardhaugh *et al* 1969).

4.8 HOPPER BEHAVIOUR

Bands of hoppers exhibit a fairly well-defined diurnal pattern of behaviour. These are described in Ellis & Ashall (1957), and in the *Locust Handbook* (Anti-Locust Research Centre 1966). The main points of relevance to forecasters are as follows.

- Hopper bands usually change in size and density diurnally. At night the hoppers *roost* in vegetation, but during the day they usually spend 2–3 hours *marching* in the morning and again in the afternoon. A marching band may extend over an area much larger than that of the roost site. Ellis & Ashall (1957) found that marching bands covered 1.5–6.5 times the area of roosting bands. Conversely, the *average* density of hoppers in marching bands is considerably less than that in roosting bands. Fig. 4.4 shows that the average density of *roosting* first instar hoppers was about 1200 in a square metre in studies of the Short Rains breeding area in eastern Africa, while the average density of *marching* first instar hoppers was about 400 in a square metre. The corresponding figures for *fifth* instar hoppers were 190 and 12. Reported sizes of bands usually refer to bands when they are marching. If marching bands are reported as dense it is probable that hoppers are at high densities only at the leading edges, and that they are at much lower densities behind the leading edge. Estimates of sizes of hopper populations should take these variations into account.
- Individual hopper bands increase in size as they get older, they march further, and nearby bands join together (see Section 2.3.1.1). As a result, the *number* of bands reported during a breeding season does not provide a good approximation of the number of hoppers present unless the instar of the bands and their sizes are also given.
- Because swarms often break up as they mature, and they lay in several adjacent areas nearly simultaneously, reports of only a few early-instar bands in an area should be treated with caution as they may mean that control units have been able to locate only a proportion of the bands in an area. If only a few bands are reported in the *later* instars, however, this may be evidence that gregarisation is in progress (see Section 2.6).
- In habitats where vegetation is sparse, hopper bands may march up to 30 kilometres and may traverse areas where other laying has occurred. These occasions may give rise to apparent rates of development

which are either far too slow or rapid for the area, season and month as given in Table 4.10. Similarly, reports of bands of mixed instars, e.g., seconds and fourths, should be taken as evidence that bands which hatched about a fortnight apart had coalesced and not that some hoppers had a very rapid rate of development and others a very slow one.

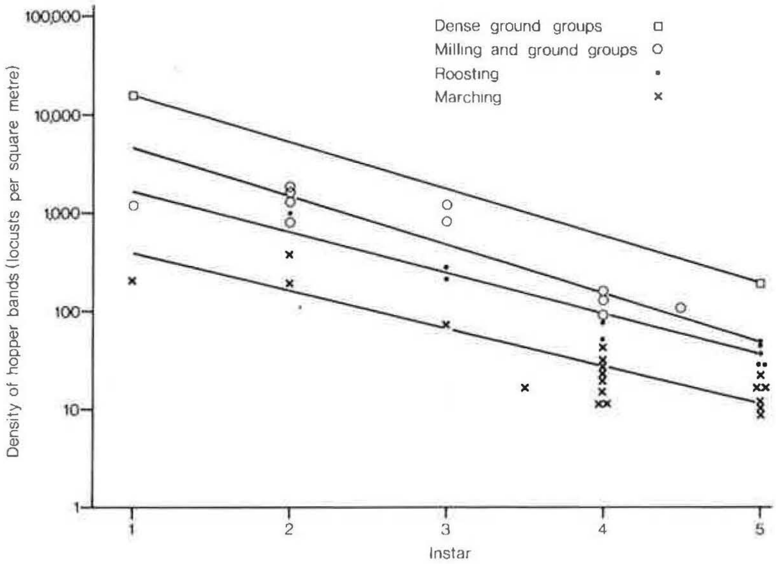


Fig. 4.4 Average density of bands of Desert Locust hoppers displaying various behaviour patterns (after Ellis & Ashall 1957, Stower & Roffey unpublished).

4.9 FLEDGING

At the final moult, the hopper stage ends and the adult stage begins. The final moult is often called FLEDGING because it is at this time that the fore and hind wings of the adult become fully developed. At first the wings are soft and crumpled, but within a few minutes they expand and begin to harden. Newly emerged adults are called FLEDGLINGS. At first their skin is soft and weakly pigmented, but in a few hours it hardens and acquires the colouration of the young immature adult (Uvarov 1966).

4.10 BREEDING BY LOW-DENSITY POPULATIONS

The main differences in behaviour, physiology and colour between solitarious and gregarious hoppers have been summarised in Section 2.2, and the seasonal breeding areas of locusts during recessions (when most populations are at low densities) are summarised in Section 2.5. In this Section, other aspects of breeding in which there are differences between solitarious and gregarious populations are summarised.

4.10.1 SYNCHRONISATION

One of the most characteristic features of breeding by solitarious locusts is that individuals of all stages (eggs, hoppers and adults) are present simultaneously. Although the very early stages of seasonal breeding by solitarious locusts are seldom observed, it appears from studies such as that made in Tamesna (see Section 2.6.2.1) that low-density adults arrive in a breeding area over a period of several weeks, mature and lay, so that there is a continual emergence of young hoppers. If the breeding site remains suitable, the new-generation adults may stay in the same breeding area, mature rapidly and start to lay afresh. If breeding continues still longer, the initially low-density populations are likely to start to gregarise late in the first generation or in the second generation, and breeding may then become more synchronous, as seems to have occurred, for example, in India and Pakistan in August-October 1973 (see Section 2.6.2.2).

4.10.2 HOPPER DEVELOPMENT

In Section 4.7.2 it was noted that solitarious hoppers sometimes had an extra instar between the normal third and fourth instars. There is some evidence that six-instar forms take longer to develop. Rao (1960) reported that six-instar hoppers, in one set of experiments in field cages, took an average of 60 days to complete development, whereas five-instar forms took an average of 51 days. In a field population on the northern coast of Ethiopia, the mean development period of five-instar hoppers was 41 days, whereas that for six-instar hoppers was 45 days (Stower & Greathead 1969).

4.10.3 HOPPER BEHAVIOUR

In marked contrast to the concerted behavioural activities of hoppers in bands, solitarious hoppers at low densities behave as individuals, roosting, feeding, climbing and resting in and on vegetation (Popov 1968). At low densities they do not form ground-groups or march, as is characteristic of the behaviour of hoppers in bands. If densities rise, however, the process of gregarisation may commence and hoppers may then start to form small basking groups, and eventually marching may commence (see Section 2.6.2.1). Reports of ground-grouping, basking groups or marching amongst previously solitarious or green hoppers should be taken as evidence that gregarisation is in progress. If such behaviour is reported over several square kilometres, forecasters should be alert to the possibility that day-flying swarms may be produced.

4.11 RAINFALL MAPS

It has been shown that rain is essential for the full development of the Desert Locust: it provides the soil moisture needed for egg laying and development, and the fresh vegetation upon which the newly hatched hoppers feed (Sections 4.5.1 and 4.7.1). Rain also seems to be essential for the sexual maturation of locusts (Section 4.2). The locust forecaster therefore needs to know where and when rains have fallen, and where they are likely to fall in the forecast period. Ideally, there should be *daily* rainfall maps, showing where and how much rain has fallen, and in detail comparable to that on the wind and temperature maps. In fact, such maps are not available operationally because there are too few reports to describe properly the complex patterns of rainfall distribution. Nevertheless, it is possible to produce daily or longer-period rainfall maps that have some value.

4.11.1 USEFULNESS OF RAINFALL MAPS IN FORECASTING

The rains upon which the Desert Locust breeds are often short-lived, and separated by spells of weeks or months with little or no further rain. Daily rainfall maps may therefore be used to get precise estimates of the earliest possible dates of maturation and laying, when the locust evidence is vague. The date of earliest fledging can then also be estimated, whether it has already happened or not. Moreover, the maps should show the greatest extent of any breeding. Such estimates are used to help build up the best possible assessment of the current locust situation (Section 10.3). Records of accumulated rainfall, over a week or a month, can also be useful, for they still enable estimates to be made of whether there could have been breeding, even though the timing is imprecise.

Fig. 4.5 a to f. Satellite pictures of rain clouds over the North- and South-Central Regions, illustrating the following features.

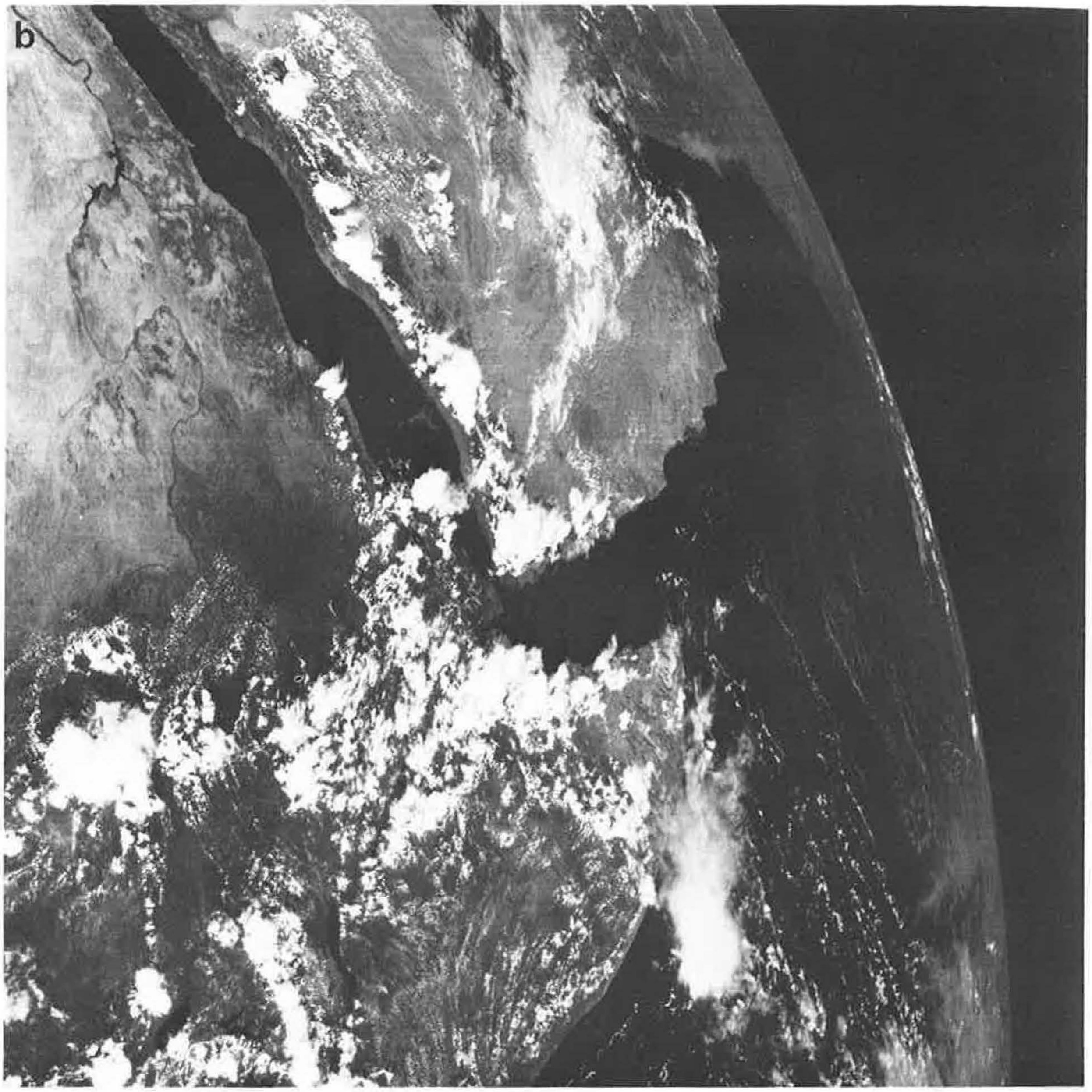
- Scattered spring (a and b) and winter (e) rains over Arabia from patchy layered clouds in bands lying north-east to south-west.
- Spring showers in rows over the mountains of Oman and south-east Iran (a), and over Arabia–Yemen (b), due to daytime convection forming cumulonimbus clouds (bright, white masses with fuzzy tops streaming downwind).
- Long Rains (a, b) and Short Rains (d) showers from scattered and clustered cumulonimbus clouds (accompanied by many smaller convection clouds — those over southern Somalia tend to be in rows, probably reflecting the wind direction — compare Fig. 3.17b).
- Monsoon rains over Sudan and Ethiopia (a to d, furthest north in c) and over Yemen, Oman and south-east Iran (d), from clusters of cumulonimbus clouds.
- Dry weather over much of the Somali Peninsula during the south-west monsoon (c) — little cloud in the north, and largely shallow cloud sheets in the south.
- Largely clear skies of mid-winter (e) except for:
  - broken cloud sheets at the RSCZ (Q in Fig. 3.17a), where isolated cumulonimbus clouds might form;
  - patchy convective clouds over the Ethiopian highlands, where light showers might form;
  - convective clouds in lines along the mountains on the eastern side of the Red Sea, and the northern side of the Gulf of Aden, possibly leadings to scattered showers;
  - convective cloud in a line just inland of the east coast of Somalia — possibly on the sea breeze front, where light showers might form.

Pre- and post-monsoon rains over south-east Arabia associated with an Arabian Sea cyclone shown in (f) still moving westward over the sea.

a 1155 GMT 13 April 1978
b 1225 GMT 2 May 1978
c 1125 GMT 7 August 1978
d 1125 GMT 23 October 1978
e 1155 GMT 28 December 1978
f 11 June 1977

4.11.2 THE CAUSES OF DESERT RAINS

Rain falls from clouds, and clouds form where moist air rises far enough through the atmosphere for the resulting cooling by expansion to cause condensation of some of the moisture into countless tiny droplets. In some clouds, these droplets can grow into rain drops large enough to fall quickly, and perhaps reach the ground. Hence, rain is associated with upward moving air, and with wind convergence to feed the updraughts. Only a few convergence areas lead to rain, however, because the air may be too dry or the updraughts too shallow. Over most of the invasion area, heavy rains fall from clouds in *convective* updraughts, often rising from near the ground and reaching 10 – 15 kilometres above sea level. Such clouds (called CUMULONIMBUS) have dimensions of order 10 kilometres and last for an hour or two, and they are easily seen on satellite pictures as bright masses (e.g., Figs. 4.5a-d), sometimes with fuzzy edges where cloud tops spread out in the high atmosphere (e.g., Figs. 4.5 a and b). As the clouds move across country, rain falls over strips about 10 kilometres wide and a few tens of kilometres long (depending on the speed of movement). Individual rain SHOWERS may give falls up to 50 millimetres, sometimes more, but they may well be isolated and leave unwetted areas between them. Sometimes showers occur in lines (e.g. Fig. 4.5a and b) or clusters e.g. Fig. 4.5b and 4.6b), hundreds of kilometres across, leading to widespread heavy rain. Although the lines and clusters may last up to 10 hours, sometimes more, individual shower clouds still have much shorter lives, although there are occasions when particular showers, often large, persist for many hours as they cross country. Showery rains are very patchy; hence a day's record from a given gauge may be quite unrepresentative of places only a few kilometres away.



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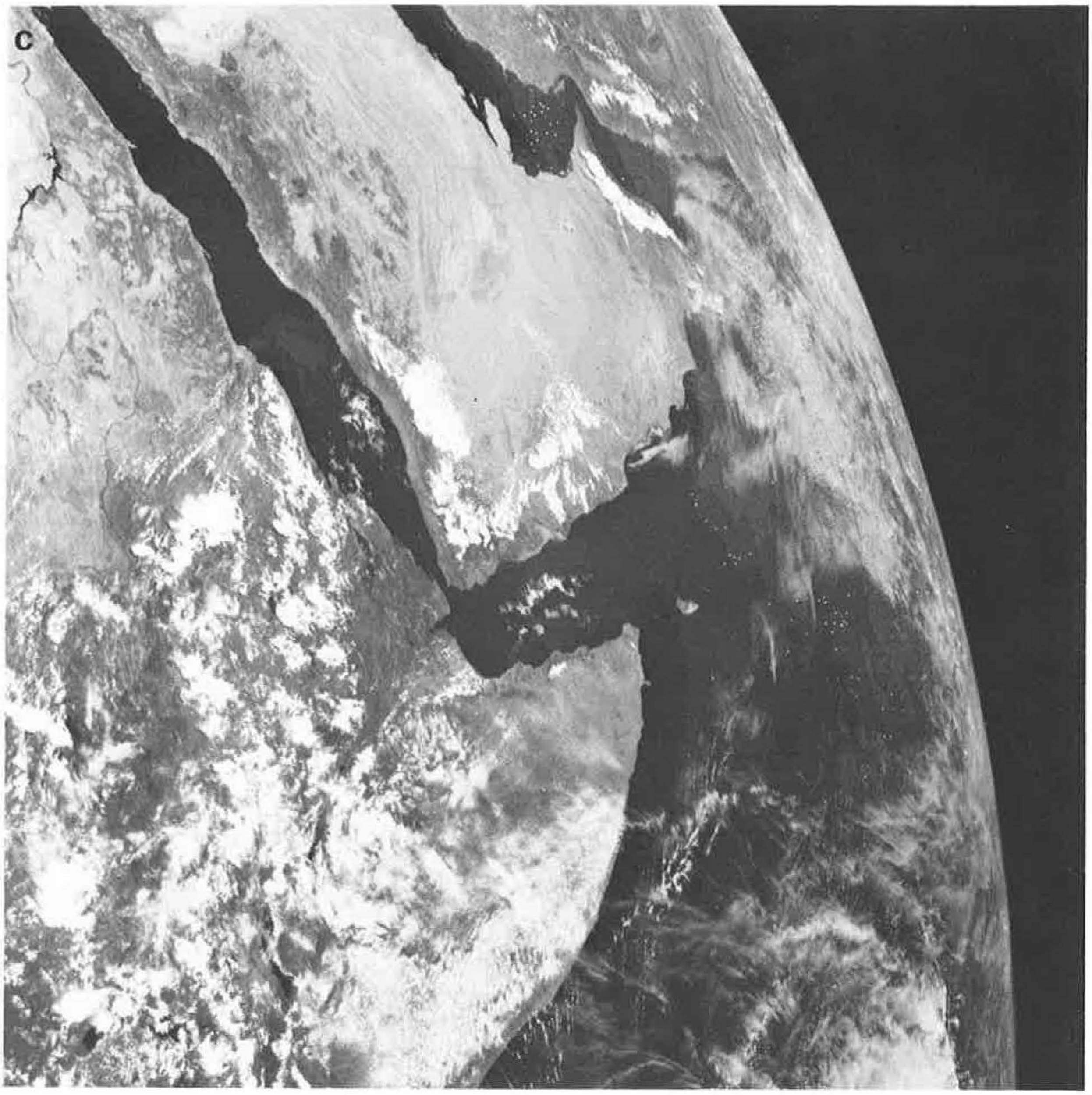
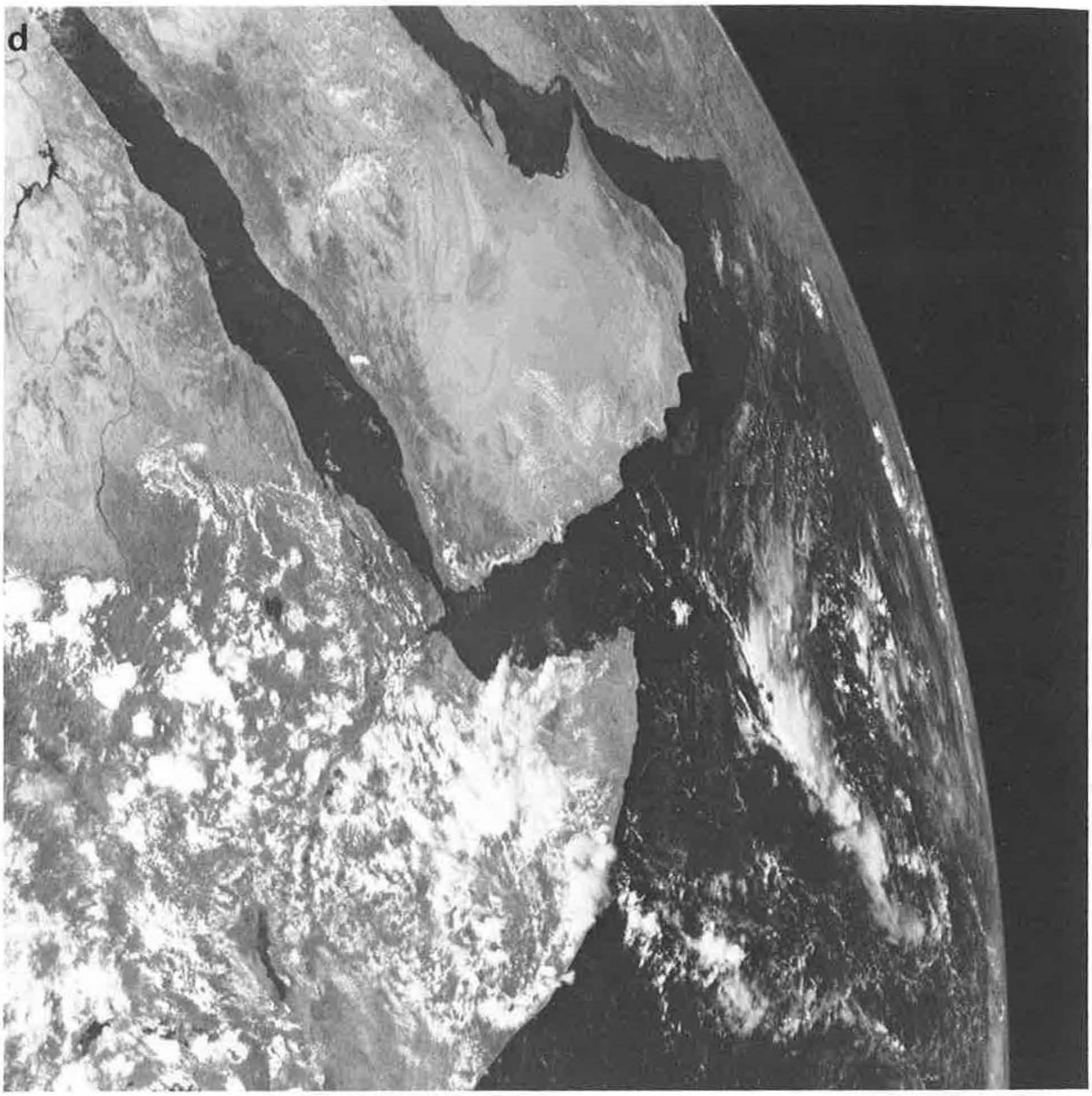
Rain may affect locust flight not only directly, by inducing settling, but also indirectly, by lowering the body temperature, perhaps below the threshold for flight. Not only is direct sunshine very likely to be cut off but also there is cooling due to partial evaporation of the rain caught by the locust. Falling drops also chill the air by evaporation: sudden falls of temperature are well known happenings near rainstorms. The mass of chilled, dense air sinks, strikes the ground and spreads outwards from the rainstorm as a strong, gusty wind up to a kilometre deep and sometimes reaching places many tens of kilometres from where it was raining. These spreading downdraughts bring a complexity to the wind patterns on scales of tens of kilometres that is only poorly reflected in the observations from synoptic stations, which may be 100 kilometres or more apart. The leading edge of such a storm outflow is a small-scale cold front, followed by air that may be 10°C, even 20°C, cooler than ahead, and accompanied by powerful wind convergence, within which airborne locusts can become concentrated.

Individual showers may well lead to patches of ground suitable for breeding, but it is the larger rainstorms that are a greater concern to the locust forecaster, because they can start or maintain large locust upsurges (Section 2.7). The formation of such storms is often associated with certain kinds of wind systems on a larger scale (Section 3.3.4). In parts of those systems there is weak but persistent wind convergence near the earth's surface, and the resulting upward motion leads not only to areas favouring the growth of shower clouds but also other clouds, often in *sheets* hundreds of kilometres across, that can themselves give spells of rain, though generally lighter than the showers. For example, the *winter and spring rains* (of Africa west of the Sahara (Mauritania, Western Sahara), the Mediterranean and Sahara countries of North Africa, the Middle East, south-west Asia, and countries around



the southern Red Sea and Gulf of Aden, and at times as far south as the equator) are brought by the mostly *eastward*-moving cyclones and waves of middle latitudes (Section 5.3, 6.3, 8.3). These wind systems are sometimes weak near the earth's surface, and the rainy spells are more easily associated with winds at heights of 5–15 kilometres above sea level. At these heights, winds blow mostly from the west in winter and spring, but embedded in them are large waves, often 3–6 around the world, moving generally eastward at speeds of 5–10° longitude each day (Fig. 4.7). The area east of a wave trough and west of a wave ridge is one where upward motion is likely to form extensive cloud sheets. Satellite cloud pictures often show these sheets as broken bands, much larger than cumulonimbus but not usually as bright (e.g., Figs. 4.5a and 4.6a). The southern ends of these bands lie from time to time over any part of the invasion area north of about 10°N. If at the same time warm, moist winds are blowing in the lowest few kilometres of the atmosphere from low latitudes into the area of upward motion there is the possibility of having widespread heavy rains. The locust forecaster should keep a continuous watch for these waves on wind maps for the upper atmosphere (available in aviation weather forecast offices). Together with satellite cloud pictures, and surface observations of clouds and rain, they can be used to help determine the time and extent of rains, including those in remote places that may go unrecorded otherwise. It must be remembered, however, that not all extensive cloud masses bring rain, and few bring *widespread* and *heavy* rain. Cloud pictures from geostationary satellites are particularly valuable because they are available many times a day, and can therefore be used to watch the growth of rainstorms, even those that are too short-lived to be properly recorded by the twice-daily pictures from polar-orbiting satellites. It may also become possible to estimate area average rainfall *rates* from satellites, using cloud top temperature or brightness as a guide, or by using micro-wave

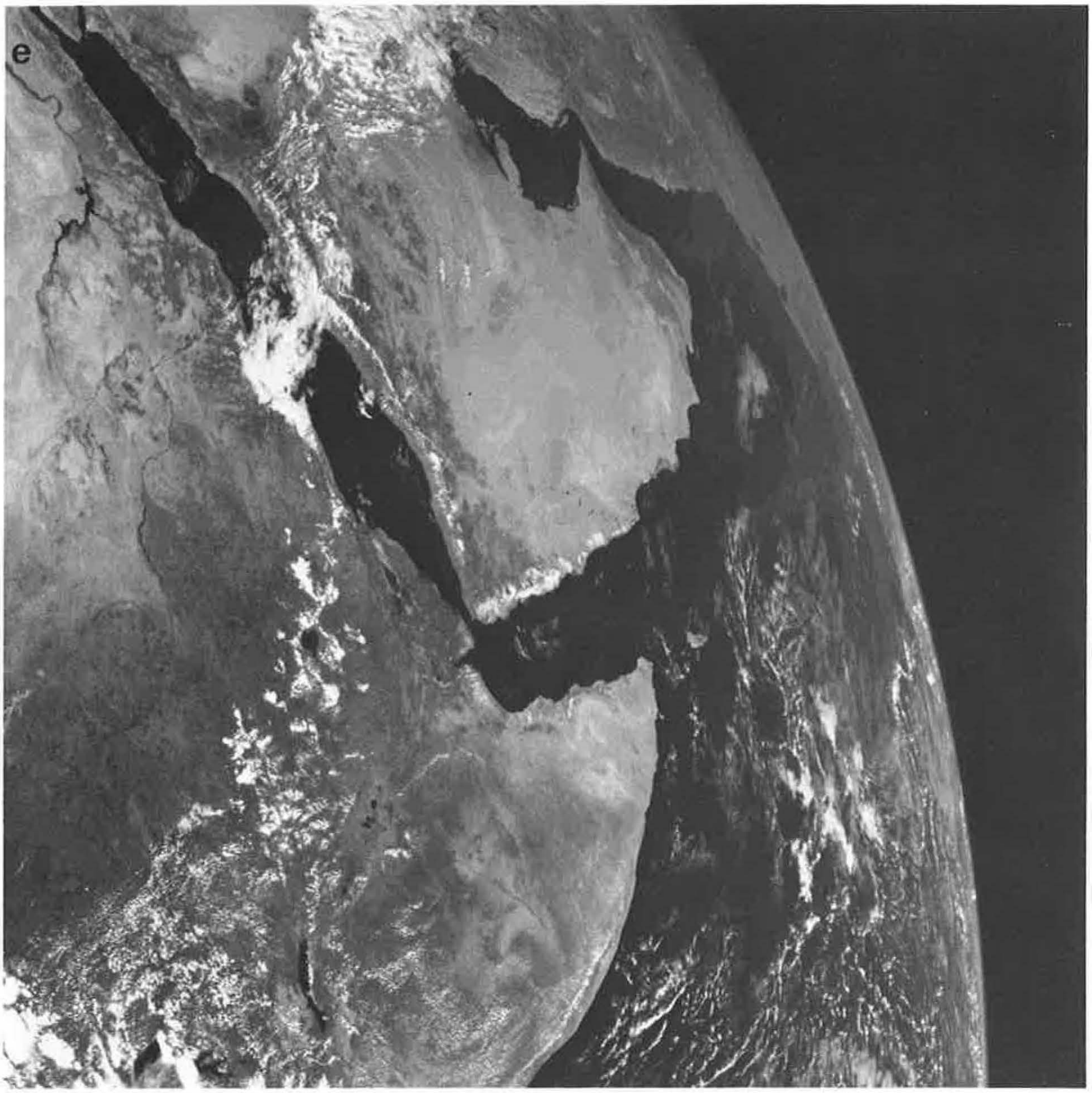


sensors, although it will still be necessary to estimate *amount* from several estimates of rate during the life of a storm.

The *monsoon rains* (of Africa south of the Sahara, countries around the southern Red Sea, also Pakistan and India, and occasionally south-eastern Arabia) are brought by the mostly *westward*-moving cyclones and waves in the equatorial westerlies (Sections 5.3, 6.3, 7.3, 8.3). These wind systems are often weak near the earth's surface, and the rainy spells are more easily associated with winds at heights around 3 kilometres above sea level. Unfortunately, in some regions, there are often too few observations at these heights to clearly show the wind systems.

Rainy spells within the ITCZ over East Africa are often associated with subtle and not easily seen changes in wind systems between 5 and 15 kilometres above sea level. From time to time, however, vigorous cyclones form in the ITCZ over the Indian Ocean, and they can bring widespread and heavy rains to coastal areas of Somalia, south Arabia, Pakistan and India in the periods May-June and October-November (Section 5.3), i.e., at the beginning and end of the Asian south-west monsoon.

Moisture for all these rains comes mostly from evaporation of the low-latitude oceans and forests. Monsoon and ITCZ rains are fed by moisture from the Indian and South Atlantic Oceans, and the same moisture to a large extent feeds spells of heavy winter and spring rains of higher latitudes in the invasion area, although some comes from the North Atlantic Ocean and smaller seas such as the Mediterranean Sea, Red Sea and Persian Gulf. The tropical easterlies seldom give rain in the Desert Locust invasion area, because the depth of convection is seldom greater than 5 kilometres.



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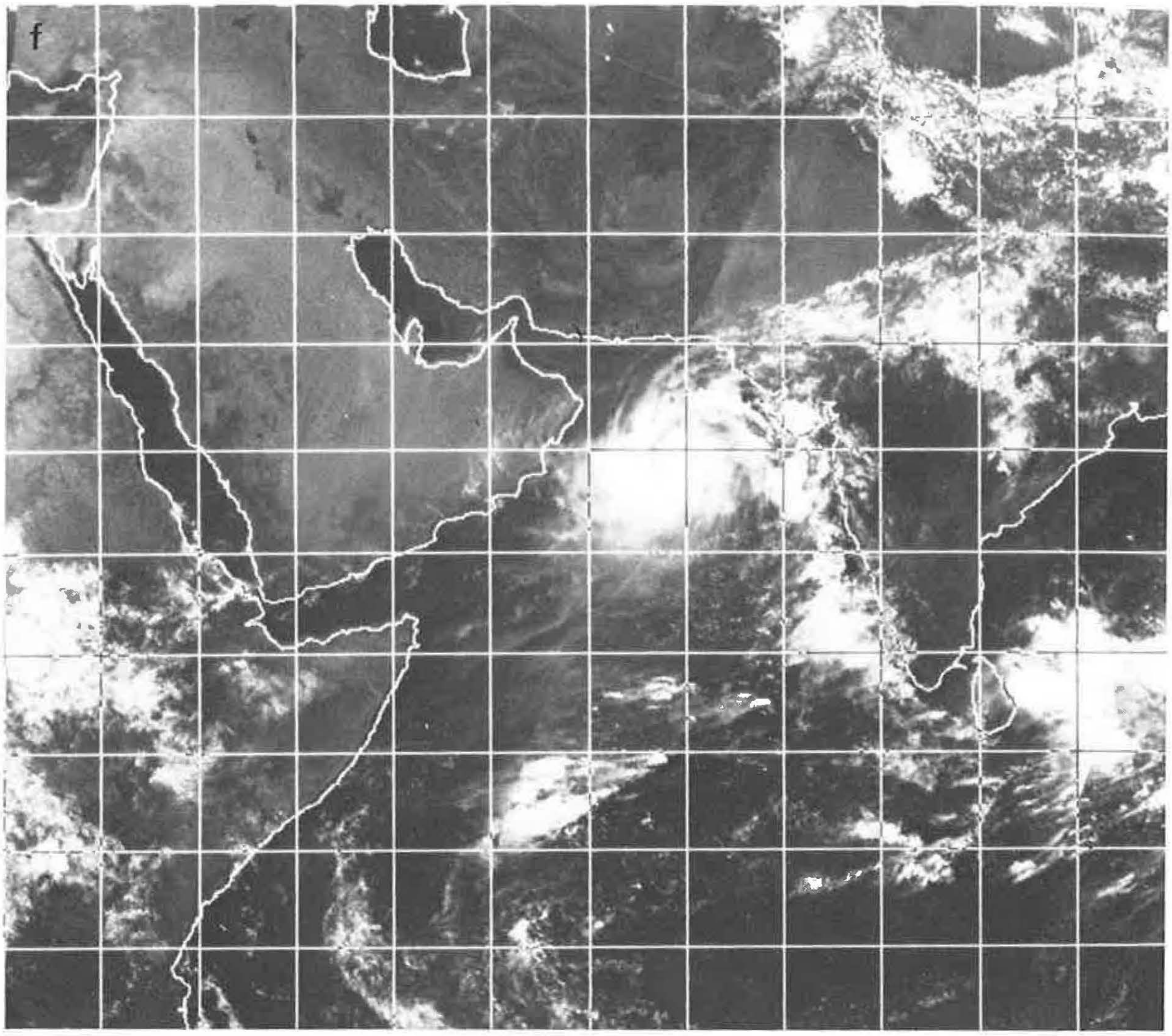
Mountains are well known to affect the amount and distribution of rainfall. There are two reasons for this: firstly, complex patterns of upward motion develop when the wind blows across a highland area (*barrier effect*); secondly, daytime heating is more likely to lead to deep convective mixing over highlands than over plains (*thermal effect*). The two kinds of upward motion both lead to greater cloudiness and *rainfall over mountains.* There are many days when showers form *only* over mountains (especially near coasts, where daytime sea breezes and upslope winds can feed moisture into the storms). For examples of isolated showers forming over the Sahara mountains, see Fig. 4.6b; for more widespread showers along the mountains bordering the Red Sea and Gulf of Aden, see Fig. 4.5b; and for lines of showers on the mountains of Oman and south-east Iran, see Fig. 4.5a.

Because most desert rains fall from convective clouds, and atmospheric convection is generally deepest in the afternoon, it is at that time of day that showers are most likely to form. Scattered showers tend to die out after sunset, so the heaviest rains on days with scattered showers fall most often in the late afternoon. Lines and clusters of showers tend to persist well into the night, and sometimes more than 24 hours, and heavy rains can then fall at other times of the day, although the morning is the least likely time. Rains in well-marked cyclones often fall at any time of the day or night.

Coastal rains are affected by wind convergence at the leading edge of the sea breeze as it spreads inland (e.g., see Fig. 4.5e), so there may be a sharp afternoon peak in the frequency of occurrence of rain. Near *mountains,* the timing of rain can be very complex. The thermal effect can lead to earlier and heavier showers than over the plains, but lines of showers may move away from the mountains. The barrier effect is itself often modified by the thermal



effect so that the strength and position of updraughts varies from day to night, and of course with any day-to-day change of the large-scale wind systems. There are further complexities where wind direction changes greatly through a depth comparable with mountain height.

4.11.3 CONSTRUCTION AND AVAILABILITY OF RAINFALL MAPS

Every country has its own network of raingauges; most are read daily, some only weekly or monthly. In the Desert Locust invasion area, however, there are large areas with no gauges. There are other large areas where gauges are so sparse that the rainfall distribution on a given day can be no more than very imperfectly known. Synoptic weather stations report their rainfall twice or four times daily, but they are often so widely spaced that the reports have limited value. The main advantage of synoptic rainfall reports is that they are available within a few hours. Monthly totals from these stations are reported a few days after the end of the month on the international meteorological communications system and should be available from most national meteorological services. Other raingauge records, both daily and monthly, are usually not available until too late for use in locust forecasting. Some of these records, however, may be available within a week or two (often through government departments of agriculture, forestry or hydrology). By combining them with reports from synoptic stations it may be possible to construct monthly rainfall maps showing the distribution of rain by means of ISOHYETS (lines drawn joining places with the same rainfall). The drawing of isohyets in highland areas is not easy, but fortunately these areas are likely to have the densest networks of gauges in arid areas, because the greater rainfall there encourages permanent settlement.

In the absence of *gauge* records, descriptive accounts must be used to build up the best possible assessment of rains that may have fallen. Locust field reports and newspapers can provide useful information, but it must be used with caution because amounts may be exaggerated, and timing and extent may be incorrectly reported. Deductions from satellite cloud pictures and daily weather maps (both of which are usually available at main weather forecasting centres within a few hours of observing time) can add useful information on timing and extent of rains shown on monthly maps. The locust forecaster is advised to prepare his own monthly rainfall maps, using the above-named sources; otherwise they may not be available in time to be useful.

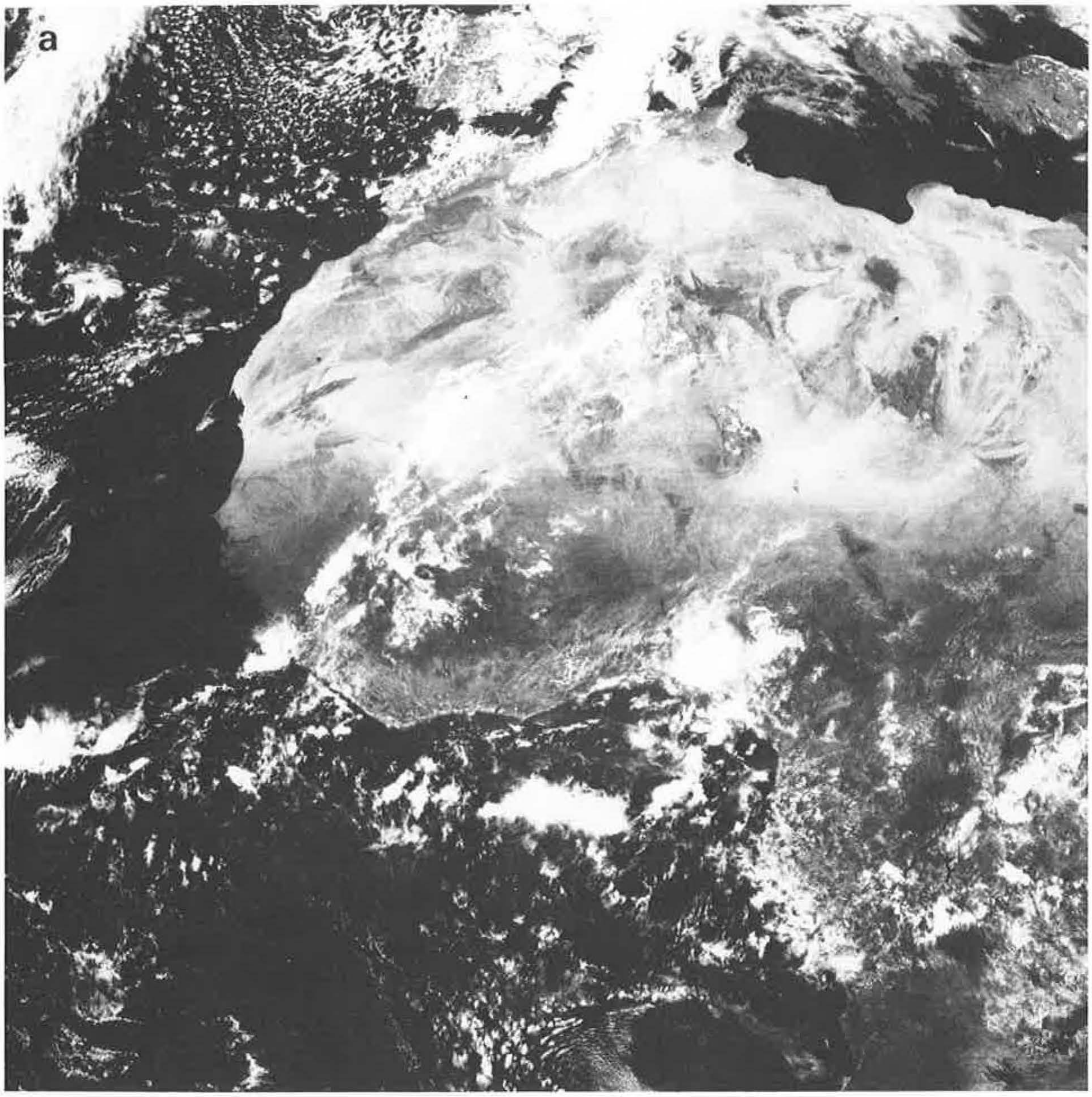
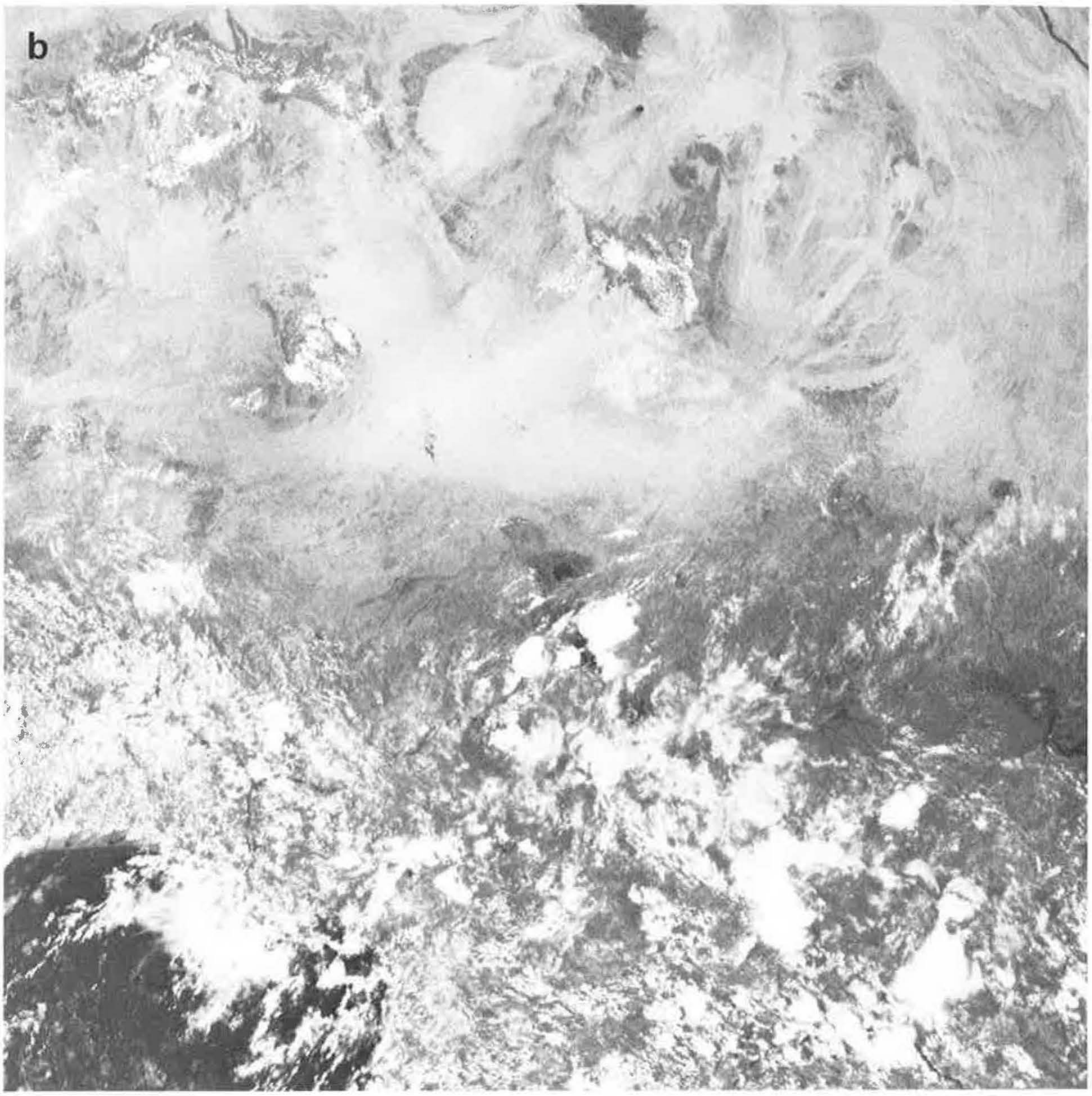


Fig. 4.6 a to c. Satellite pictures of rain clouds over the Western Region, illustrating the following features.

- Scattered spring (a) and winter (c) rains over the Sahara (from patchy but extensive cloud sheets in bands lying north-east to south-west) and over lands bordering the Mediterranean Sea.
- Spring showers over the Sahara mountains of Aïr and Tibesti (a) from isolated cumulonimbus clouds.
- Scattered monsoon showers (b) from cumulonimbus clouds over the mountains of Hoggar, Aïr and Tibesti, and from cloud clusters further south.

a 1155 GMT 30 April 1978
b 1225 GMT 20 September 1978
c 1125 GMT 1 December 1978



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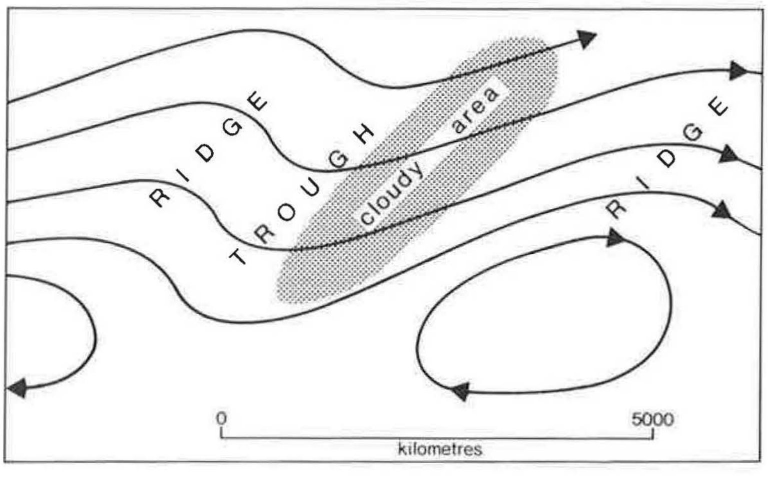
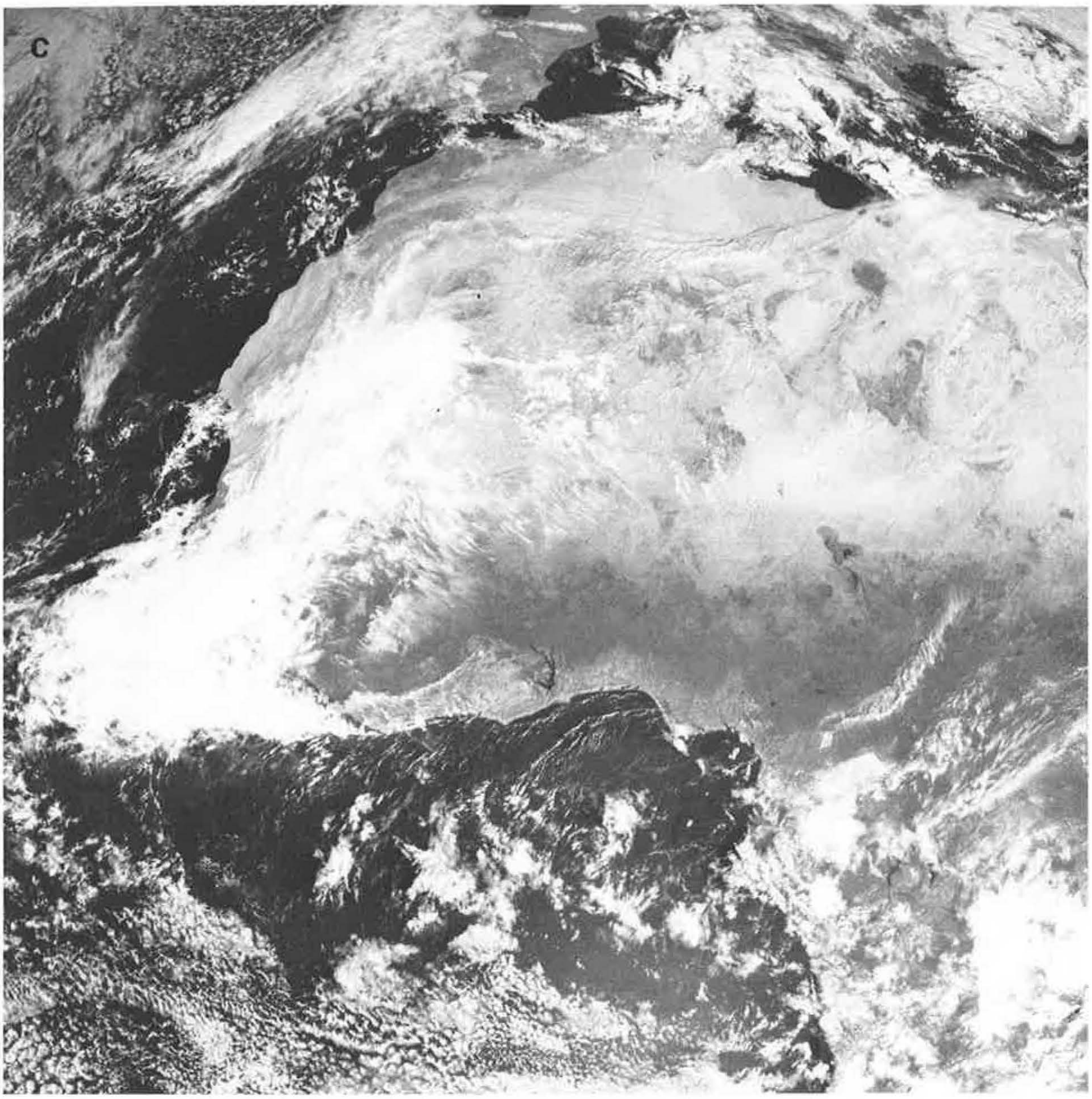


Fig. 4.7 Schematic streamlines on a weather map for heights about 5–15km above the ground, showing a trough in the west winds and associated area of clouds.


C

PART 2

REGIONAL BREEDING AND MIGRATIONS

This part of the Manual deals with the biogeography of breeding and migration. It is divided into four chapters, each dealing with seasonal breeding and migrations in one of the four Regions of the Desert Locust invasion area (Fig. 2.4). The treatment is in much greater detail than in Section 2.4.

Each chapter includes a list of countries comprising the Region, with information on the annual frequencies of swarm and hopper band infestations in it, a brief survey of the main physiographic features of the Region, and an account of weather systems and climate affecting locust movements and breeding. The locust data are arranged so as to provide the forecaster with background information on the events to be expected at various times of the year, and to help him visualise possible future developments by analogy with events in the corresponding seasons of the past.

Breeding

In each Region the *distribution* of breeding, the *origins* of breeding swarms, and the *times* of breeding are discussed season by season, in all cases starting with the summer (or monsoon) season to facilitate comparison between Regions. (See Section 2.4 for definitions of seasons.) The characteristics of seasonal breeding are illustrated further in a series of diagrams (Figs. 5.2, 6.2, 7.2 and 8.2) derived from data on maps of hopper infestations for each month of the 36-year period 1940 – 75, which are available in the cartographic archives of the Centre for Overseas Pest Research. On the diagrams, the summer, winter and spring breeding seasons in each country (or in the coastal and inland parts of most countries bordering seas) are presented in the form of histograms showing:

- the number of occasions in which the *first* hopper bands of the breeding season were reported in a given month,
- the number of occasions when the *last* hopper band in infestations starting that season fledged in a given month.

The value of *n* below each histogram is the number of years in which the breeding had started in a given season. These histograms provide information on the following points.

- The seasons of breeding in each country. It can be seen from Figs. 5.2, 6.2 and 8.2 that in the northern parts of the Eastern, North-Central and Western Regions there is only *one* breeding season — spring. In a number of areas, breeding occurs in *two* seasons: summer and winter (e.g., Senegal — Fig. 8.2), winter and spring (e.g., coastal Iran — Fig. 5.2; and Somalia south of 8°N — Fig. 7.2), or spring and summer (e.g., inland Ethiopia north of 10°N — Fig. 6.2). In many countries, breeding may occur in summer, winter and spring. The rainfall seasons with which all such variations in breeding are associated are discussed in the appropriate sections of each chapter.
- The areas where breeding seasons are either distinct or they are liable to merge. For example, in Afghanistan (Fig. 5.2) and in Morocco (Fig. 8.2), hopper bands appearing in the spring months are likely to finish fledging from May to July, when hopper infestations within these countries (and the campaigns against them) come to an end. Again, in inland Ethiopia north of 10°N (Fig. 6.2), once the summer hoppers have fledged in September and October, the area becomes free of hoppers till next spring. On the other hand, in many areas the hopper infestations starting in any one rainy season may continue to appear without a break into the following season, so that fledging extends over *two* seasons — see, for example, the histograms for summer breeding in India and inland Pakistan (Fig. 5.2), or for winter breeding in coastal areas of Sudan and Yemen (Fig. 6.2), or for spring breeding in coastal Saudi Arabia (Fig. 6.2). In all these examples two or more successive generations of hoppers are likely to be involved. Finally, in some areas hopper infestations starting in one season may sometimes continue to appear there without a break through *three* successive seasons, with locusts passing through three or more successive generations — see, for example, the histograms for breeding starting in summer on the Red Sea coast of Saudi Arabia, or in spring in the People's Democratic Republic of Yemen (Fig. 6.2). These examples are not exhaustive; the forecaster will need to assess the characteristics of the breeding seasons in different parts of his Region by examination of all relevant histograms.

- The probability of having hopper band infestations during a particular season in a given area. This can sometimes be assessed from the frequency with which gregarious breeding had occurred there during the 36 considered years — contrast, for example, the histograms for summer and winter breeding in inland Sudan (Fig. 6.2) or in Mauritania south of 21°N (Fig. 8.2).
- The months in which first hatchings or last fledgings are most likely to occur. For example, in Algeria north of 32°N, spring hatching is most likely to begin in April, and the last bands are most likely to fledge in July; whereas in Mauritania south of 21°N, summer bands are most likely to appear from August onwards, and to complete fledging in October (Fig. 8.2). Or, in India the first summer hatchings are most likely in July, and fledging is about equally likely to end in September or in November (Fig. 5.2). The forecaster will find many other such indications by examining the histograms for his Region.

Migrations

Following each breeding season there are, in each chapter, descriptions of the migrations of the new swarms towards and over the next seasonal breeding areas. These descriptions are amplified by SUMMARIES — accounts of the actual migration histories of swarms that had developed in a given Region in the corresponding season of a particular year. These Summaries cover the movements of these generations of swarms from the times of their fledging until their death; they are grouped together between Chapters 8 and 9. The Summaries, in turn, are amplified by CASE STUDIES — illustrated descriptions of movements of swarms over periods of days or weeks, and of the weather systems in which these movements took place. Maps to accompany the Summaries and Case Studies are gathered into Volume II for ease of reference. Each Summary has the following maps.

- A set of consecutive monthly maps showing the area of interest and the distribution of swarms discussed in the text (other swarms may have been present but are not shown — they are mentioned in the text).
- One or more maps of the same area, high-lighting changes in monthly distribution by means of arrows indicating the generalised limits of distribution and directions of spread (shown broken where there is considerable doubt), and showing sources and periods of fledging discussed in the text (other sources may have been present but are not shown — they are mentioned in the text).

Almost every Case Study has the following maps.

- A map showing the area of interest, places mentioned in the text, and the distribution of locust reports during the period of the Case Study, using the symbols explained on page 27 of Volume II.
- One or more weather maps for specified times, each showing temperatures (Celsius), winds (for symbols, see Fig. 3.12), schematic streamlines, atmospheric fronts (for symbols, see Volume II), isobars (pressure in millibars), and an outline (broken lines) of the area covered by the locust distribution map.

The general accounts of migrations, the Summaries and the Case Studies are arranged, or cross-referenced, under periods of several consecutive months to provide the forecaster with readily available analogues of swarm movements and relevant weather systems during each such period, which between them cover the whole year (see lists of contents to Chapters 5 to 8).

When choosing the generations to be dealt with in Summaries and Case Studies, preference was given to periods when locust events were well documented, and when meteorological data for the Case Studies were readily available. Care was taken to provide representative examples of movements both within and between Regions. But it must be admitted that a fully comprehensive analysis of all the data in the archives of the Centre for Overseas Pest Research would require greater resources than those that were available for the preparation of this Manual. The forecaster must therefore bear in mind that not all possible migrations, nor even all known ones, could be illustrated in Chapters 5 to 8, and he should be on the alert for deviations from the analogues provided. An analysis of the remaining data could provide both useful training for forecasters as well as further analogues to supplement those in this Manual.

It is made abundantly clear in Chapters 5 to 8 that not one of the Regions is self-contained: all of them are liable to send swarms to, and be invaded from, neighbouring Regions. Accounts of such inter-regional movements, cross-referenced to relevant Summaries and Case Studies, are similarly grouped under season to help forecasters to be constantly aware of the possible sources of invasion from outside their Regions. Moreover, because inter-regional movements are so frequent, effective forecasting in any one Region is not really practicable without full knowledge of current developments in all other Regions.

5 THE EASTERN REGION

5.1 POSITION OF THE REGION AND COUNTRIES INCLUDED

The Region occupies the eastern part of the invasion area and extends from the western boundary of Iran and the shores of the Persian Gulf and of the Gulf of Oman eastward through Iran, Pakistan and India as far as Assam. In the north it extends over most of Afghanistan and into Soviet Middle Asia (which is reached by swarms only rarely, but which was invaded in 1929 almost as far north as the Aral Sea). The invasion area reaches from India into Kashmir and Nepal, which are occasionally invaded by swarms, and covers most of the Indian Peninsula, though the frequency of invasions in areas south of latitude 20°N is very low.

The countries of the Region are listed in Table 5.1 in the order of the annual frequencies of swarm infestations in them. It will be seen that these frequencies are high in Pakistan, Iran and India, where they are comparable to the highest annual frequencies in the North-Central Region; in all three countries there have been swarms and hopper bands not only in plague years (totalling 21 years during the period 1940 to 1975) but also during recessions. Of the remaining countries, the frequencies reach a medium level in Afghanistan (where infestations may have been under-reported), and elsewhere are very low.

Table 5.1 Number of years with recorded Desert Locust infestations in the Eastern Region during the 36 years from 1940 to 1975.

	Swarms	Hopper Bands
Pakistan	32	28
Iran	28	21
India	27	26
Afghanistan	15	14
Bangladesh	5	0
Nepal	3	0
USSR	1	1

5.2 MAIN PHYSIOGRAPHIC FEATURES

These are as follows (see Fig. 5.1).

- The great Himalaya ranges, mostly over 5,000m high, forming the southern rim of the Tibet plateau and continued to the west and north-west by the Hindu Kush range of Afghanistan, and by the Pamirs and other highlands of Soviet Middle Asia.
- The region of lower ranges rising to 2,000 – 3,000m and enclosing several large inland drainage basins, which occupies Iran, most of Afghanistan and western Pakistan. The narrow coastal plains of southern Pakistan and Iran are bordered by the low ranges of Makran and the higher ranges of the Zagros mountains, and broaden out at the head of the Persian Gulf into the plains of Khuzistan. Because of their low temperatures, the extensive mountains provide an effective barrier to locust movements in winter, when swarms spread northward mainly through the inland drainage basins forming belts of lower ground through eastern Iran and western Pakistan and western Afghanistan.
- The great plains, i.e. the lowlands of the Turkmen and Uzbek Republics in Soviet Middle Asia, and the plains of the Ganges and Indus basins, and of Gujarat.
- The low ranges and tablelands of the plateau of Deccan.

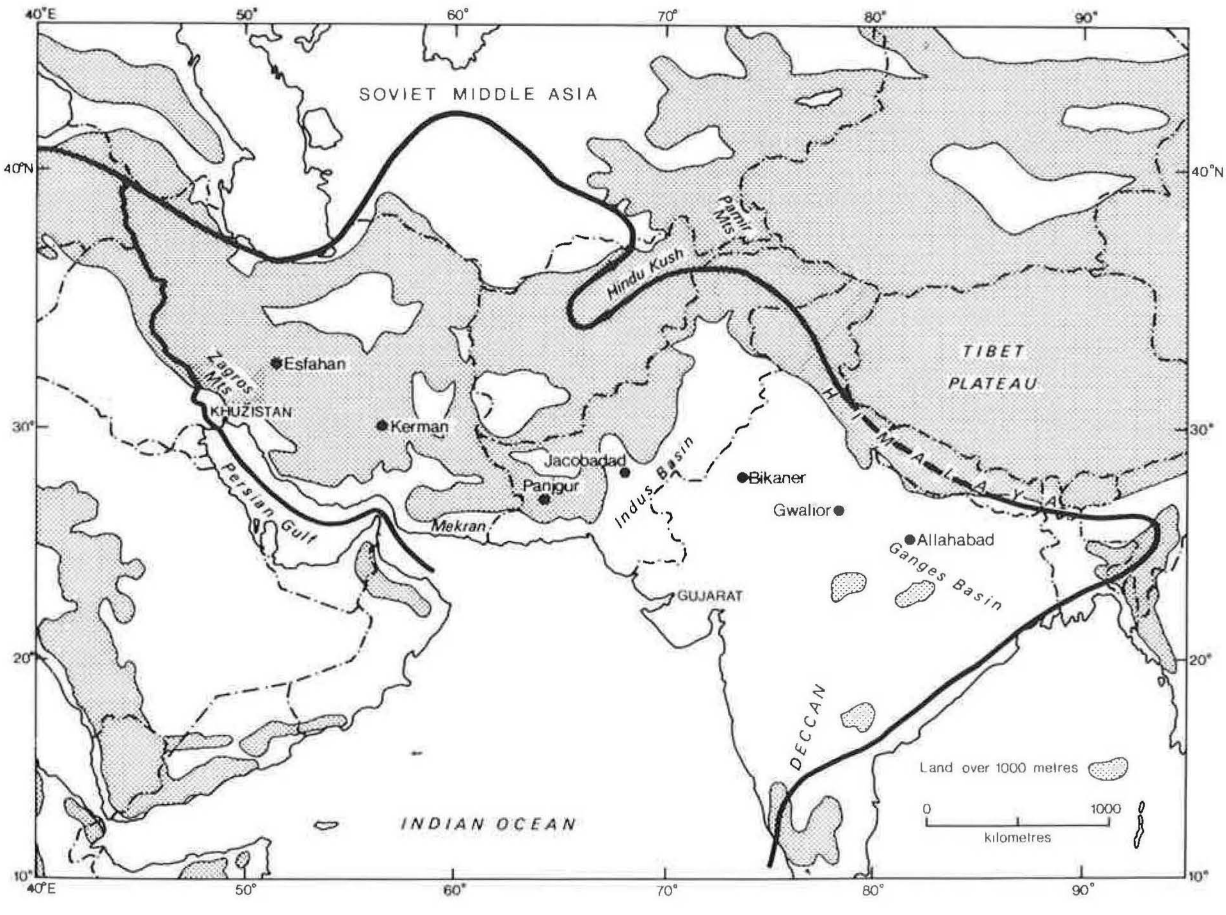


Fig. 5.1 Physiography of the Eastern Region. Mean rainfalls at places shown are listed in Table 5.2.

5.3 WEATHER AND CLIMATE

In mid *winter,* when the ITCZ lies south of the equator, the weather of the Eastern Region is dominated by *subtropical anticyclones* and *eastward-moving waves and cyclones* (known as WESTERN DISTURBANCES in India and Pakistan; see Section 3.3.5). As a result, winds blow mostly from the north-west (but from the north-east over peninsular India and the Arabian Sea — see, for example, Figs. C5.3b and C5.6b — and also over Soviet Middle Asia), with spells of a day or two from other directions, notably from between south and east. This pattern is very similar to that in the Western Region, but the mountain chains of the west and north greatly affect the windflow, which is largely along the valleys, sometimes making it difficult to find the eastward-moving waves and cyclones.

In mid *summer,* the subtropical anticyclones still dominate the weather of the western part of the Region, and winds there blow for long spells from between north and north-west, for passing waves are often weak. By contrast, in the east and over the Arabian Sea there is a marked change by mid summer: the *ITCZ* has moved north to lie along the south-eastern edge of the highlands of Iran and Pakistan, and along the southern side of the Himalaya mountains (H of Fig. 3.17b; and see, for example, Figs. C5.1b, C5.2b, C6.2b, C8.1b and C8.2b), and to the south of it there are *monsoon* west winds over India, much of Pakistan, and the south-eastern corner of Iran, with *westward-moving waves and cyclones.* The depth of the monsoon varies on average from about 1 km over Pakistan to about 5 km over peninsular India, but there are changes from day to day. Thus, the monsoon is a wedge with its top sloping upwards to the south-east; above it are winds blowing from between north-west (over Iran and Afghanistan) and east (over central India). Close to the Himalaya mountains there is often an east or south-east airstream near the ground during the monsoon season, with a corresponding MONSOON TROUGH in the isobars along the Ganges valley (see Figs. C6.1b, C6.2b and C8.2b for examples).

From mid winter to mid summer there is a progressive change in the wind pattern over the Region. By March, with rising temperatures and falling pressures over peninsular India, weak lows are often present there, but during the next three months the centres tend to form further north and by June there is one almost daily over western Pakistan. It persists there almost stationary during the monsoon season (B of Fig. 3.17b), but during October it fades away. As a result, winds over Pakistan and northern India back from the winter north-westerlies to monsoon westerlies or south-westerlies, and at the same time they strengthen, sometimes leading to dust storms (Ramaswamy & Kailasanathan 1971). Over peninsular India, the winter north-easterlies back to north-west by May (but to south-west along the east coast — like those at the same time of year along the coast of south-eastern Arabia, see Section 6.3); and during the monsoon they back to west. Hence, the onset of monsoon winds is nowhere sudden, as it often is in the other three Regions.

A reverse change takes place after the monsoon, as the seasonal cyclone over Pakistan fades, and winds weaken and turn to mostly north-west again over Pakistan and northern India. South-west winds persist along the east coast of peninsular India into October, before the return of winter north-easterlies.

Despite the undramatic *wind* changes at onset and retreat of the monsoon, there is nevertheless a strong seasonal variation in *rainfall.* In the *west* of the Region (Iran, Afghanistan and western Pakistan), the eastward-moving disturbances of winter and spring bring most of the annual rainfall, and in the first two countries the summer is largely rain-free. In the *east* (northern India and south-eastern Pakistan), it is convection in the moist monsoon winds from the Arabian Sea, modified by westward-moving disturbances, that brings most of the annual rainfall, although there are some winter and spring rains, especially over western and northern Pakistan and the far north of India. Thus, there is only *one rainy season* in Iran and Afghanistan, *two rainy seasons* in western and northern Pakistan and the far north of India, and *one rainy season* in south-eastern Pakistan and northern India. This general seasonal distribution is illustrated by Table 5.2, which shows mean monthly rainfall at selected places along a west-east line from central Iran to northern India.

Table 5.2 Monthly mean rainfall (mm) at selected places along a west-east line across the Eastern Region (see Fig. 5.1 for places named).

	Longitude °E	Period of record	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Esfahan	52	1951 – 60	19	16	18	16	8	1	5	1	T	3	19	20	126
Kerman	57	1951 – 60	36	22	46	22	20	2	7	0	4	3	8	32	202
Panjgur	64	1931 – 60	24	18	17	8	3	3	27	8	1	0	1	11	121
Jacobabad	68	1931 – 60	8	8	7	2	4	6	37	22	1	0	1	3	99
Bikaner	73	1931 – 60	6	7	6	5	7	27	87	104	45	6	3	2	305
Gwalior	78	1941 – 60	22	7	9	3	10	69	283	282	167	42	3	6	903
Allahabad	82	1931 – 60	20	22	14	5	8	100	283	333	195	40	6	6	1032

T = less than 0.5 mm
Taken from *Climatological normals*, WMO No. 117 TP 52.

Day-to-day changes in the weather are a result of the movement and development of atmospheric disturbances (see Section 3.3.5). *North of the ITCZ,* the eastward-moving disturbances are of the same kind as those in the North-Central and Western Regions, illustrated by Fig. 3.17a (some examples can be seen in the Case Study weather maps, e.g., Fig. C2.3b), when short spells of winds from between east and south at times replace the more common north-westerlies, especially in winter and spring. The south-eastward-moving windshift lines (such as L of Fig. 3.17a), marking the return of north-west winds, may be difficult to find over the highlands, however, probably because they are broken up over rough country. Moreover, they are slow to reform after reaching the plains of Pakistan and northern India. Convective clouds within the warm southerly winds ahead of a windshift line bring the occasional winter and spring rains (see, e.g., Rao & Srinivasan 1969, Singh 1963, and Swaminathan 1969), especially over mountains (see, e.g., Fig. 4.5a). Behind the windshift line there is a return to cool, dry, north winds that sometimes result in a 'cold wave' (night minimum temperatures more than 6°C below normal; see Rai Sircar & Datar 1963) and much reduced locust flight. Cyclone centres sometimes cross the highlands of Iran and Afghanistan, but they more often pass further north — over the plains of the Turkmen and Uzbek Republics. Sometimes weak cyclones form within waves as they cross Pakistan and north-west India (induced lows of western disturbances). Weak anticyclones between cyclones or waves give spells of east winds on their southern sides that can take swarms from India or Pakistan to Oman or Iran in early winter (e.g., Fig. C2.4b), or further west across Iran (e.g., Fig. C4.5b). Just before the monsoon (May-June), and again just after (October-November), rare severe cyclones from the Arabian Sea move north to bring strong winds and widespread rains to southern Pakistan and north-western India (see Fig. C8.1b for a June example, and Fig. C2.4b for one in November; see also Fig. 4.5f and Gupta *et al* 1977).

During the *monsoon season,* from about June to October, cyclones form over the northern Bay of Bengal or over north or central India and move slowly west or north-west (such as K of Fig. 3.17b), sometimes reaching Pakistan or even the northern Arabian Sea (e.g., Fig. C5.1b). These MONSOON DEPRESSIONS bring heavy rains, and are the main source of rain over the deserts of eastern Pakistan and Rajasthan (see, for example, Figs. C5.2b and C6.2d; see also Kulshrestha & Gupta 1964, Desai 1970, and Rao 1976). South-westward movement of swarms out of India and Pakistan on winds ahead of monsoon depressions is illustrated in Case Studies 4.2 and 5.1. Sometimes the cyclonic wind patterns are weak near the ground (see, for example, Figs. C4.2b, C4.3b, C4.4b and C8.2b), and such cyclones are better recognised on weather maps for heights of 3–5 km above sea level. Heavy monsoon rains over Pakistan and northern India also accompany wave troughs in the upper atmosphere at longitudes 60–70°E (Ghosh & Veeraraghavan 1975, Kumar & Saxena 1969, Rao, M.S.V. *et al* 1970, and Rao, Y.P. *et al* 1970). To the east of these upper troughs, monsoon depressions tend to turn northward. At times during the monsoon season, a slow-moving wave in the middle latitude west winds of the upper atmosphere (see Fig. 4.8) extends as far south as India in longitude 80–90°E, and the surface wind pattern changes to one more like that of spring. The monsoon trough over northern India then disappears (e.g., Fig. C4.1b), and whereas there may be heavy rains over north-eastern India and Bangladesh, over north-west India and Pakistan there is little or no rain. Such a dry spell, or MONSOON BREAK, can last up to three weeks (see, e.g., Ramamurthy 1969, Desai 1970, and Rao 1976). It is the frequency and persistence of monsoon depressions and breaks that largely determine the duration and amount of rain in a given monsoon season. Away from the monsoon depressions there can be scattered showers, especially over the mountains of western Pakistan and south-eastern Iran (see, e.g., Fig. 4.5d).

A consequence of the seasonal change in wind pattern over the Region is a corresponding change in the dominant directions of swarm movement (see Section 5.4). *North of the ITCZ,* winds are mostly from the north-west, but day-time temperatures on average do not exceed 20°C north of about 25°N in mid winter (except over the great plains of Pakistan and northern India) and there may be little or no flight on many days because the weather is too cold. In winter, most flight takes place on the warmest days, which are those with winds from between east and south, and sometimes south-west. Overall displacement in winter is therefore mostly *towards* the north-west — i.e. against the dominant wind direction. It is this movement that takes monsoon swarms out of India and Pakistan. During spring, daytime temperatures rise, and on average exceed 20°C almost everywhere by April, so that movements by then are mainly *from* the west and north-west. Iran and Afghanistan are clear by summer, and swarms enter Pakistan and India either during the spring or the start of the monsoon season (Section 5.14). In the latter case, swarms cross the ITCZ over Pakistan and the south-eastern corner of Iran (see H on Fig. 3.17b), presumably by flying above the thin end of the monsoon wedge and then coming to the ground to roost (see, for example, Case Study 6.1). *South of the ITCZ,* movement is mostly from the west or south-west (e.g., Figs. C4.1b and C8.2c), but near monsoon depressions it can be in other directions: southward on their western sides (e.g., Figs. C4.2b and C5.2b), and westward on their northern sides (e.g., Figs. C5.1b, C6.2b, C6.2d and C8.2b), the latter contributing to an east-west, to-and-fro movement in some years (e.g., 1954 — see Case Study 6.2).

5.4 SEASONAL BREEDING AND MIGRATIONS: GENERAL COMMENTS

Within the Region, breeding takes place in the summer, winter and spring seasons. In inland areas of Iran, in Afghanistan and (very rarely) in Soviet Middle Asia, it has been recorded in spring only, though in coastal areas of Iran it may occur in both winter and spring (see Fig. 5.2). In all these three countries, locusts mature and breed on the rains associated with atmospheric disturbances moving in winter and spring from the west.

The breeding regimes are more complex in India and, particularly, in Pakistan, which receives not only the winter and spring rains but also some monsoon rains. In India the main breeding season is during the monsoon, with breeding sometimes continuing into the winter months and also, on occasion, in spring. In Pakistan, both monsoon and spring breeding have been frequent and important; and there may be winter breeding following from the monsoon, or starting in the winter months (see Section 5.9 and Fig. 5.2).

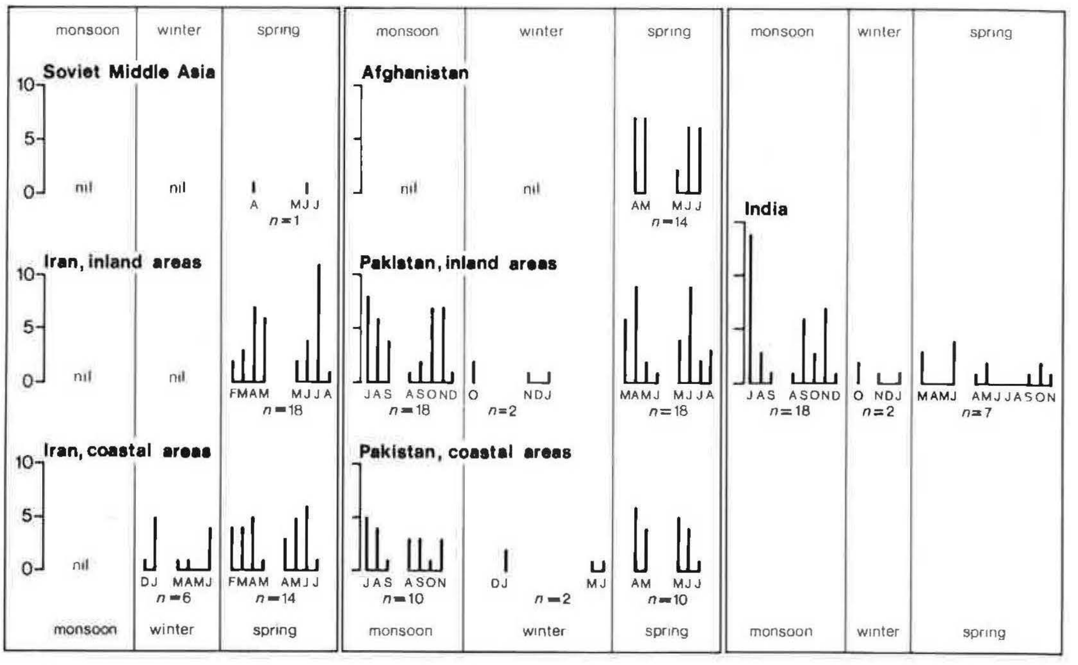


Fig. 5.2 Seasonal breeding in the Eastern Region: monthly frequencies of beginning and ending of hopper infestations. In each column, the monthly frequency of *hatching of first hopper bands* is shown on the left, and *fledging of last hopper bands* on the right. *n* is the number of years of records used.

There are regular seasonal migrations between the regional monsoon and spring breeding areas, with Iran and Afghanistan becoming clear of swarms in summer, and India and most of Pakistan usually in winter (see Sections 5.6 and 5.14). In addition, the Region may be invaded by swarms from other Regions in winter, in spring and in early summer (see Sections 5.7, 5.11 and 5.15); and may, in turn, send swarms to its neighbours (see Sections 5.8 and 5.12).

5.5 MONSOON BREEDING (JULY TO OCTOBER)

Distribution. Monsoon breeding within the Region is restricted to India and Pakistan only. It may be widespread, however, and take place over large parts of south-eastern and eastern Pakistan and north-western India (see Fig. 2.4a). The full extent of the areas in which monsoon breeding has been recorded from 1939 to 1975 can be seen on the hopper-band frequency maps for the months August to October. It will also be seen from these maps that in Rajasthan in India the frequencies of monsoon hopper infestation in any one degree square are among the highest for the whole invasion area, and are comparable to those during the summer breeding in Ethiopia and Sudan (Section 6.5). Frequencies are somewhat lower in Pakistan, but this may be due to under-reporting.

Populations involved. The populations which breed during the summer monsoon are the spring generation swarms originating in the Eastern Region and those early spring swarms produced there which do not become involved in the main spring breeding (see Sections 5.9 and 5.14). In addition, swarms (or other populations) reaching and laying in the monsoon breeding areas may include immigrants of the early spring and main spring generations originating in the North-Central Region (see Section 5.15 and the example forecast of Section 11.5).

Times of breeding. Maturation and laying by swarms which breed on the monsoon rains starts usually in July, with the first *hopper bands* appearing most frequently from July or August. When spring rains are late, the first hopper bands sometimes appear in June (see summer and spring diagrams in Pakistan and India, Fig. 5.2 and Section 5.13).

Fledging and swarm formation of the first monsoon generation may begin in August, but more frequently in September, and continue in October. When monsoon rains start late or finish early, only *one monsoon generation* is produced, e.g. in 1951 (see Summary 2) or in 1964. More often the rains continue in September and even October, resulting in maturation of monsoon swarms remaining in the source area and in production of the *second monsoon generation.* Usually it is not possible to distinguish from the reports either (a) the residual mature swarms of the spring generation and rapidly maturing early monsoon swarms, or (b) the later hatchings of the first and the earlier hatching of the second generation of monsoon hoppers, but in general the latter appear in the second half of September or in October, and *fledge* and form swarms in late October or November and occasionally as late as early December.

5.6 MIGRATIONS OF MONSOON SWARMS, SEPTEMBER TO DECEMBER

Monsoon swarms forming in north-western India and Pakistan between August and December usually move out westward or north-westward towards and into the spring breeding areas. Not infrequently some of them move out to south or to east of the source areas, and such swarms subsequently disappear without issue. The directions in which they migrate depend on the weather systems and winds which affect the source areas at the time of emigration.

Occasionally, considerable scattered populations remain in Rajasthan following emigration of swarms (as in 1960-61 season), and these may be re-concentrated into swarms at the beginning of the following monsoon season (see Summary 8 and Cochemé 1966a).

Westward movements

Westward emigrations from the source areas may begin in late August (as in 1961) but more frequently in September (as in 1950 and 1952) and sometimes not till October (as in 1951, when south-westerly winds prevailed over the source areas throughout September; or in 1960, when the September emigrations were to the east or south). Occasionally, the westward moves are delayed till November — December (as in 1949, due to late formation of swarms — see Section 2.7.2). During westward migrations, swarms appear in Baluchistan and Makran of Pakistan, and spread to southern Iran, which may be first invaded in any month between September and December. The initial emigrations are usually followed by further waves of westward-moving swarms, as in October 1950, or in November 1952 and November 1961 (see Summaries 1 on 1950, 2 on 1951, 3 on 1952, 4 on 1960 and 5 on 1961).

Examples of weather systems in which swarms may emigrate to the west are provided by the events in September 1961 and October 1960, when swarms moved out with the easterly and north-easterly winds blowing over north-western India, Pakistan and eastern Iran, on the north-western sides of monsoon depressions over India (see Case Studies 4.4 and 5.1). In 1961, the initial move, taking swarms into the Makran of Pakistan in early September, was followed in mid September by their spread into southern Iran and across the Gulf to Oman on north-easterly winds ahead of another monsoon depression moving over the area from the east (Case Study 4.2).

A westward emigration from northern India into the uplands of central Pakistan, which occurred later in the season (in late October — early November 1951), took place on the easterly winds blowing on the northern side of a western disturbance advancing over the area (see Case Study 2.3). This was followed in late November — early December 1951 by a movement of a few swarms into the western Makran of Pakistan and south-eastern Iran, with north-easterly winds blowing between an Arabian Sea depression moving northward over Rajasthan and Punjab, and a high over Iran (Case Study 2.4). Yet another example of the situations in which swarms may emigrate to the west occurred in mid November 1961, when a second wave of swarms moved from north-western India and eastern Pakistan into western Pakistan and adjoining parts of Iran during a spell of north-easterly winds which prevailed over the area during the first half of the month as pressure remained high to the north-west (Case Study 5.3).

The westward advance of monsoon swarms may continue on to Oman, as happened in September 1961 (see Summary 5 and Case Study 5.2) or in October 1950 and 1952, and November 1952 (see Summaries 1 and 3; see also Sections 5.8 and 6.7). Swarms may spread further west and then north-west through the coastal lowlands and foothills of southern and south-western Iran, sometimes reaching the Bushehr area and the lowlands of southern Khuzistan in October or November (as in 1950, 1952, 1960, 1961; see Summaries 1, 3, 4 and 5). Such advances occur mainly during the spells of warm south-easterly winds which blow over the Persian Gulf area ahead of waves and cyclones moving in from the west over the Middle East (for an example, see Case Study 4.5).

Some of the swarms moving during winter over the coastal lowlands of Pakistan and Iran may be able to mature, and then breed in winter or early spring (see Section 5.9).

Northward movements

Monsoon swarms emigrating initially to the west, or remaining in, or continuing to form in the source areas, may become involved in movements to the north, which are more usual in the later part of winter or in spring, but may begin in Pakistan and north-west India from September onwards and in Iran before the end of the year. For example:

- in September 1952, some swarms in Pakistan moved northward from their source areas to Quetta and Punjab, with the northward trend continuing in October into the North Frontier Province and to the Afghanistan border (Summary 3);
- in early October 1951, there was a northward move to northern Rajasthan and to Multan (Summary 2);
- in November and December 1949, many of the swarms forming in the source areas of Rajasthan, Sind and Bahawalpur moved north into Punjab (Section 2.7.2);
- in December 1950, swarms invading southern Iran spread north into the central part of the country (Summary 1);
- in December 1961, there was a progressive northward movement in eastern Iran and western and north-central Pakistan, with swarms spreading to Afghanistan (Summary 5).

An example of the weather systems with which the northward moves may be associated is described in Case Study 2.1, dealing with a northward spread in north-west India and Pakistan during early October 1951, when there were southerly winds over the area on the eastern side of the weakening seasonal low over western Pakistan (B of Fig. 3.17b; and see Section 5.3). Another example is described in Case Study 5.5, dealing with the northward spread of swarms in eastern Iran and northern Pakistan and into Afghanistan in December 1961, during spells of warm southerly winds.

Eastward movements

Examples of early eastward movements of monsoon swarms out of the source areas and over northern India occurred in, e.g., September 1952 and September 1960 (Summaries 3 and 4), when swarms spread to eastern Rajasthan and western Uttar Pradesh and, in 1960, to 80°E over Madhya Pradesh. The movement was with light westerly monsoon winds which prevailed over north-west and north India in the absence of monsoon depressions (Case Study 4.1). Some of the swarms reaching Madhya Pradesh moved southward in October (see the next sub-section), whereas others flew north-eastward to Bihar in late October during a seasonal spell of south-westerly winds over eastern India (see Case Study 4.3 and Section 5.3). The north-eastward trend continued in November 1960 through Bihar and north-eastern Uttar Pradesh, and in December, when swarms reached Bangladesh and Assam.

Other examples of eastward emigrations occurred, e.g., in October 1951, when swarms moved east and south-east from north-eastern Pakistan and northern Rajasthan to western Uttar Pradesh with westerly and north-westerly winds blowing to the north of an anticyclone extending over north-western India from the Arabian Sea (see Summary 2, Case Study 2.2). Eastward emigration may occur also in November or December — e.g. November 1952 (Summary 3) and November 1961 (Summary 5), when swarms still present in the source area moved north-eastward to Delhi and western Uttar Pradesh with south-westerly winds blowing ahead of a depression which had reached Rajasthan from the west and then had swung northward to Punjab (see Case Study 5.4). Another example of north-eastward emigration occurred in December 1950, when the late monsoon swarms forming in Rajasthan moved north-east through Uttar Pradesh towards the Nepal border (Summary 1). For examples of eastward movements in late winter and spring, see Section 5.11.

Southward and south-eastward movements

These may begin in September, and have been recorded in all winter months (see also Section 5.11). For example, in mid September 1961 some young swarms moved southward out of the source area to Gujarat and the Rann of Kutch — on north-easterly and northerly winds blowing ahead of a monsoon depression moving from east to west over northern India (Summary 5, Case Study 5.2). In October 1952 there were repeated southward moves out of the source area through to the Rann of Kutch (Summary 3). Some of the swarms were carried far out to sea by winds associated with an Arabian Sea low, and some reached the Kerala coast of southern India, where they were destroyed by birds (Rao 1954). Again, there was a southward move in November 1950, when a swarm appeared near Bombay (Summary 1).

A striking *circular* movement of monsoon swarms over peninsular and north-eastern India occurred between September and December 1960 (Summary 4). In the last ten days of September and in early October, after movement of swarms from the source area eastward to Uttar Pradesh and Madhya Pradesh (see third sub-section above), some swarms moved southward through southern Madhya Pradesh to Maharashtra and northern Karnataka; further to the west there was a movement south to Gujarat. The southward movements were with northerly and north-easterly winds which blew over central and western India in association with a low that had developed over Andra Pradesh (Case Study 4.2). During the first ten days of October, while this depression moved inland over central India and caused north-westerly and westerly winds to blow over most of peninsular India, the swarms from southern Madhya Pradesh moved south-east to Orissa, and from Maharashtra and Karnataka east to the coastal aras of Andra Pradesh (Case Study 4.3). In the last ten days of October, the winds over eastern India become south-westerly and the swarms in Andra Pradesh displaced to the north-east. This trend continued in November through Orissa, and in December the swarms reached Bangladesh and Assam, converging there with the swarms that had moved north-east through eastern Uttar Pradesh (see third sub-section above). The swarms persisted in the east till March 1961, after which they apparently died off.

5.7 WINTER INVASIONS FROM OTHER REGIONS, OCTOBER TO DECEMBER

At the time when monsoon swarms are moving out of their source areas, swarms originating in other Regions are doing likewise, and may invade the Eastern Region in the course of their migrations. Such immigrations have been recorded from October onwards and may also take place as late as spring (see Section 5.10).

Winter immigration by summer swarms originating in the North-Central Region may have occurred in, e.g., late November 1960, when swarms reaching south-western Iran may have included some moving in from north-eastern Arabia on westerly winds blowing over the area in the wake of an eastward-moving disturbance (see Summary 4, and Case Study 4.5; compare also Case Study 10.4). Another example occurred in December 1958, when the Eastern Region, which was then free of swarms, was invaded by some originating in the summer areas of the North-Central Region. The spread of these swarms over the Arabian Peninsula in October and November was followed in December by eastward movements on a wide front, which took swarms across the Gulf into south-western and southern Iran, whence some spread to south-eastern Pakistan (see Summary 9). The swarms subsequently spread widely and bred over the spring breeding areas of the Eastern Region. Yet another instance was in December 1967, in the early stages of the 1967-68 plague upsurge, when groups and swarms of the early winter generation produced in south-eastern Arabia moved north across the Persian Gulf on strong southerly winds ahead of a disturbance moving eastward over the area, and appeared along some 500 km of the coast in south-western Iran. This incursion resulted in the spread of the plague into the Eastern Region (see Section 2.7.3 and Fig. 2.15c).

5.8 WINTER EMIGRATIONS TO OTHER REGIONS, OCTOBER TO DECEMBER

While the Eastern Region may be invaded from other Regions, monsoon swarms originating in it may, in turn, spread to the latter. An example of migration of monsoon swarms to Oman in September 1961 has been referred to in the first sub-section of Section 5.6, and the weather system (a monsoon depression) during this movement is described in Summary 5. Other instances of migrations on to Oman occurred in, e.g., October 1950 and October 1952 (in both of which some monsoon swarms reached also eastern or north-eastern Arabia), in November 1952, and in November and December 1949. In the latter two years, swarms spread to south-western Arabia and across the Gulf of Aden to the Somali Peninsula (for details see Sections 6.7 and 7.7, and Summaries 1 and 3, Section 2.7.3, and Fig. 2.13e).

5.9 WINTER (OCTOBER-JANUARY) AND EARLY SPRING (FEBRUARY-MARCH) BREEDING

Distribution. As can be seen from Fig. 2.6b, winter breeding can occur in India and Pakistan, and in the coastal areas of Iran. Early spring breeding, with hatchings from February, may occur in the coastal and southern inland areas of Iran, and coastal areas of Pakistan (see hopper-band frequency map for February, and Fig. 5.2). The map for November shows that the frequencies of winter hopper infestations in any one degree square did not exceed four or five out of 37 years in India and Pakistan, and only two years in Iran, while those in early spring in Iran (cf. February map) did not exceed four.

Populations involved. These consist of monsoon swarms remaining to breed in the monsoon breeding areas (see below) or spreading westward through southern Pakistan and Iran (see Section 5.6). They could also be summer or early winter generation swarms originating in the North-Central Region and invading the Eastern Region in the last quarter of the year (see Section 5.7).

Times of breeding. In India and Pakistan, the winter breeding is usually a *continuation of monsoon breeding* (see summer histograms on Fig. 5.2), with the October and occasional November hatchings belonging to the later (second) monsoon generation, which fledges in November or early December and, like those of earlier monsoon swarms that do not rapidly mature and breed, moves out of the source areas (see Section 5.6). Occasionally during the recession years (as in 1970 and 1973 in India, and 1973 and 1975 in inland Pakistan), the first hopper bands were reported in October, with fledging in November or January, though monsoon breeding and hoppers at lower densities had occurred there in the preceding months.

Sometimes coastal winter breeding in Iran and Pakistan, with hoppers *hatching* in December or January, and *fledging* about March (and possibly earlier), merged with early and main *spring* breeding, with fledging between April and June (see winter histograms, Fig. 5.2). On other occasions, the first hoppers appeared from early February (as in 1951 and 1959) and fledged in early April. Winter and early spring swarms may join in the northward migrations of monsoon swarms (see Section 5.11) and take part in the later stages of the main spring breeding (as in 1951, see Summary 1).

5.10 WINTER AND SPRING INVASIONS FROM OTHER REGIONS, JANUARY TO MAY

During this period, the Eastern Region may continue to be reached by summer swarms (and also those of winter or early spring) from other Regions. Thus, in late February-early March 1952, some of the Short Rains swarms that had migrated from the Somali Peninsula to north-eastern Arabia and southern Iraq (see Section 6.11) moved south-eastward into south-western Iran (Summary 10, Case Study 10.4), and by late March had spread through southern Iran and to south-western Pakistan. Again, in March 1958, when summer and winter swarms produced in the North-Central Region, together with the Short Rains swarms which had moved to Arabia from the Somali Peninsula, had reached north-eastern Saudi Arabia and the Middle East, there was a marked eastward spread into south-western and southern Iran and as far as south-western Pakistan. An example of an invasion of western Iran from southern Iraq occurred in March 1959 (Summary 9).

The immigrant swarms reaching south-western and southern Iran and southern Pakistan may either breed in the coastal areas or spread in a general northward direction (as do monsoon swarms at that season — see Section 5.11), or both, and breed widely over the eastern spring breeding areas (see Summaries 9 and 10).

Yet another example of an invasion of the Eastern Region occurred in April 1950, when swarms of the early spring generation produced in Oman apparently moved north to southern Iran and joined the Iranian early spring swarms in their northward move and late spring breeding in eastern Iran (see Summary 7).

An important incursion into the Eastern Region by large numbers of locusts at low densities occurred in spring 1973. These almost certainly originated during the preceding winter and early spring breeding on the Red Sea coast of Arabia and moved out in March-April 1973, reaching Afghanistan in April and Rajasthan in April-May (see Fig. 2.11). They and their progeny greatly contributed to an incipient plague upsurge in the Eastern Region later in that year (see Section 2.6).

5.11 MIGRATIONS OF MONSOON, WINTER AND EARLY SPRING SWARMS, JANUARY TO JUNE OR JULY

Movements in areas west of the monsoon breeding zone

The westward and northward movements performed by swarms emigrating from their source area in the period September to December (see Section 5.6) continue to occur in late winter and spring, with the northward migrations of swarms that had initially moved out to the west becoming particularly important for the spread over the spring breeding areas. There may also be return eastward movements by monsoon swarms, analogous to those described in Sections 5.7 and 5.10. Such re-invasions become apparent only when swarms move back into areas previously cleared.

Examples of continuing *westward spread* occurred in January 1951, when swarms moving west over southern Iran finally reached Khuzistan (Summary 1), or in March 1961, and March-April 1962. Such movements were associated with warm southerly or south-easterly winds blowing ahead of windshift lines advancing towards the Persian Gulf area from the west (see Case Studies 10.5, 10.7 and 10.8).

In the 1960-61 season, when there was a marked departure of monsoon swarms to the east as well as repeated emigration to west (so that north-western India and Pakistan were almost free of swarms by the end of 1960 (see Summary 4), the continued westward movements led to the clearance of eastern Iran and also to the absence of gregarious breeding in spring 1961 in the Eastern Region to east of 58°E (Summary 8). In the 1953-54 season, on the other hand, when the westward movements resulted in the clearance by March 1954 of areas to east of 57°E, there was a return movement in April by the now mature monsoon swarms into eastern Iran, Afghanistan, Pakistan and north-western India, with further moves from Afghanistan and Pakistan into India in May (Summary 6; and see last paragraph of this sub-section).

The usual *northward spread* towards and through the spring breeding areas of the Eastern Region (see Fig. 2.6a for generalised movements of monsoon swarms, and Fig. 2.4c for distribution of spring breeding) is illustrated by, e.g., the events of the 1950 – 51 season, when, in January 1951, swarms from southern Pakistan and Iran moved northward to the Punjab of Pakistan, to the Afghan border in central and west Pakistan, and to southern Khorasan in east Iran. The northward movements continued in February and March, when north-western India became free except for north-western Punjab, while swarms in Pakistan spread still further north in the Punjab and into Afghanistan. There were further northward extensions of invaded areas in east Iran and in Afghanistan in April-May (see Summary 1). Another example is provided by migrations of monsoon swarms in the 1961 – 62 season, when, following the northward spread in Pakistan, Iran and Afghanistan in December (see Section 5.6), the northward migrations continued in Iran in January, and in Afghanistan and eastern Iran in March and April. In that year, swarms spread exceptionally far to the north and crossed the boundary of north-western Afghanistan into southern Turkmen Republic in Soviet Middle Asia (see Summary 5).

Northward spread is a usual seasonal occurrence in winter and spring, and is associated mainly with the warm southerly winds blowing ahead of eastward-moving waves and cyclones passing through Iran, Afghanistan and Pakistan during these seasons (see examples in Case Studies 5.5, 10.5, 10.7 and 10.8). As in the North-Central and Western Regions during the cold season (see Chapters 6 and 8), these intermittent warm southerlies must be of great importance in the winter and early spring movements in Pakistan, Iran and Afghanistan where, away from the coastal areas (see Section 5.2), swarms must be often grounded in these seasons by low temperatures during spells of prevailing north-westerly winds (Section 5.3).

Eastward movements in that part of the Eastern Region lying west of the monsoon breeding zone are clearly detectable in this season only on occasions when swarms migrate into areas previously free of locusts (as in April 1954, Summary 6). Like the westward winter and spring movements, the eastward migrations alternate with those in northward directions. A good example is provided by the events in spring 1952, when Short Rains swarms from the Somali Peninsula reaching south-west Iran in late February-early March (see Section 5.10) moved into areas free of swarms. The invaders spread east and north-east through southern Iran in March, and then east through

Pakistan and north through east Iran and Afghanistan in April (see Summary 10). A comparable eastward and northward spread occurred between December 1958 and May 1959 after the Eastern Region (which was clear of swarms at the time) had been invaded by summer generation swarms from the North-Central Region by early December (see Summary 9).

Whereas the *northward* moves across this part of the Region during the cooler season are associated with spells of a day or two with southerly winds ahead of some eastward-moving depressions, the *eastward* moves take place on the following, more usual, north-westerly winds when they are warm enough for sustained flight (see Case Study 10.4).

Finally, from about May onwards, migrations over Iran, Pakistan and Afghanistan acquire a marked eastward bias which results in the invasion of monsoon breeding areas by spring swarms (see Section 5.14). Such movements may involve also old monsoon or winter-early spring swarms during the last stages of their migrations — as, in May and June 1951, when populations of swarms moving into north-western India included both old and young swarms (see Summary 1). Similar invasions of Pakistan and India by mature swarms coming in from the west or north-west occurred in, e.g., May and June 1952 (see Summary 10), and in May 1954 (Summary 6). Examples of some of the weather systems in which swarms move from the west to monsoon breeding areas are referred to in Section 5.14.

Movements in areas east of the monsoon breeding zone

Movements into the area east of the source areas of monsoon swarms, such as can occur from September to December (see Section 5.6), may occur also in the following months. In January 1951, for example, some of the monsoon swarms spreading northward in north-west India moved north-east through Uttar Pradesh to the Nepal border. In the same month there was a south-eastward move through southern Rajasthan, continuing in February over Madhya Pradesh into Bihar, where they disappeared (Summary 1). In March 1962, swarms that had reached western Uttar Pradesh in the preceding November moved progressively eastward through Uttar Pradesh and Bihar into Bangladesh and Assam, where they disappeared after mid April (Summary 5). The movement was with the seasonal north-westerly and westerly winds that prevail over northern India throughout the month (see Case Study 5.6). Finally, when east Pakistan and north-west India are reached by mature monsoon or winter-early spring swarms in the last stages of their migrations (see last paragraph of first sub-section), they may sometimes spread eastward beyond the monsoon breeding areas. Examples are: May 1954 (when they reached western Uttar Pradesh during a spell of north-westerly winds — Summary 6), and June 1951 (when they reached east to Bihar — Summary 1). For examples of weather systems during such eastward spread see Section 5.14.

Breeding and dying-off of swarms

As monsoon swarms move over the spring breeding areas that lie to the west and north of the monsoon breeding belt (compare Figs. 2.6a and c), they may begin to mature and lay from December or January on the coasts, and from about February or March in the interior, with the layings tending to become progressively later from south to north in Iran, west Pakistan and Afghanistan. In the later stages of spring breeding, monsoon swarms may be joined by rapidly-maturing members of winter-early spring generations produced in the coastal areas (see Section 5.9). The breeding swarms usually die off in the spring breeding areas during the period from May to July, and any old monsoon swarms returning to monsoon breeding areas in May-June are probably too senile to continue breeding. It is possible, however, that members of the early spring generation moving into monsoon areas (as in 1951 and in 1954 — see Summaries 1 and 6) may sometimes survive to breed on the first monsoon rains.

5.12 WINTER AND SPRING EMIGRATIONS TO OTHER REGIONS, JANUARY TO MAY

Since north-westward movements associated with spells of south-easterly winds continue to occur over south-western Iran throughout winter and spring (see Section 5.10), it is to be expected that throughout this period eastern Arabia and Iraq remain open to invasions of swarms from the Eastern Region (cf. Section 5.8). Examples of such invasions occurred in April-May 1951 (when swarms spread from south-west Iran into Kuwait and possibly other parts of north-east Arabia, and into southern Iraq — see Summary 1), and in April 1962 (when swarms moving north-west over western Iran spread into northern Iraq — see Case Study 10.8).

5.13 MAIN SPRING BREEDING (MARCH TO JUNE OR JULY)

Distribution. Spring breeding (see Fig. 2.6c) takes place in all the countries of the Region, though between 1939 and 1975 it occurred once only in Soviet Middle Asia (see Fig. 5.2), and then over a restricted area. The frequency of its occurrence has been high in Iran, Pakistan and Afghanistan, in all of which countries it can be widespread and give rise to large populations of swarms, but it has been less frequent in north-western India (see Fig. 5.2). The full extent of the areas over which the main spring breeding has been recorded can be seen from hopper-band frequency maps for April to June. These maps also show that the higher frequencies are comparable in April and May in Iran and Pakistan, and that in June the frequencies in Afghanistan (where they may be under-reported) are nevertheless of the same order as in Pakistan and Iran in the same month.

Populations involved. Swarms breeding during this season are those of the monsoon generation that have spread over the spring breeding areas of the Region (see Sections 5.6 and 5.11), augmented in some years by swarms formed in the coastal areas of Pakistan and Iran, following winter or early spring breeding. In addition, breeding populations may include summer- or winter-generation swarms invading the Eastern Region from the North-Central and the South-Central Regions (see Sections 5.7 and 5.10), and in some years they consist entirely of such immigrants (e.g. in 1952 and 1959 — Summaries 9 and 10).

Times of breeding. In the coastal areas of Iran, the main spring breeding sometimes follows the winter and early spring breeding *without a break,* but not infrequently the first *hopper bands* do not appear till April. In inland areas of Iran, where there is no winter breeding and early spring breeding is rare, and where first appearances of hoppers tend to be later further north, the first *hatching* begins most frequently in April or in May. *Fledging* and formation of new swarms comes to an end most often in May or June on the coast, and in July in the interior, where it may very occasionally continue into August (Fig. 5.2).

In Afghanistan, the first *hopper bands* are equally likely to appear in April or in May, and *fledging* and swarm formation usually ends in June or July.

In Pakistan, spring *hopper bands* have been recorded on the coast from April or May, but earlier spring breeding may sometimes occur in the interior, particularly on occasions when some swarms over-winter in the northern part of the country (e.g., in the 1949–50 and 1950–51 seasons), with the first hopper bands appearing from March in the northern lowland areas. More usually, however, the first hopper bands appear from April. Throughout Pakistan, *fledging* and swarm formation may end in May or June, but most frequently in June in the interior; occasionally they continue into July on the coast, and not infrequently till July or August in the inland areas (Fig. 5.2).

In India, spring *hatching* may occasionally occur from March in north-western Punjab (again on occasions when some swarms overwinter there) with such hoppers fledging in April or in May. More widespread hatchings may begin in June, following rains in May or June accompanying either late but well-marked western disturbances (e.g., 1950, 1959 and 1974), or pre-monsoon cyclones moving inland from the Arabian Sea (e.g. 1943). These hatchings lead on to the early stages of monsoon breeding, which continues through the summer (and sometimes into winter), with fledging and swarm formation ending between September and November (Fig. 5.2).

5.14 MIGRATIONS OF SPRING SWARMS, MAY TO JULY OR AUGUST

From about May onwards, swarms produced in the spring breeding areas of the Eastern Region begin to move east or south-east towards the monsoon breeding areas of eastern Pakistan and north-western India (Fig. 2.6a). The first immigrant swarms from Iran (or from further west — see Section 5.15) and from Afghanistan usually appear in Pakistan from May or June onwards, coming in through coastal or interior Baluchistan or through the north-western part of the country. The immigrants, as well as the spring swarms originating in Pakistan itself, continue in eastward or south-eastward directions to north-western India, which may be first reached in May or June. Since the formation of spring swarms in their source areas continues from April or May into July (see Section 5.13), east Pakistan and north-west India may be invaded by successive waves of swarms continuing to arrive through June and in July. Examples of such repeated immigrations into monsoon breeding areas between May and July 1950, May and July 1954, and in June and July 1961 are described in Summaries 7, 6 and 8 respectively.

The eastward and south-eastward movements to the monsoon breeding areas may be associated with a variety of weather systems. Swarms may move from Iran, Iraq and north-eastern Arabia with the almost daily north-westerly winds blowing over the Persian Gulf area and Iran towards Pakistan (see Summary 6). Once the monsoon spreads inland in the countries bordering the northern Arabian Sea, the eastward migrations through southern Iran and Pakistan may be with the westerly or south-westerly monsoon winds after swarms have crossed the ITCZ (as, e.g., in June 1961, Case Study 8.1). These monsoon winds may also bring swarms to the coasts of Iran or Pakistan, or to Kutch and Kathiawar, from southern Arabia — as in July 1968 (see Section 2.7.3, Fig. 2.15 f) or in June 1954 (see Case Study 6.1). The south-eastward movements from Iran, Afghanistan and northern Pakistan may be with the upper north-westerly winds blowing above the south-west monsoon (see Case Study 6.1; see also Section 5.3).

Swarms flying over south-eastern Iran and southern Pakistan may fly out to sea with northerly winds blowing on the western sides of depressions moving east to west across India (e.g. in June 1954, see Case Study 6.1), or by northerly winds blowing on the western side of Arabian Sea cylcones moving towards north-west India — as in June 1961. (On the latter occasion, swarms reached the Rann of Kutch on westerly winds which later blew over the northern Arabian Sea as the cyclone moved north-east towards Rajasthan — see Case Study 8.1.)

From south-eastern Pakistan and adjoining parts of India, swarms may move north and north-east through east Pakistan and Rajasthan with south-westerly monsoon winds (as in July 1961, Case Study 8.2).

Swarms moving in from the north-west, west and south-west may become involved in eastward migrations which take them far beyond the monsoon breeding areas. In June 1950, for example, some of the swarms invading

Rajasthan moved eastward across northern India as far east as Bihar, but most of them returned to west Rajasthan in July (Summary 7). In June 1954, swarms remained to the west of 75°E in the first half of the month because of persistent easterly winds on the north side of a low over central India. In the second half of June they spread east and south-east over Madhya Pradesh, and east to 83°E during a spell of north-westerly winds blowing ahead of a monsoon depression moving up the Ganges valley, but retreated westward by the end of June on easterly winds on the north side of a low moving across India from Orissa. With the return of westerly monsoon winds in early July, swarms again spread east (to 84°E), but by mid July they returned finally to monsoon breeding areas with easterly winds blowing over northern India on the north side of another monsoon depression (see the series of Case Studies 6.2).

Such eastward surges of spring swarms over northern India and their westward returns, on changing winds associated with the passages of monsoon depressions, occur quite frequently during this season. In most years, most swarms return to monsoon breeding areas, and the oscillations cease as swarms begin to breed and become less mobile. In 1955, however, almost all the invading spring swarms moved east and south-east right across northern India as far as Bihar and Orissa, failed to return and disappeared without issue (Bhatia & Mital 1962) — an event resulting in a plague recession in the Eastern Region until the reinvasions of 1958 and 1959 (Waloff 1966).

In the monsoon breeding areas, maturation and first layings by swarms begin with the onset of monsoon rains in July; in the second half of July or in August most of them are mature and laying. It is likely that most of them die off by about October, and in years of protracted breeding they are replaced by breeding swarms of the first monsoon generation (see Section 5.5).

5.15 LATE SPRING AND SUMMER INVASIONS FROM OTHER REGIONS, MAY TO JULY OR AUGUST

During this period, the Eastern Region may be invaded by locusts of the spring generation that originated in the North-Central Region and have moved east towards the monsoon breeding areas, in which they subsequently breed.

For example, the large scattered populations arriving in Pakistan and north-west India from May to July 1949 consisted mainly of locusts produced in Oman, and breeding by these populations and their progeny during the 1949 monsoon led to an upsurge of the plague (Section 2.7.2). Again, swarms invading Pakistan and India from May to July 1954, and in June and July 1961, included those originating in the central and north-eastern Arabian Peninsula and in Iraq (see Summaries 6 and 8, and the example forecast of Section 11.5). Finally, the swarms arriving in south-east Iran and southern Pakistan in July 1968, and spreading to monsoon breeding areas in Pakistan and India, were likely to have originated in central and north-western Arabia and to have moved across Oman (see Section 2.7.3, and Fig. 2.15 f). For references to weather systems with which the eastward movements from North-Central to Eastern Regions may be associated in this season, see Section 5.14.

5.16 LATE SPRING AND SUMMER EMIGRATIONS TO OTHER REGIONS, MAY TO JULY OR AUGUST

Apart from an emigration by monsoon swarms from south-west Iran into Iraq in April or May 1951 (referred to in Section 5.12), there do not appear to have been any recorded cases of movements of swarms out of the Eastern Region — possibly because of the prevalence of north-west winds over and near the Persian Gulf and Gulf of Oman. Movements from Iran to south-east Arabia may occur, however, when northerly winds blow over the area ahead of monsoon depressions advancing form the east towards Iran (see Case Study 4.4), or ahead of an Arabian Sea cyclone moving north towards the shores of Iran.

6 THE NORTH-CENTRAL REGION

6.1 POSITION OF THE REGION AND COUNTRIES INCLUDED

This Region extends over the central part of the Desert Locust invasion area, from the western boundaries of Egypt and Sudan to the western boundary of Iran and the eastern and south-eastern shores of the Arabian Peninsula. The Oman Peninsula had formerly been put in the *Eastern* Region (see Waloff 1966, 1976) but in this Manual it has been put in the *North-Central* Region, which is here considered to include the entire Arabian Peninsula. In the north it extends through the Middle East and northward to Turkey, while in the south it is bounded by latitude 10°N cutting through Sudan and Ethiopia, and by the Gulf of Aden shores of Arabia (see Fig. 2.4). The countries of the Region are listed in Table 6.1 in the order of the annual frequency of occurrence of swarms in them. It will be seen that this frequency is high or very high in the countries bordering the Red Sea and the Gulf of Aden, where swarming populations have occurred both during plague years (totalling 22 in this Region over the considered period) and also during recessions. The frequency of infestations falls off markedly in the Middle East countries, which are reached by swarms only during plagues.

6.2 MAIN PHYSIOGRAPHIC FEATURES

The most prominent physiographic features of the region are (Fig. 6.1):

- two deep rift valleys, one occupied by the Red Sea and the Danakil depression (and continuing beyond the region through Ethiopia and the East African plateau), the other occupied by the Gulf of Aden;
- two blocks of high ground flanking the southern Red Sea and the Gulf of Aden: (a) the Ethiopian Highlands, which rise to 2000 – 3000 m above sea level but decrease to 1000 – 2000 m in their northward extension in Eritrea, and (b) the Yemen plateau and Asir mountains, which rise to over 2000 m but decrease in altitude to 1000 – 2000 m in their eastward extension in P.D.R. Yemen.

Table 6.1 Number of years with recorded Desert Locust infestations in the North-Central Region during the 36 years from 1940 to 1975.

	Swarms	Hopper Bands
Ethiopia north of 10°N	30	32
Saudi Arabia	29	28
Sudan north of 10°N	28	30
P.D.R.Yemen	27	23
Yemen A. R.	24	25
Egypt	23	12
Oman and eastern Rub al Khali	22	14
United Arab Emirates	22	12
Republic of Djibouti	20	13
Jordan	19	16
Kuwait	18	16
Iraq	16	14
Israel	15	8
Syria	12	9
Qatar	7	3
Bahrein	7	3
Turkey	6	5
Lebanon	4	1

To west and north of the Ethiopian block, most of the African section of the Region consists of low tablelands 200 – 500 m high, which slope gradually to the north but rise locally to 1000 m, and 2000 m in the Gilf Kebir and Darfur uplands of south-western Egypt and western Sudan, and to 500 – 1000 m in the broken lines of Red Sea Hills in eastern Sudan and Egypt. The tablelands and plains are traversed by the Nile and its great tributaries bringing run-off from the Ethiopian Highlands, while the narrow coastal plains are crossed by numerous wadis draining to the sea from these Highlands and Red Sea Hills.

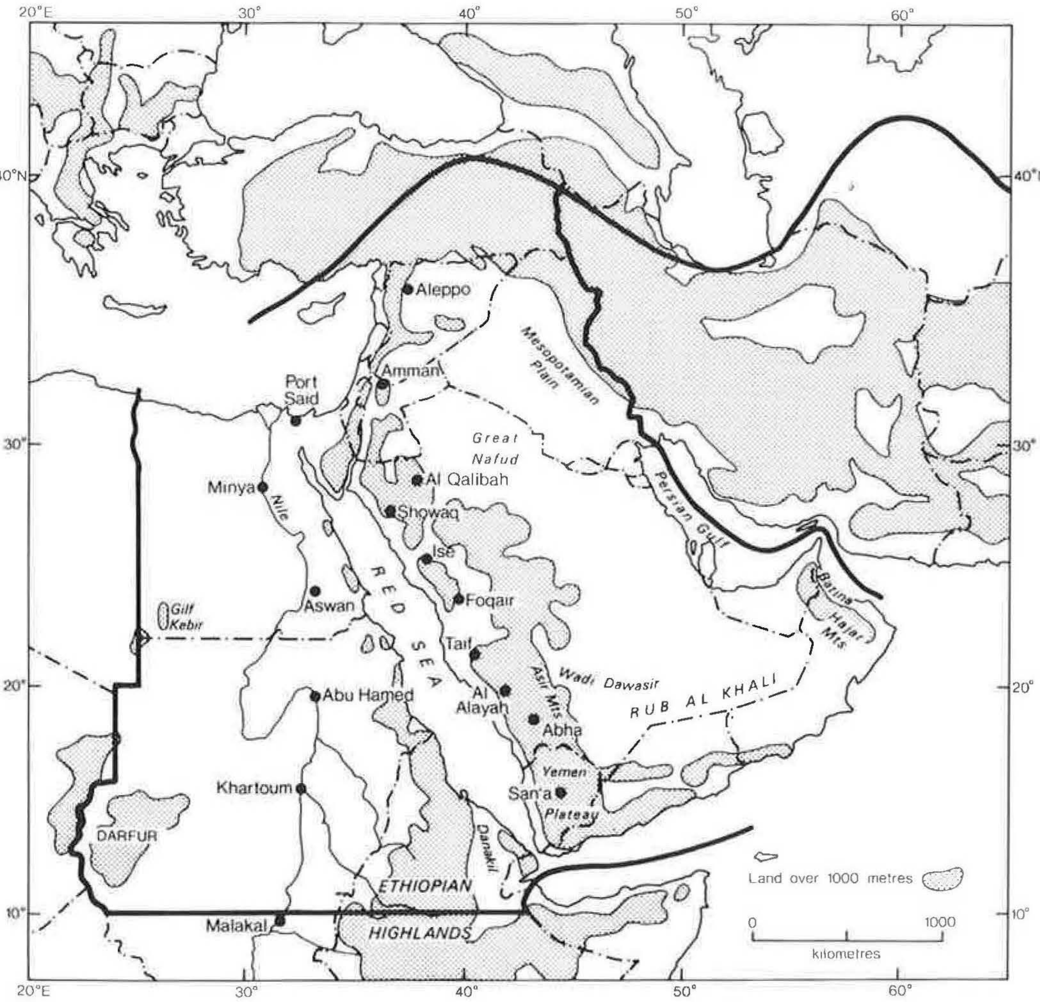


Fig. 6.1 Physiography of the North-Central Region. Mean rainfalls at places shown are listed in Tables 6.2 and 6.3.

In Arabia to north and east of the Yemen and Asir Highlands, much of central and western Saudi Arabia and of Jordan are occupied by extensive plateaux rising to over 1000 m, and continued in the north by the higher ground of western Syria and Lebanon. In general, however, altitudes decrease eastward towards the Persian Gulf and the Mesopotamian plain, which is flanked to the north and east by the mountains of Turkey and north-western Iran. In south-eastern Arabia, the lowlands are separated from the sea by the Hajar mountains, rising locally to over 2000 m and running parallel to the narrow Batina coast.

As on the African side, the narrow Red Sea coastal plains are traversed by numerous wadis draining from the highlands and providing favourable breeding habitats for locusts. Some important wadis run inland from the Asir mountains, to form the Wadi Dawasir.

A large area of northern Saudi Arabia is occupied by the sands of the Great Nafud, while the sands of Rub al Khali extend right across southern Arabia and are reached by floods in the wadis draining inland from the higher ground in Yemen A.R., P.D.R. Yemen, Dhufar and Oman.

6.3 WEATHER AND CLIMATE

In mid *winter,* when the ITCZ lies south of the equator, the weather of the North-Central Region is dominated by *subtropical anticyclones* and *eastward-moving waves and cyclones* (Section 3.3.5). As a result, winds blow mostly from between north-west and north-east, but with spells of a day or two from other directions. This pattern is very similar to that in the Eastern and Western Regions (Sections 5.3 and 8.3), but the highlands produce some important distortions.

- The highlands of Turkey-Iran cause winds to blow from the west (over Syria) or north-west (over Iraq, M of Fig. 3.17a), or from the opposite directions ahead of eastward-moving disturbances.
- Over Oman, north-west winds from the Gulf meet easterlies from the Arabian Sea at the semi-permanent Oman Convergence Zone south of the Hajar Mountains (R of Fig. 3.17a; see also Pedgley 1970c).
- Over the northern Red Sea, winds in the lowest 0.5 – 1.0 km are channelled between the uplands on either side — they often blow from the north-west (O of Fig. 3.17a). These winds are moist, and contrast with the drier winds above — the east and north-east trade winds blowing around the northern end of the high plateau of the south-western Arabian peninsula.
- Over the southern Red Sea, a branch of the Arabian Sea trade wind blows along the Gulf of Aden, turns through the Bab el Mandeb and continues as a south-east wind between the highlands of Yemen and Ethiopia (P of Fig. 3.17a). This south-east wind meets the north-west wind from the northern Red Sea at the Red Sea Convergence Zone (RSCZ, Q of Fig. 3.17a; for examples, see Figs. C11.1b, C11.3b, C14.1b and C17.3b; see also Pedgley 1966). The RSCZ lies across the Red Sea about north to south, or north-east to south-west, on average near 41°E from October to May, oscillating north and south over periods of about five days under the influence of varying strengths of the opposing winds, as disturbances move east across the area. Sometimes the south-east wind can spread far to the north (see, for example, Fig. C11.2b), and even cover the whole length of the Red Sea (when the RSCZ disappears temporarily, reforming as the cold front of the disturbance spreads from the north-west). The moist south-east wind deepens as it over-rides the north-westerly, often spilling over, and around the northern end of, the high plateau of the south-west Arabian peninsula as a *south* or *south-west* wind, and similarly with the high Ethiopian plateau as an *east* wind. In both areas the moist winds meet dry trade winds, and no doubt mix with them by daytime convection. At greater heights, above about 3 km, winds are little affected by these highlands — they are westerly in mid winter, but become easterly in the south during the spring, as the average latitude of centres of the subtropical anticyclones at these heights moves north. This complexity of large-scale winds and superimposed synoptic changes over the southern Red Sea is compounded by daytime sea breezes and upslope winds (Section 3.3.5, and see Fig. C11.1b for an example) and night-time land breezes and downslope winds. The scarcity of weather observing stations in the area, however, makes it difficult to assess the wind pattern on any given day.

In mid *summer,* the subtropical anticyclones still dominate the weather of the north, but passing waves are then often weak; hence winds blow for long spells from between north and north-west. By contrast, in the south there is a marked change by mid-summer: the ITCZ has moved north, reaching about 20°N over the Red Sea and 25°N over Oman (Fig. 3.17b; and see Figs. C11.1b, C11.3d and C14.2b for examples), and to the south of it there are *monsoon* west winds. The monsoon is distorted, however, by the highlands.

- Over interior Oman, the surface monsoon is deflected to blow from south or even south-east by the Hajar Mountains, and it turns around their northern end into the Strait of Hormuz (Fig. 3.17b), where it meets a shallow south-easterly flow from the Gulf of Oman (Pedgley 1970c).
- Over Sudan, the surface monsoon is deflected to blow almost from the south by the Ethiopian highlands, and it turns around their northern end to become part of the north-westerly wind over the Red Sea, blowing between the highlands on either side. In the lowest 0.5 – 1.0 km of the atmosphere, however, the Red Sea north-westerlies have come from the Mediterranean Sea (P of Table 3.2b and Fig. 3.17b). These north-west winds meet a more direct stream of the south-west monsoon from eastern Ethiopia (G

of Fig. 3.17b) at the Afar Convergence Zone (ACZ; Q of Fig. 3.17b; see also Tucker & Pedgley 1977b). The ACZ lies near the Bab el Mandeb from about June to September, oscillating north and south over periods of a few days under the influence of pulses in the north-westerlies. Sometimes the ACZ moves north over the southern Red Sea and is then followed by weak south-east winds. The Ethiopian plateau is crossed by the upper part of the monsoon south-west winds from Sudan, which turn to west or north-west before flowing above the north-west winds over the southern Red Sea and Danakil. To the east, over the highlands of the south-western Arabian peninsula, the north-eastern edge of the moist monsoon meets the dry north winds at the ITCZ, whose average position is uncertain but is probably seldom far north-east from the highlands. As in winter, this complexity of large-scale winds and superimposed synoptic changes is compounded by daytime sea breezes and upslope winds (Section 3.3.5), and night-time land breezes and downslope winds.

These wind patterns around the southern Red Sea have been described in some detail because they affect the complexities there of not only the seasonal swarm movements but also the rainy seasons, and hence breeding. These complexities are probably the greatest of the whole invasion area, and are discussed later in this Chapter.

From mid winter to mid summer there is a progressive change in the wind pattern over the Region: the ITCZ and following monsoon winds spread north in surges (sometimes with temporary retreats). Over Sudan, the ITCZ reaches about 10°N by March, and 20°N by July-August. In the east, however, the advance is slower, and more complex: the ITCZ reaches the south-western Arabian peninsula during May, by which month the winter north-easterly trade winds ahead of it along the south-east coast of the Arabian peninsula have reversed to south-westerly in response to rising temperatures and falling pressures over land. These south-westerlies obscure the passage of the ITCZ and onset of the monsoon along the south-east coast. From mid summer to mid winter there is a reverse and rather faster change in the wind pattern.

As a result of these changes, there are well-recognised seasonal variations of wind direction at each place within the Region. Likewise there are seasonal variations in rainfall. *North of the ITCZ,* the eastward-moving disturbances bring most of the rain associated with well-marked wave troughs and cyclones in the upper atmosphere (Section 4.11.2; see also Aelion 1958, Bugaev *et al* 1962, Habtemichael & Pedgley 1974, Jurcec 1970, Naguib 1970 and Tantawy 1964b), and falling in winter and spring (see, e.g., Fig. 4.5a, b and e), whereas the summer is largely rain-free. *South of the ITCZ,* by contrast, it is convection in the moist monsoon winds from the Atlantic and Indian Oceans, modified by westward-moving disturbances, that brings much of the rain to Sudan, Ethiopia and the southern Arabian peninsula, which therefore falls in summer (see, e.g., Fig. 4.5a to d). Nevertheless, some winter and spring disturbances of high latitudes do promote convective rains over and around the Red Sea, particularly the south (see, e.g., Fig. 4.5a and b), where the moist south-easterly winds from about October to May allow scattered showers to form along the seaward-facing escarpments and nearby plateaux on many days (and even over the coastal plains on a few days), but such rains are least likely in mid winter (compare Fig. 4.5e).

It follows from this brief account that annual rainfall amount, and duration of the rainy season, vary with latitude. The *winter-spring rains* of the north *weaken southward,* more or less disappearing south of about 30°N, but the spring rains (and to a lesser extent the early winter rains) over the highlands and coastal plains of Ethiopia and the south-western Arabian peninsula are almost continuous with the *summer rains,* which *strengthen southward,* starting at about 20°N. In the west, away from the highlands, these changes are illustrated by Table 6.2, which shows mean monthly rainfall at selected places along the Nile Valley. For comparison, Table 6.3 shows mean monthly rainfall at selected places along a line through the highlands from Aleppo (36°N) to San'a (15°N), and illustrates the several rainy seasons around the southern Red Sea. Over the deserts of Egypt and northern Sudan, rains between about 20° and 30°N are rare: average annual falls are almost nil, and there can be no measurable rain for several years at a time. Nevertheless, heavy rainstorms do occur from time to time during the winter and spring (see Sections 2.7.2 and 2.7.3). Such rains are less rare at the same latitudes over Arabia, for moist southerly winds form the Red Sea sometimes allow deep convective clouds and rainstorms to form on or ahead of cold fronts associated with eastward-moving disturbances (Section 3.3.6 and Figs. 4.5a and b; also Pedgley 1970, 1974b, and Zohdy 1969), particularly near the RSCZ. A further peculiarity of the weather of the southern Red Sea is the occasional spells of winter rain at the RSCZ, falling from sheets of cloud with tops at most little higher than the bordering highlands (Pedgley 1966), but sometimes accompanied by isolated cumulonimbus clouds (see, e.g. Fig. 4.5e).

Table 6.2 Monthly mean rainfall (mm) at selected places along the Nile valley (see Fig. 6.1 for places named).

	Latitude °N	Period of record	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Port Said	31	1941–60	11	12	9	2	4	0	0	0	T	2	9	18	66
Minya	28	1941–60	1	1	T	1	1	0	0	0	T	1	T	1	5
Aswan	24	1941–60	T	0	T	T	1	0	0	0	0	0	0	0	2
Abu Hamed	20	1931–60	0	0	0	0	1	0	5	10	1	0	0	0	17
Khartoum	15	1931–60	0	0	0	1	5	7	48	72	27	4	0	0	164
Malakal	10	1931–60	0	0	3	24	95	115	153	167	144	75	6	1	783

T = less than 0.5 mm
Taken from *Climatological normals,* WMO No. 117 TP 52.

Table 6.3 Monthly mean rainfall (mm) at selected places along a north-south line through the highlands from Syria to Yemen (see Fig. 6.1 for places named)

	Latitude °N	Period of record	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Aleppo	36	1951 – 60	63	46	36	35	14	4	T	2	T	18	27	74	319
Amman	32	1931 – 60	68	59	44	13	5	T	T	T	1	4	31	48	273
Al Qalibah	28	1966 – 71	7	3	5	7	4	0	0	0	0	5	19	3	53
Showaq	26	1966 – 71	12	1	5	15	7	0	1	0	0	0	18	8	67
Ise	25	1966 – 71	9	1	3	13	4	0	0	0	0	0	23	2	55
Foqair	23	1966 – 71	29	12	14	24	4	5	1	0	4	0	43	9	145
Taif	21	1966 – 71	18	14	27	51	36	12	9	9	22	19	44	5	266
Al Alayah	20	1966 – 71	56	40	35	67	57	9	12	12	11	6	44	21	370
Abha	18	1966 – 71	26	55	34	73	50	18	46	46	7	2	34	2	393
San'a	15	1938 – 47	2	3	27	42	33	4	66	89	13	3	9	5	296

T = less than 0.5 mm

Compiled from records published by the Hydrology Division of the Ministry of Agriculture and Water, Kingdom of Saudi Arabia, except Aleppo and Amman (which are taken from *Climatological normals*, WMO No. 117 TP 52) and San'a (which are taken from Toffolon 1960)

Day-to-day changes in the weather are a result of the movement and development of atmospheric disturbances (see Section 3.3.5). *North of the ITCZ,* the eastward-moving disturbances are of the same kind as those in the Eastern and Western Regions, shown on Fig. 3.17a, and described in Section 4.11 (see also Tucker & Pedgley 1977a). Several examples can be seen in the Case Study weather maps, including *cold fronts* moving east across the Middle East (Figs. C10.5b, C10.7b, C10.8b, C10.9b and C17.7b) and Arabia (Figs. C4.5b, C5.5b, C10.3b and C10.4b), and *anticyclones* between spells of southerly winds (Figs. C10.3b, C11.1b and C11.3b). During spring, DESERT DEPRESSIONS from the Western Region (Section 8.3) move eastward at about 30°N (for example, Figs. C10.6b, C11.3b and C11.4b; see also Pedgley 1972 and Tantawy 1964a). Others form near the northern end of the Red Sea and move eastward to the Gulf (Pedgley 1974b). Along the south-east coast of the Arabian Peninsula, dry northerly winds behind a cold front meet cooler, moister oceanic winds at a semi-permanent coastal front (R of Fig. 3.17a, and see Fig. C11.1b for an example) like the trade front of north-west Africa (Section 8.3). In spring the oceanic winds are south-westerly, as mentioned above; in winter they are north-easterly, but on days when winter continental northerlies are strong they blow out to sea and the coastal front disappears, especially at night, sometimes taking swarms from Arabia to the Somali Peninsula. *South of the ITCZ,* day-to-day changes in the winds are small, and most synoptic weather disturbances are weak. Even so, the intensity and distribution of rainstorms within the monsoon vary from day to day, apparently in response to changes in the position, size and strength of the subtropical anticyclones at heights between about 5 and 15 km above sea level. Sometimes the ITCZ moves near 25°N, bringing rare monsoon rains to southern parts of Libya and Egypt (Christophe 1966, Pedgley 1974a). Sometimes a weak monsoon cyclone or wave moves westward across the Arabian Sea, bringing rain to the south-eastern Arabian peninsula. One in July 1967 helped to bring about a plague upsurge (see Section 2.7.3 and Pedgley 1970b). More significant are the rare but powerful cyclones associated with the ITCZ over the Arabian Sea, which can bring heavy rains to south-eastern Arabia and the Gulf of Aden in the seasons May-June and October-November, also sometimes helping to bring about a plague upsurge (see Section 2.7.2 and Fig. 4.5f; see also Colon *et al* 1970, Desai 1967, Ebdon & Oxley 1975, Pedgley 1969, Vittal Sarma 1968). An extended wave trough can lead to rare monsoon rains over Iran (Ramaswamy 1965) like those over Pakistan and India (see Section 5.3).

A consequence of the seasonal change in wind pattern over the Region is a corresponding change in the dominant directions of swarm movement (see Section 6.4). *North of the ITCZ.* Mid-winter temperatures on average do not exceed 20°C north of about 27°N, even away from the highlands, so there may be little or no flight on many days because the weather is too cold. In winter, most flight takes place on the warmest days, which are often those with southerly winds. Overall displacement in *winter* is therefore mostly from between south-east and south-west (including crossings of the Red Sea from Sudan and Ethiopia to Arabia), even though dominant winds are from between north-west and north-east. Hence, the Region can be invaded from the three other Regions. During *spring,* daytime temperatures rise and on average exceed 20°C almost everywhere by April, so that swarm movements from then until summer are mostly from between north-west and north-east — towards the ITCZ and summer breeding grounds in the south of the Region as well as in the other three Regions. In the south, winter and spring movements are mostly westward, both in the interior of Arabia and along the coastal plains (and then northward over the Red Sea coastal plains to north-western Arabia), but winter north-easterlies from southern Arabia can take swarms to the Somali Peninsula above the low-level winds channelled along the Gulf of Aden rift. Even in the warmest months, however, day-time temperatures in the highlands of the south may still be too cold for much flight. By contrast, late spring and summer temperatures over lowland Arabia and the Middle East can exceed 45°C and be too high for daytime flight, with the result that young spring swarms fly by night (see Chapter 8, also Chapter 3). *South of the ITCZ,* movement is mostly from the west — from the south-west over the southern Arabian peninsula and Sudan (but from the south in southern Sudan on the one occasion when swarms came from Uganda and Kenya — see Section 6.10); and from the north-west over the Red Sea, taking swarms from Sudan and northern Ethiopia to eastern Ethiopia and the South-Central Region.

6.4 SEASONAL BREEDING AND MIGRATIONS: GENERAL COMMENTS

Breeding takes place in the Region in summer, in winter and in spring . The *summer* belt, where swarms breed on rains falling south of the ITCZ, runs through Sudan, Ethiopia and southern Arabia (see Fig.2.6a); whereas the *spring* belt, where breeding takes place on the rains brought by eastward-moving atmospheric disturbances, extends over the Middle East, over most of the Arabian Peninsula, and along both sides of Red Sea.

There is an overlap of areas with summer and spring breeding around the southern Red Sea and in southern Arabia, due to the overlap of rainfall regimes (Section 6.3). Both summer and spring breeding within the Region can lead to the production of large populations of swarms.

Winter breeding occurs mainly on the Red Sea coastal areas of Sudan, Ethiopia and Arabia, which are subject to occasional rains associated with eastward-moving disturbances. The belt in which winter breeding may occur extends from the south-western to the southern Arabian Peninsula (Fig. 2.6b), which occasionally receives winter rains associated with eastward-moving disturbances.

Because of the overlap of seasonal rainfall regimes (Section 6.3), the strictly seasonal occurrence of breeding (characteristic of, e.g., interior Sudan or interior Saudi Arabia and Middle East) breaks down in areas adjoining the southern Red Sea and Gulf of Aden. As will be seen below (Sections 6.5, 6.9, 6.13 and Fig. 6.2), breeding beginning in any one season in these areas may quite often continue into the next season, last for many months at a stretch, and lead to a rapid production of several successive generations.

Movements of swarms between seasonal breeding areas often involve long range migrations. Because the Region lies in the middle of the invasion area, and is bordered by other Regions to west, to east and to south, it is particularly liable, at all seasons, to be invaded by immigrant swarms from other Regions, and to send emigrant swarms to its neighbours.

6.5 SUMMER BREEDING (JULY TO OCTOBER)

Distribution. Summer breeding takes place in a belt which is continuous with the summer breeding belt of the Western Region (Section 8.5) and runs between latitudes 14°N and 21°N across Sudan and northern Ethiopia. The belt dips south in north-eastern Ethiopia, where it is continuous with the summer breeding areas of the South-Central Region (Section 7.5), and extends on the other side of the Red Sea through Yemen A.R. and the adjoining part of the Tihamah of Saudi Arabia, P.D.R. Yemen and southern Oman (see Fig. 2.6a). The total extend of the areas in which summer breeding may take place in the Region can be seen on the hopper band frequency maps for August and September. It will also be seen from these maps that the summer frequencies of hopper infestations in any one degree square are higher in Sudan and northern Ethiopia than anywhere else in the invasion area except Rajasthan. These frequencies decrease eastward through Yemen A.R. and P.D.R. Yemen and are apparently low in Oman — though the frequency of breeding there is likely to be under-reported.

Populations involved. These are the spring generation swarms produced within the spring breeding areas of the Region (Sections 6.13 and 6.14, and the example forecast in Section 11.5), supplemented by swarms of the Long Rains generation which may move in from the South-Central Region and, occasionally, by swarms moving in from the Western Region (see Section 6.15).

Times of breeding. Throughout the summer breeding belt, *hopper bands* of the summer generation may start appearing from late July or August and less frequently from September. In the interior of Sudan, northern Ethiopia, Republic of Djibouti, interior Yemen A.R., P.D.R. Yemen and Oman, *fledging* and formation of new swarms take place mainly in September or October, though in Sudan they may be most frequent in September, and continue sometimes till November. It may similarly continue till November, and possibly into December, in southern Oman (Fig. 6.2).

In coastal areas around the southern Red Sea, *hopper infestations* starting in late July or August may sometimes continue right into winter and even into spring, with *fledging* continuing till January in Sudan, till February on the Yemen Tihamah, and till April on the Saudi Tihamah (see Fig. 6.2).

6.6 MIGRATIONS OF SUMMER SWARMS, OCTOBER TO DECEMBER

Swarms appearing in the summer breeding belt of the North-Central Region begin to leave their source areas and migrate towards the winter or spring breeding areas, or both, from late September or October onwards (see Fig. 2.6a). It is usual for the summer breeding belt in Sudan and north-western Ethiopia to become clear by November.

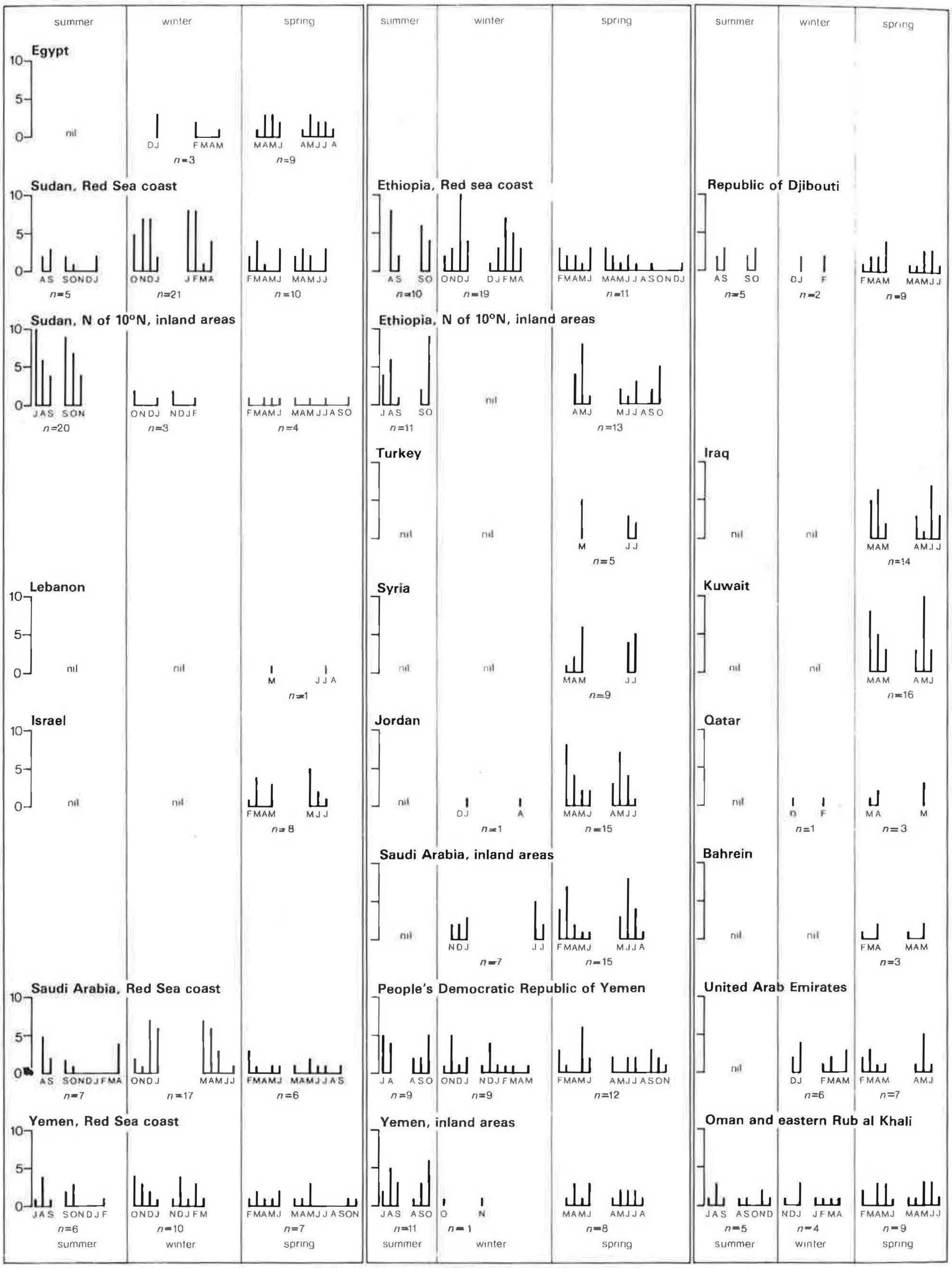


Fig. 6.2 Seasonal breeding in the North-Central Region: monthly frequencies of beginning and ending of hopper infestations. In each column, the monthly frequency of *hatching of first hopper bands* is shown on the left, and *fledging of last hopper bands* on the right. *n* is the number of years of records used.

From Sudan, swarms may migrate to Arabia by moving north and north-east and traversing Egypt and the northern Red Sea in late September-October (as in 1950, 1958 and 1968 — see Section 2.7.2, Summary 9 and Section 2.7.3). Other summer swarms from Sudan and Ethiopia may move first east to the Red Sea coastal areas (where they may in some years be joined by swarms moving north from the South-Central Region) and then in a northerly direction, or cross the sea to Arabia (as in October — November 1952 and 1958, see Summaries 3 and 9). For examples of weather systems in which swarms move north along the coast, or cross the sea, see Case Study 10.2.

During the same season, summer swarms produced in southern Arabia tend to move westward (Fig. 2.6a) to the countries bordering the western Gulf of Aden and southern Red Sea (as in October 1967, see Section 2.7.3). There they join the local summer swarms in moving northward into coastal and interior Saudi Arabia, and they mingle with swarms that had crossed the sea from Ethiopia and Sudan.

Red Sea coastal areas and inland areas of Saudi Arabia are invaded most frequently from October or November. Along the coast, swarms tend to displace in a northward direction, whereas in the interior of the Arabian Peninsula the movement may be to north-east, to north-west, or to north (see Fig. 2.6a), and lead to the invasion of southern Middle East countries in the last quarter of the year. Thus, Kuwait may be first reached from October, and Jordan, Israel and southern Iraq from November, with the first swarms appearing most frequently in November or December. These northward movements over the Arabian Peninsula and into Middle East countries take place on warm southerly winds associated with eastward-moving waves and cyclones (see Section 6.3). For further examples of such movements see Section 6.11. Between spells of warm southerly winds, winter temperatures in the inland areas of the Arabian Peninsula and in the Middle East may often be too low for flight, so swarms may become immobilised.

6.7 LATE SUMMER-WINTER INVASIONS FROM OTHER REGIONS, SEPTEMBER TO DECEMBER

During the season when summer swarms produced in the North-Central Region are moving to their winter or spring breeding areas, summer swarms from other Regions are similarly leaving their source areas, and frequently spread to the North-Central Region in the course of their migrations.

The most frequent invasions are probably from the *Eastern Region,* where monsoon swarms usually move out of the summer breeding areas between September and November and migrate in a general westward direction across Pakistan and southern Iran (see Sections 5.6, 5.8). Some may reach the Oman Peninsula as early as September (as in 1961, see Summary 5; and see also Case Study 5.2 for an example of weather systems in which such movements may occur), but invasions of Oman are more usual in October or November. In some years the immigrant swarms may spread right across southern Arabia, invading P.D.R. Yemen and Yemen A.R. — as in October and again in November 1952 (see Summary 3) or in November and December 1949 (see Section 2.7.2, and Fig. 2.13e); in both these years some of the swarms crossed the Gulf of Aden to the Somali Peninsula (see Sections 6.8 and 7.7).

In some years, monsoon swarms may also spread from south Iran to eastern and north-eastern Arabia — as in October 1950 (when monsoon swarms appeared in Oman and in Qatar — see Summary 1) and in October 1952 (when swarms spread from south-west Iran on to Hasa (in Saudi Arabia) and to Kuwait — see Summary 3).

Monsoon swarms spreading to south-western Arabia may join the local summer swarms (and summer swarms immigrating from Africa), and move northward with them to Saudi Arabia — as in November-December 1952 (see Summary 3).

Summer swarms immigrating from the *South-Central Region* usually move in across the Harar Plateau and through Danakil and the Red Sea coast of Eritrea. For example, swarms moving north through north-eastern Ethiopia in October 1952 and October 1954 included some summer swarms originating in the northern part of the South-Central Region (see Summary 3, and Rainey 1976). Such immigrants join the local summer swarms in moving north along the western coast of the Red Sea, or in crossing the sea to Arabia.

Finally, the region may on occasion be invaded by summer swarms from the *Western Region.* An example occurred in November 1954, when swarms originating in the western summer belt (and possibly including some which had originally migrated west from Sudan, see Section 8.8) moved north-east across Libya, and invaded Egypt, where they spread across the North-Western Desert and the Mediterranean coast (see Summary 17, and Case Study 17.6 for weather systems in which the movement took place; the subsequent history of these swarms is described in Summary 17).

6.8 WINTER EMIGRATIONS TO OTHER REGIONS, OCTOBER TO DECEMBER

While the North-Central Region may often be invaded by summer swarms from other Regions, many of the summer swarms originating within it may move out to breed beyond its borders (see Fig. 2.6a).

Thus, summer swarms produced in Sudan and Ethiopia may move south-east and invade the *South-Central Region,* as happened in October 1954, and in October and November 1958 (see Section 7.7 and Summaries 9 and 13). In addition, the South-Central Region may be invaded by monsoon swarms spreading first to Arabia from the

Eastern Region and later flying south across the Gulf of Aden — as in November 1952, and in November and December 1949 (see Section 7.7, Summary 3, and Section 2.7.2). Similarly, summer or early winter swarms produced in southern Arabia may move south across the Gulf of Aden — e.g. the movements in December 1967 of mature swarms originating in Oman (see Section 2.7.3).

Summer swarms moving first north-east across the Arabian Peninsula may later move eastward and invade the *Eastern Region* (Fig. 2.6a), as in December 1958, when they spread right across southern Iran (see Summary 9). Again, in December 1967, immature swarms of an early winter generation originating in Oman moved northward across the Persian Gulf to coastal areas of south-western and southern Iran (Section 2.7.3). See Section 5.7 for further details and references to Case Studies of examples of relevant weather systems.

Finally, summer swarms produced in Sudan may move out not only to the Red Sea coasts and Arabia or to the South-Central Region but also westward into the *Western Region* and spread right across it, breeding subsequently in western winter and spring breeding areas. Such movements have occurred in, e.g, October 1950, October 1954 and October 1968 (see section 2.7.2, Summary 17 and Section 2.7.3). See Section 8.8 for further details, and Sections 8.6 and 8.8 for references to Case Studies of examples of weather systems for westward movements.

6.9 WINTER (OCTOBER-JANUARY) AND EARLY SPRING (FEBRUARY-EARLY MARCH) BREEDING

Distribution. Many of the summer generation swarms on the move towards the spring breeding belt pass over areas where they encounter winter rains and can mature and breed. This often happens with winter rains (Section 6.3) on both shores of the Red Sea, and winter breeding there is frequent. Winter breeding may occur also in the Republic of Djibouti, in P.D.R. Yemen and United Arab Emirates, and occasionally in inland Saudi Arabia (see Fig. 2.6b). In all the above mentioned areas, winter breeding may merge, without a break, with the early spring breeding, and sometimes continue into spring (see Fig. 6.2). Occasionally, winter breeding occurs in the interior of Sudan (as, e.g., in the cultivations of the Atbara area in October and November 1967 — see Section 2.7.3), or in the interior of the Yemens, or in Oman, or in eastern Rub al Khali, where it may form a continuation of summer breeding into winter (see section 2.7.3), or begin in winter and continue into spring (as in the 1948-49 season, see Section 2.7.2).

The total extent of the areas in which swarms may breed in winter can be gauged from hopper band frequency maps for November to January, while the extent of early spring breeding areas can be seen on the map for February. it will also be seen from these maps that the highest winter frequencies of hopper infestations in any one degree square are to be found in the Red Sea coastal areas of Sudan, Ethiopia and Saudi Arabia, and that the frequency of infestations remains very high in these areas in early spring.

Populations involved. Swarms which breed in *winter* not only originate in the summer breeding areas of the *North-Central Region,* but also often include summer swarms immigrating from the *South-Central Region,* and monsoon swarms moving in from the *Eastern Region* (see Section 6.7 above).

Populations breeding in *early spring* consist of local summer and immigrant summer and monsoon swarms which continue laying or do not mature till early spring. In some cases they may include, or even consist entirely of, rapidly maturing earlier swarms of the winter generation (as on the western and eastern coasts of the Red Sea in the 1967-68 seasons, see Section 2.7.3).

Times of breeding. In interior Sudan and interior Yemen, where breeding in winter can be an extension of the summer breeding season, winter *hatching* begins from October, and *fledging* terminates from late November.

On the eastern and western shores of the Red Sea (except in Egypt) and in P.D.R. Yemen, winter *hatching* may start in any month between October and January, but most frequently in October or November on the Tihamah in Yemen A.R., in November in P.D.R. Yemen, in November or December in Sudan, in December in Ethiopia, and in December or January on the Tihamah of Saudi Arabia. In Egypt, no winter hatching has been recorded till January (see Fig. 6.2). In the interior of Saudi Arabia, winter hatching may occasionally start between November and January, and in the United Arab Emirates in December or January.

Fledging of the winter generation generally ends between December and February (most frequently in December or February on the Tihamah of Yemen A.R., and in January or February on the coasts of Sudan and Ethiopia — see Fig. 6.2). Fledging of the early spring generation usually comes to an end in March or the first half of April.

6.10 WINTER AND SPRING INVASIONS FROM OTHER REGIONS, JANUARY TO MAY

Invasions by swarms from the Eastern and the South-Central Regions, which may begin in early winter (see Section 6.7) may recur in mid and late winter and in spring — but by then the immigrants usually comprise swarms of the winter or early spring generations.

The most frequent invasions are apparently from the *South-Central Region.* Following the appearance of the Short Rains swarms on the Somali Peninsula, some of them may cross the Gulf of Aden to south-western Arabia (as in mid January 1952). More usually they move west or north-west to the Republic of Djibouti and the Harar Plateau, and from there spread northward through Danakil and coastal Eritrea, whence they may migrate across the Red Sea to Arabia (as in January and February 1952, see Summary 10). The weather systems with which such northward emigrations may be associated are illustrated in Case Studies 10.1 and 10.2. Other northward emigrations of Short Rains swarms to north-eastern Ethiopia occurred, for example, in February 1955 and 1962, March 1952 and 1962, April 1952, and May 1954 and 1955 (see Summaries 10, 11, 12, 14 and 15); the weather systems with which such northward moves may be associated in spring are illustrated in Case Study 11.1

Very rarely, when Short Rains swarms reach the most south-western and western parts of the South-Central Region, they may move north through Uganda as far as Bahr el Ghazal Province of Sudan, and possibly further north, as in April 1955 (see Summary 14 and Case Study 14.4).

Invasions of Arabia from the *Eastern Region,* such as occur in early winter when monsoon swarms are moving westward from their source areas and frequently reach Oman (see Section 6.7), may sometimes continue into late winter (as in 1949, see Section 2.7.2). Eastern Saudi Arabia may receive incursions until spring — as in April and May 1951, when monsoon swarms that had spread to south-western Iran went on to invade north-eastern Saudi Arabia as well as Kuwait and southern Iraq (see Summary 1). Again, in April 1962 some of the swarms moving north through western Iran spread into northern Iraq (Summary 5, Case Study 10.8).

6.11 MIGRATIONS OF SUMMER, WINTER AND EARLY SPRING SWARMS, JANUARY TO JUNE

During most of this period the movements of locally produced or immigrant swarms (the earlier migrations of which have been described in Sections 6.6, 6.7 and 6.10) are mainly in a general northward direction.

Any swarms that may be present in the western Red Sea coastal areas (i.e. the local summer and winter-early spring swarms, and the Short Rains swarms immigrating from the south — see Section 6.10) all tend to displace gradually to the north — for example, the spread of immigrant Short Rains swarms through north-eastern Ethiopia in January — February 1952, with swarms invading the southern half of the Sudan coast in March (Summary 10). Other examples of northward movements of swarms through north-eastern Ethiopia in February 1955 and February — March 1962 are described in Summaries 14 and 15. In some years, the northward movements may occur further north and lead to invasions of Egypt — as possibly in January 1955 (see Summary 17 and Case Study 17.7) or in April 1961 (see Case Study 10.6). The weather systems in which swarms may move north along the coast are illustrated in Case Studies 10.2 and 10.6.

Northward movements of swarms through north-eastern Ethiopia may continue in the later part of the spring season — as in April 1952 and in May 1954 and 1955, when they involved the (by then) mature swarms of the Short Rains generation (but see also Section 6.15). In all these years, swarms moved west in May, crossing the highlands in the Eritrean Province and spreading to central Sudan; in May 1954 they moved right across Sudan and in June reached Chad. On all these occasions the old Short Rains swarms were in the last stages of their life-cycle, and died off in the summer belt without breeding (see Summaries 10, 11 and 12). The weather systems in which swarms spread north to Eritrea and then west into Sudan in May 1954 are illustrated in Case Studies 11.1 and 11.2.

On the Arabian Peninsula, too, the locally produced or immigrant summer (and monsoon) swarms (see Sections 6.6, 6.7 and 6.10) tend to move in a general northward direction, both in the coastal and in the inland areas, continuing the general trend which was apparent from October to December. From about January they may be augmented by Short Rains swarms crossing the Red Sea or Gulf of Aden from the Somali Peninsula (see Section 6.10), and by winter swarms originating in Red Sea coastal areas (Section 6.9), and from about March by early spring swarms. For example, most of the Short Rains swarms that had moved north over north-east Ethiopia from the Somali Peninsula in January 1952 crossed the Red Sea to south-western Arabia, and in early February spread rapidly over the Arabian Peninsula, with some reaching southern Iraq and Israel (see Summary 10, and Case Studies 10.2 and 10.3). A very similar movement occurred in the 1957-58 season, when the summer swarms from Sudan and Ethiopia that had crossed the Red Sea to western Arabia in the last quarter of 1957 were followed in January 1958 by further waves of swarms crossing the sea to Arabia, consisting of winter swarms produced on the Red Sea coast of Sudan, and Short Rains swarms from the Somali Peninsula moving to Arabia across north-east Ethiopia. The combined populations of swarms had spread over central and northern Saudi Arabia by the end of January.

Again, whereas some of the winter-early spring swarms produced on the Tihamahs of Yemen and Saudi Arabia (see Section 6.9) may remain to breed there in the spring (as, e.g., in 1968; see Section 2.7.3), others may move north-east into central and northern Saūdi Arabia, increasing still further the populations which may be already present in those areas. For example, in the 1958-59 season, when winter and early spring breeding on the Tihamah of Saudi Arabia led to the formation of numerous new swarms, many of them migrated in March to the interior of the Arabian Peninsula. There they matured rapidly and became indistinguishable in the reports from the maturing and breeding earlier immigrants of the summer generation (see Summary 9). Similarly in 1968, following winter and early spring breeding on the Tihamahs, numerous groups and swarms spread in March from the coast to inland Saudi Arabia and bred there in the spring (see Section 2.7.3 and Fig. 2.15d).

The general northward tendency of displacements persisting through winter and spring results in a gradual spread of swarms into more northern parts of the Middle East (as well as repeated incursions into already invaded areas). Whereas the southern borders of the Middle East may be reached in the last quarter of the year (Section 6.6), the first invasions of southern Syria have not been recorded till January, and northern Syria and northern Iraq are usually not invaded till March, and Turkey until April or May. Examples of the spread of swarms over the Arabian Peninsula in winter and early spring, and of invasions of the Middle East from March to May in 1952, 1953 and 1959 are described in Summaries 3, 9 and 10.

Although the northward spread of swarms with southerly winds associated with the passage of depressions may sometimes be very rapid (Summary 10), it often takes place in a series of smaller steps, on successive spells of southerly winds. Examples are provided by the gradual advance over southern Iraq in February 1952 (see Case Studies 10.3 and 10.4), or over Syria in March 1961 (Case Studies 10.5 and 10.6), or through Jordan in March-April 1962 (Case Study 10.7) and over northern Iraq and into Turkey in April-May 1962 (Case Study 10.8). Movements of swarms may temporarily take a marked eastward or south-eastward bias, with swarms moving with westerly or north-westerly winds that follow the passage of a front (as from north-east Arabia and southern Iraq on to Hasa and south-west Iran in late February — early March 1952, Case Study 10.4). At other times swarms may swing to north-west or west on south-easterly or easterly winds blowing towards a depression approaching from the west — e.g., the north-westward move over northern Saudi Arabia towards Israel, early February 1952 (Case Study 10.3), or the westward spread of swarms in north Iraq, Syria and Turkey in May 1962 (Case Study 10.9).

In late spring, temperatures have risen so much that movement no longer takes place mostly on southerly winds, and *old* swarms present in the northern Arabian Peninsula and in the Middle East may move from there across north-east Africa towards the summer breeding belt of Sudan — as do the *young* swarms at this season (see Section 6.14). Examples are provided by movements of old Short Rains swarms from north-east Arabia to Egypt and Sudan in May 1952 (see Summary 10) or by the invasion of Egypt from the east in May 1959 (Summary 9).

As the swarms discussed in this Section spread over the Arabian Peninsula and Middle East they begin to mature and lay — in Saudi Arabia occasionally already in winter (Section 6.9), but in most areas usually from February or March. The last of these swarms die off by late May or in June, but in the more northern parts of the Region they may occasionally survive till July.

6.12 WINTER AND SPRING EMIGRATIONS TO OTHER REGIONS, JANUARY TO MAY

As at other times of the year, in winter and spring the Region is liable not only to be invaded from outside, but also to send swarms to other Regions.

Examples of southward movements in *winter* to the *South-Central Region,* by swarms originating in or migrating through the North-Central Region, are given in Sections 6.8 and 7.7. There are no clear cases of such movements later in the season, but it appears probable that they do occur; examples of such movements in *summer* are dealt with in Section 6.15.

On the other hand, there are a number of examples of movements of swarms migrating from or through the North-Central Region into the *Eastern Region.* For example, in late February — early March 1952 the Short Rains swarms from the Somali Peninsula that had migrated to north-eastern Arabia and Iraq moved south-east into Iran, spreading subsequently far over the eastern spring breeding areas (Summary 10, Case Study 10.4). A similar movement into south-west Iran by summer swarms invading northern Arabia and Iraq occurred in March 1959 (Summary 9). In April 1950, swarms of the early spring generation forming in Oman apparently moved north to Iran (Summary 7); whereas in March — April 1973, large populations of scattered locusts resulting from winter — early spring breeding on the Red Sea coast of Arabia apparently moved out eastward, reaching Afghanistan in April and Rajasthan in April — May (Section 2.6). See Section 5.10 for more details and subsequent histories of invading locusts.

6.13 MAIN SPRING BREEDING (MARCH TO JUNE OR JULY)

Distribution. As can be seen from Fig. 2.6c, main spring breeding may occur in the Red Sea coastal areas of Egypt, Sudan and Ethiopia, sometimes extending in the latter into inland areas of northern Eritrean Province and into the Danakil depression. To east of the Red Sea, it may occur in all the states on the Arabian Peninsula, and in all the Middle East countries of the Region including southern Turkey. The total extent of the areas in which this breeding may occur can be seen on the hopper band frequency maps from April to June. It will further be seen from these maps that the highest frequencies of hopper infestations in any one degree square during this season have occurred in inland Saudi Arabia and Kuwait, with frequencies falling off to the north in the Middle East countries, over the southern part of the Arabian Peninsula, and in the coastal areas of the Red Sea, where they decrease considerably in comparison with hopper infestation frequencies in winter and early spring (see Section 6.9).

Populations involved. These consist of swarms of the summer, winter and early spring generations originating in the North-Central Region, but they frequently include also the immigrant monsoon swarms from the Eastern Region, and swarms of the summer and the Short Rains generations invading the Region from the South-Central Region (see Sections 6.5 to 6.7, and 6.9 to 6.11).

Times of breeding. In the main spring breeding season over most of the North-Central Region, hatching may start in any month between late March and June, and fledging may terminate in any month between late April and June or July.

In the Red Sea coastal areas of Ethiopia and Yemen A.R., as well as in P.D.R. Yemen, such *main* spring breeding may sometimes follow the *early* spring breeding (Section 6.9) without a break. It may also continue, *without a break,* right through the *summer* and into *winter,* with fledging taking place till November or January (see Sections 6.3 and 6.9 and Fig. 6.2).

Similarly, in other areas in which breeding may occur in *early* spring, namely the coast of Sudan, Republic of Djibouti, the Red Sea coast and interior of Saudi Arabia, and the United Arab Emirates and Oman, spring *hatching* may either start in March or April, or form a continuation of hatching in the earlier part of the season. But in most of these areas *fledging* terminates between late April and June or July, though during the exceptionally protracted spring breeding in 1968 (see Section 2.7.3) the last of the hoppers in north-western Saudi Arabia did not fledge till early August. On the southern part of the Tihamah of Saudi Arabia, however, spring breeding may occasionally continue into summer, with fledging in September (see Fig. 6.2).

Turning now to areas where there is *no early spring breeding,* both the main spring and late spring or early summer breeding may occur on occasion in interior Sudan and interior Yemen, and more frequently in inland areas of northern Ethiopia (see Fig. 6.2). *Fledging* of late spring hoppers terminates in July or early August (see, for instance, the late spring breeding in northern Ethiopia in 1968, Section 2.7.3); but occasionally in Sudan, and more frequently in northern Ethiopia, breeding starting in spring may continue through summer with fledging ending in September or October (Fig. 6.2).

Finally, in the northern part of the Region, namely in Egypt and the Middle East countries to north of Saudi Arabia, the first *hatching* of spring hoppers may start in any month from March to May or June, and the last of the hoppers usually fledge in May to July. Very occasionally, in Egypt, the last of the hoppers fledge in August — as during the unusual breeding in 1948 in the Mediterranean coastal areas (see Section 2.7.2). In the most northerly part of the spring breeding belt, namely in southern Turkey, there has been no hatching before May, and hoppers fledged in June and July.

The *formation of young swarms* of the main spring generation usually becomes general in May and June over most of the spring breeding areas, which become free of swarms in June or July as they move out of their source areas.

6.14 MIGRATIONS OF SPRING SWARMS, MAY TO AUGUST

Spring swarms originating on the Arabian Peninsula and in the Middle East reach their summer breeding areas by moving out to south-west, south, south-east or east.

Many of the swarms migrate from the northern Arabian Peninsula *south-westward* to Sudan and northern Ethiopia, moving over the northern Red Sea and Egypt or directly across the central Red Sea (as in May 1954, see Summary 11; see also the example forecast in Section 11.5). In Sudan, the swarms spread west, and in 1954 some of them migrated far into the Western Region. Other examples of invasions of north-eastern Africa from the Arabian Peninsula with swarms spreading westward across Sudan and into the Western Region occurred in May — June 1950 (Section 2.7.2, and Fig. 2.13g), in May 1955 (see Summary 12) and in June 1968 (see Section 2.7.3, and Fig. 2.15e). The weather systems in which swarms crossed the Red Sea from Arabia in May 1954, and in May 1955 and June 1968 are illustrated in, respectively, Case Study 11.2, and in Steedman (1977), while the weather systems during their westward spread are illustrated in Case Studies 11.3 and 11.4.

South-westward movement may develop further south on the Arabian Peninsula as in May 1949, when swarms produced in interior Oman spread west and south-west to P.D.R. Yemen, Yemen A.R. and south-western Saudi Arabia (see Section 2.7.2).

At other times the movements of spring or late spring swarms originating in central and northern Arabia or on the western side of the Red Sea may be in a more *southward* direction and result in invasion of south-western Arabia and of the South-Central Region. For example, in May and June 1955 some of the swarms originating in Saudi Arabia moved south over the western part of the Arabian Peninsula and invaded Yemen A.R. and P.D.R. Yemen (see Summary 12). A similar southward movement occurred in 1968, when some of the late spring swarms forming in central and western Saudi Arabia moved south in July — August and invaded Yemen A.R. and P.D.R. Yemen (see Section 2.7.3, and Fig. 2.15f). Similarly, spring swarms may sometimes move south along the *western* side of the Red Sea — for example, the late spring swarms which formed in July — early August 1968 in northern Eritrea, and which moved in August south through coastal areas and Danakil to the Republic of Djibouti, Harar Plateau and Somalia (see Section 2.7.3, and Fig. 2.15f).

Spring swarms moving out *eastward* either originate on the eastern side of the Region or move to it in the course of their migrations. Thus, swarms produced in spring on the northern part of the Oman Peninsula usually move to the Eastern Region by flying out to the east or north-east across the sea. One of many examples of such movements occurred in 1949, when locusts produced in the spring of that year in the United Arab Emirates moved in scattered formations between May and July, to the monsoon breeding areas of Pakistan and India (see Section 2.7.2). The eastward movement may also start from central and north-eastern Saudi Arabia and from Iraq, as in late May and June 1954, and in June 1961, with the swarms migrating towards the monsoon breeding areas either across southern Iran, on the north-westerly winds predominating at that season in the Gulf area, or by first moving with north-westerly winds towards the ITCZ lying across the southern part of Arabian Peninsula, and then flying across the sea to Pakistan and India with south-westerly winds (see Summaries 6 and 8, and Case Study 6.1).

Another example of initial south-eastward movement towards south-eastern Arabia followed by a north-eastward flight across the sea is provided by migrations of some of the late spring swarms forming in central, western and north-western Saudi Arabia in late June — July 1968, which moved in July to southern and south-eastern Oman, and from there to south-eastern Iran, Pakistan and India (see Section 2.7.3 and Fig. 2.15f).

Swarms reaching the summer breeding belt of the North-Central Region may begin to mature and lay by the end of July, and are usually all mature and breeding there in August and September.

6.15 LATE SPRING AND SUMMER EMIGRATIONS TO OTHER REGIONS, MAY TO AUGUST

It will be clear from the preceding Section that spring swarms originating in the North-Central Region may spread beyond its boundaries to the west, to south and to east (see Fig. 2.4c).

Examples of the *westward* spread into and across the *Western Region* in the period May to July by spring swarms reaching north-eastern Africa from Arabia and the Middle East, with references to Summaries or Chapters describing the movements, and to Case Studies illustrating the relevant weather systems, are given in Sections 6.14 and 8.15. It must be added that these westward emigrations may include old Short Rains swarms and the young Long Rains swarms which may reach Sudan from the South-Central Region (see Sections 6.10 and 6.16). The old Short Rains swarms usually die off without breeding, but the young Arabian and Long Rains swarms moving over the western summer breeding belt mature and breed there on the summer rains.

An example of a *southward* movement though north-eastern Ethiopia by late spring swarms originating in northern Eritrea, and their spread into the northern *South-Central Region,* is referred to in Section 6.14. See also Section 7.15 for another example of summer immigration from the North-Central Region to the South-Central Region, and for reference to the seasons of their subsequent breeding in the latter.

Any *eastward* moves from or through the eastern part of the North-Central Region would result in emigration to the *Eastern Region.* Sections 6.14 and 5.15 deal with examples of such emigrations by spring swarms from Saudi Arabia and the Middle East across Iran, or from or through the Oman Peninsula, and they refer to Summaries in which these movements are described. Spring swarms from the North-Central Region which reach the monsoon breeding areas mature there and take part in the monsoon breeding.

6.16 LATE SPRING AND EARLY SUMMER INVASIONS FROM OTHER REGIONS, APRIL TO JUNE

Invasions of the Region during this season are mainly from the south. Reference has been made in Section 6.11 to movements during May 1954 and 1955 of old Short Rains swarms from the Somali Peninsula through north-east Ethiopia to northern Ethiopia and then westward to Sudan and into the Western Region. From April or May such northward movements may involve also the young Long Rains swarms appearing in the South-Central Region and moving over it in a general northward direction (Section 7.13). Examples of the northward emigrations of Long Rains swarms and invasions of north-eastern Ethiopia during spells of southerly winds (illustrated in Case Study 11.1) occurred in May 1950 (Section 2.7.2, and Fig. 2.13g), in May 1954 (Summary 11), May and June 1955 (Summary 12), and April — May 1968 (Section 2.7.3, and Fig. 2.15e). In 1954 and 1955, the Long Rains swarms crossed the Eritrean highlands to Sudan, where they mingled with spring swarms invading that country from Arabia, and spread with them west across Sudan and into the Western Region (see Case Study 11.3). In both years the swarms eventually bred in the Sudan and in the Western Region.

In other cases, most of the Long Rains invaders from the south may remain in northern Ethiopia and breed there during summer — or earlier, as in 1968, when they matured and bred there in May, giving rise to swarms of a late spring generation that fledged in July — early August, and re-invaded the South-Central Region (see Sections 2.7.3, and 6.14). See also Section 7.14 for references to migrations of Long Rains swarms across the Gulf of Aden to southern Arabia.

There are no clear cases during this season of invasions of the North-Central Region from the Eastern Region, but invasions from the Western Region may occasionally occur. An example of such an incursion into western Sudan in June 1951 is described in Section 8.16; the immigrants were most likely the swarms of the previous summer generation which had been on a Southern Circuit (see Section 8.9), but there was also a possibility that they were spring generation swarms from Libya.

7 THE SOUTH-CENTRAL REGION

7.1 POSITION OF THE REGION AND COUNTRIES INCLUDED

This Region occupies that part of the Desert Locust area which lies between latitude 10°N in Sudan and Ethiopia, and the Gulf of Aden in the north, and about 10°S in Tanzania in the south. It is bounded by the Indian Ocean in the east; on the west the limit follows the western boundary of Sudan, cuts across north-east Zaire, and runs through west and south Tanzania (see Fig. 2.4).

The countries or parts of countries included in the Region are listed in Table 7.1 in the order of frequency of annual occurrence of swarms in them. These frequencies are highest in the northern part of the Region and fall off to south and to west. In Ethiopia and in Somalia, swarms occur not only in plague years (which total 20 over the considered period), but also during recessions.

7.2 MAIN PHYSIOGRAPHIC FEATURES

These are (Fig. 7.1):

- the block of Ethiopian Highlands rising over extensive areas to above 2000 and 3000 m, and sending a tongue of higher ground through the Harar Plateau into the northern Somali Peninsula, where it descends by an escarpment to the narrow coastal plain;

Table 7.1 Number of years with recorded Desert Locust infestations in the South-Central Region during the 36 years from 1940 to 1975.

	Swarms	Hopper Bands
Somalia north of 8°N	26	25
Ethiopia north of 10°N and east of 40°E	24	20
Somalia south of 8°N	24	18
Ethiopia south of 10°N and west of 40°E	22	14
Kenya	19	16
Tanzania	12	8
Uganda	12	6
Sudan south of 10°N	8	2
North-east Zaire	3	0
Rwanda	1	0
Burundi	1	0

- the Lake Plateau of East Africa, rising to over 2000 and 3000 m in western Kenya, and to over respectively 4000 and 5000 m in the isolated volcanic peaks of Mt. Elgon and of Mt. Kenya and Kilimanjaro;
- a wide belt of eastern lowlands occupying most of the Somali Peninsula and extending into eastern Kenya and Tanzania;
- the plains of southern Sudan.

The Ethiopian Highlands and the Lake Plateau are separated by a broad corridor of land below 1000 m running across northern Kenya and joining the eastern lowlands and the Sudan plain, and are both traversed by the Great Rift Valley running south-west from the Red Sea to Lake Turkana, and southward to Lake Tanganika. The Rift Valley often serves as a channel along which swarms migrate towards the north and north-east. The highlands slow down the movements of swarms because over them air temperatures are lower, winds are more variable and cloudiness is often greater than over the lower ground. Swarms which reach them may remain trapped in them during the cooler seasons (see Sections 7.9 and 7.13).

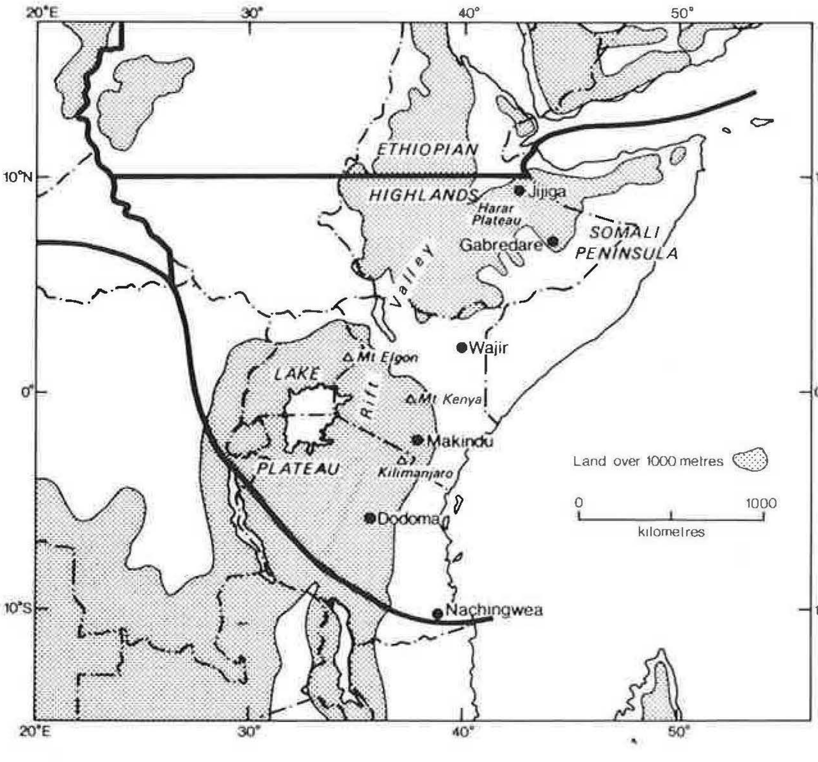


Fig. 7.1 Physiography of the South-Central Region. Mean rainfalls at places shown are listed in Table 7.2.

7.3 WEATHER AND CLIMATE

Weather, and hence locust movement and breeding, in the South-Central Region is dominated by the seasonal north-south movement of the Inter-Tropical Convergence Zone (ITCZ; see Section 3.3.5) from about 15°S in January to about 20°N in July. The extensive highlands also have a strong influence.

During the *northern winter,* winds blow from between north-east and east, coming from Arabia and the Indian Ocean (F of Fig. 3.17a; and see Fig. C13.5b). The western limit of these *trade winds* is the ARCZ, often ill-defined, on the western side of the Lake Plateau of East Africa (V of Fig. 3.17a) but sometimes moving east as far as 38°E over southern Kenya. On the leeward (south-western) side of the Ethiopian highlands, near Lake Turkana or over south-eastern Sudan (S of Fig. 3.17a), there is a convergence zone where two branches of the trade winds meet: south-easterlies from Kenya and northerlies from Sudan (see, e.g., Figs. C13.2b, C14.1b and C16.1b).

During the *northern summer,* winds blow from between south-east (in the south of the Region) and south-west (in the north), being part of the great sweep of south-west *monsoon* flow into southern Asia (see, e.g., Figs. C11.1b, C11.2b, C14.4b and C16.1b). Again the western limit of this flow is the ARCZ, on the western side of the Lake Plateau of East Africa (S of Table 3.2b and Fig. 3.17b) and continuing across south-eastern Sudan to the Ethiopian Highlands.

Between these two seasons, the ITCZ crosses the Region: northward about March-May (e.g., see Fig. C14.2b), and southward about October-November (e.g., see Figs. C13.1b and C13.4b). During this movement, the ITCZ may be poorly defined (e.g., see Figs. C13.2b and C14.3b). As a result of this movement of the ITCZ, there is a well-recognised seasonal reversal of wind direction at most places within the Region, leading to a seasonal reversal in the overall direction of swarm migration: southward in the northern winter (Section 7.6) and northward in the northern summer (Sections 7.9 and 7.12). Added to these seasonal wind changes are distortions due to mountain barriers. Much of the apparent disorder shown on the mountainous parts of weather maps can be put down to such distortions, confounded at times by the spreading downdraughts from rainstorms. Along coasts, sea breezes are common, and are easily seen on most days around Lake Victoria.

Movement of the ITCZ also affects the seasonal incidence of rainfall. There are two rainy seasons, well separated over most of the Region but almost joined in the south and in the north at opposite times of the year. Table 7.2 illustrates this distribution by showing mean monthly rainfall along a line from eastern Ethiopia to south-eastern Tanzania. The northward-moving ITCZ is associated with the LONG RAINS (see, e.g., Fig. 4.5a and b), and the southward with the SHORT RAINS (see, e.g., Fig. 4.5d), the length of the rainy season reflecting the slightly slower movement northward (the same as in the Western Region). It follows that the Long Rains fall earlier in the south than in the north (March-May in Kenya, April-June in northern Somalia); but the reverse is true for the Short Rains (September-October in northern Somalia, November-December in Kenya). These seasonal rains lead to two main breeding seasons over most of the South-Central Region (Sections 7.8 and 7.11). During the northern summer, the lee convergence zone in the south-east trade winds to the north-west of the Kenya Highlands (T of Table 3.2b and Fig. 3.17b) leads to rains there that more or less join the Long and Short Rains into one long rainy season and result in summer breeding. In the north of the Region, over and near the Harar Plateau, the single summer rainy season also leads to breeding. In western Uganda, Rwanda and Burundi (near the persistent ARCZ), rains fall for most of the year but breeding has never been recorded there. Rain also falls most of the year in south-east Sudan and south-west Ethiopia, where breeding has taken place.

Table 7.2 Monthly mean rainfall (mm) at selected places along a north-south line from eastern Ethiopia to south-eastern Tanzania (see Fig. 7.1 for places named).

	Latitude	Period of record	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Jijiga	9°N	1952 – 67	9	11	35	86	72	62	71	123	77	59	19	9	624
Gabredare	7°N	1957 – 67	1	0	29	86	53	T	1	T	6	130	41	7	354
Wajir	2°N	1917 – 70	6	5	32	75	34	2	3	2	6	24	67	23	279
Makindu	2°S	1904 – 70	40	31	81	113	29	2	1	1	2	28	174	119	621
Dodoma	6°S	1911 – 70	143	114	120	51	5	1	0	0	1	4	20	107	566
Nachingwea	10°S	1951 – 70	216	211	261	157	21	3	1	T	8	14	53	206	1151

T = less than 0.5 mm

Records for Ethiopia taken from *Summaries of rainfall* 1969, Ethiopia, National Climatological Service

Records for Kenya and Tanzania from *Climatological statistics for East Africa,* East African Meterological Department 1975.

Day-to-day changes in winds are small because most synoptic weather disturbances are weak. Even so, the intensity and distribution of rainstorms within the ITCZ can vary greatly from day to day, apparently in response to changes in the position, size and strength of the sub-tropical anticyclones (Section 3.3.5) on both sides of the equator at heights between about 5 and 15km above sea level (Johnson & Mörth 1963, Johnson 1962, 1964, Mörth 1964, Sissons 1966). Sometimes the equatorial end of an extended middle-latitude trough (Section 3.3.5) reaches the Region, and surface winds in the winter hemisphere turn to *south-east* (north of the equator; e.g., see Fig.

C14.1b) or *north-east* (south of the equator) for up to a few days, often with widespread rains. There may be an accompanying eastward movement of the ARCZ into Kenya (Johnson & Mörth 1963, Nakamura 1967, 1968). Only rarely does a tropical cyclone with widespread heavy rain and strong winds enter the Region from the Indian Ocean, usually March-May and October-November north of about 5°N; and November-April south of about 5°S (for an example in April 1966, see Neave 1967).

Along the mountain escarpment of northern Somalia, daytime northerly upslope winds meet the monsoon south-west winds ('kharif') from the plateau along a convergence zone that forms almost daily from about May to October. Figs. C11.1b, C11.2b and C14.4b illustrate days with such winds. Afternoon showers form in the convergence zone, and airborne swarms become trapped there. During the morning, monsoon winds over the plateau are often strong, and swarms stay settled. As the winds blow down the escarpment they strengthen further and lead to very windy weather over the coastal plain. By late morning, however, the monsoon weakens (most likely through convective mixing with lighter winds aloft; see Section 3.3.6), and swarms start to fly. The escarpment convergence zone, enhanced by spreading downdraughts from the showers, moves south, taking trapped swarms with it. In this way, the daily alternation of south-west and north winds can carry swarms in a zig-zag track eastward across northern Somalia (Sayer 1962). Swarms do sometimes reach the coast, however (joining with others that have come from the North-Central Region), and even cross the Gulf of Aden (see Section 7.13), although daily onset of the north-westerly sea breeze can lead to a zig-zag track along the coast (Rainey and Waloff 1948).

7.4 SEASONAL BREEDING AND MIGRATIONS: GENERAL COMMENTS

Summer, winter and spring breeding all occur within the Region. Summer breeding is comparatively restricted and local, because many of the western sections of the Region receiving summer rains are unsuitable for breeding due to their altitude or excessive rain, or both. The following accounts of seasonal breeding and movements in the South-Central Region start with summer breeding, to make the order of their discussion consistent with that adopted in Chapters 5, 6 and 8, and in Chapter 11.

The winter and spring breeding takes place on, respectively, the Short Rains and the Long Rains, and the breeding seasons and resultant swarms are designated by these names. In both seasons the breeding is often heavy and widespread, and the belts over which it takes place largely coincide (compare Figs. 2.6b and c). This coincidence in the positions of major breeding belts contrasts with the wide separation of, e.g., the summer and spring breeding belts in the North-Central and Western Regions (see Chapters 6 and 8). It results from the reversals in the predominant directions of movement in both Short Rains and Long Rains generations of swarms, consequent on the seasonal reversals of wind direction associated with the latitudinal displacement of the ITCZ, and the coincidence of the areas receiving the seasonal rains.

7.5 SUMMER BREEDING (JULY TO OCTOBER)

Distribution. As Fig. 2.6a shows, summer breeding areas are found in the northern part of the Region (northern Ethiopian Rift, Harar Plateau, Railway Area and western Somali Republic (North)), with these areas forming a continuation of a more extensive complex of summer breeding areas running through north-eastern and northern Ethiopia. Further south, summer breeding may occur locally in central and southern parts of the Ethiopian Rift, in south-west Ethiopia, on lowland areas around Lake Turkana in north-western Kenya, and occasionally in adjoining parts of north-east Uganda and south-east Sudan. The full extent of areas in which hopper bands have been recorded during summer since 1940 can be seen on hopper band frequency maps for August and September. These maps also show that the frequencies of hopper infestations in any one degree square have been high in the north, low in north-west Kenya, and lower still in other parts of the Region.

Populations involved. The swarms involved in summer breeding are those members of the Long Rains generation originating in the Region (Section 7.12) which are able to mature and lay during the first stage of their migrations. These swarms may be supplemented by immigrant spring swarms arriving from Arabia or northern Ethiopia (see Section 7.15, and the example forecast in Section 11.5).

Times of breeding. Maturation and laying take place mainly in July and August. As can be seen from Fig. 7.2, *hoppers* of the summer generation occur from August to September or October (though early hatchings may start in July) and *fledge* in September and October. The movements of resulting summer swarms are described below, together with the movements of Long Rains swarms alongside of which they migrate.

7.6 MIGRATIONS OF LONG RAINS AND SUMMER SWARMS, OCTOBER TO JANUARY)

In late September or in October, Long Rains swarms which had remained concentrated and without breeding since July in northern Somalia (see Section 7.13), and the new swarms of the summer generation forming in the northern part of the Region (Section 7.5), begin to spread south and south-west over the Somali Peninsula and East Africa, usually reaching north-eastern Kenya in late October or early November, and northern Tanzania in

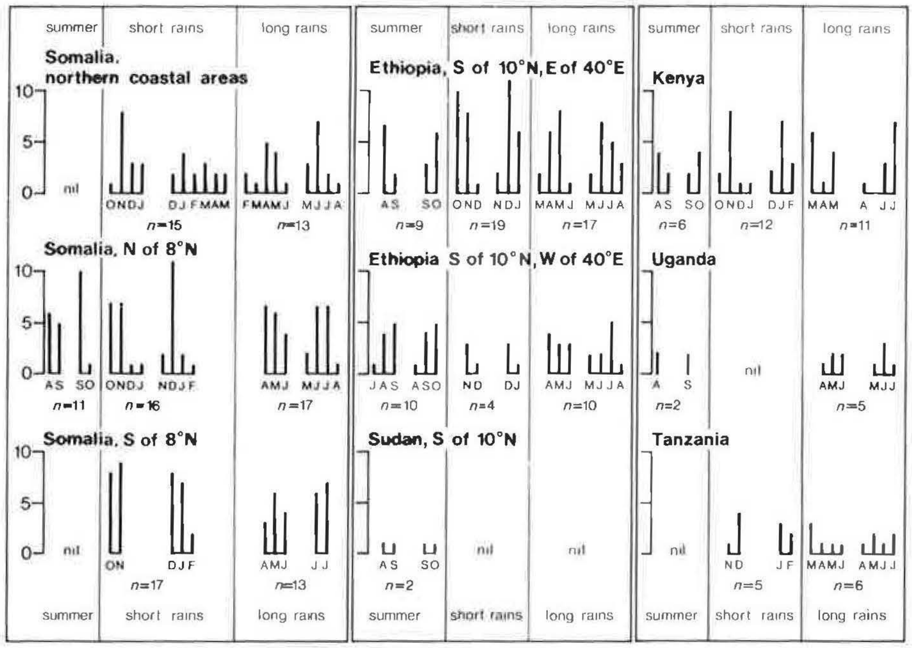


Fig. 7.2 Seasonal breeding in the South-Central Region: monthly frequencies of beginning and ending of hopper infestations. In each column, the monthly frequency of *hatching of first hopper bands* is shown on the left, and *fledging of last hopper bands* on the right. *n* is the number of years of records used.

November. As shown by Rainey (1951), the movement takes place with surface north-east winds (to the north of the southward-moving ITCZ); it coincides with the season of Short Rains, and swarms mature and breed in the course of their southward spread (see Section 7.8 and Table 7.2).

An example of the southward movement of Long Rains and summer swarms across the Somali Peninsula and East Africa in October-November 1954 is described in Summary 13, and the weather at the time is illustrated in Case Studies 13.3 to 13.5. In 1954, the swarms spread exceptionally far to the south in Tanzania, reaching 8°S in December. They were laying from October in Ogaden and the Somali Republic (South), from November in Kenya, and from December in Tanzania, where some layings continued into January (see Summary 14), by which time most of the old swarms on the Somali Peninsula and in Kenya had died off.

In the same season when East Africa may be invaded from the north, any Long Rains swarms remaining throughout summer in the Kenya Highlands (see Section 7.13), or new summer swarms produced in north-west Kenya (see Section 7.5), or both, move out to west or south. Examples of movements in November 1954 from north-west Kenya westward into Uganda, and southward and westward to Tanzania and Burundi in October, and then westward into north Uganda, south Sudan and north-east Zaire, are described in Summary 13, and weather systems are illustrated in Case Studies 13.1 and 13.2. In general, swarms emigrating westward from Kenya and Tanzania disappear without issue, perhaps from attacks by pathogens and birds.

7.7 WINTER INVASIONS FROM OTHER REGIONS, OCTOBER TO JANUARY

During the winter, when northerly winds are blowing, the Region is liable to be invaded from countries on the west side of the Red Sea, from Arabia, and from India and Pakistan. For example, young summer swarms moving on to the Somali Peninsula from the north-west in October 1954 and October-November 1958 (see Summaries 13 and 9) included swarms originating in north-eastern Ethiopia and possibly Sudan. Such invasions from the north-west are quite usual at this season, with immigrant swarms moving south, along with those already present on the Peninsula, and maturing and breeding during the Short Rains. Some examples of movements of Arabian swarms from southern Arabia on to the northern shores of Somalia in October and December 1945 are described, with weather systems at the time, by Rainey & Waloff (1948). In December 1967 there was an important invasion of the north Somali coast from Oman by groups and swarms of mature locusts that had crossed the Gulf of Aden on strong north-easterly winds (see Section 2.7.3).

Monsoon swarms from India and Pakistan in some years reach the Somali Peninsula via Oman and southern Arabia. Such invasions occurred, e.g., in November-December 1949 (see Section 2.7.2, Fig. 2.13g), and in November 1952 (see Summary 3). On the latter occasion, monsoon swarms reached also the island of Socotra (for details, and weather at the time, see Popov 1959).

The immigrants in late 1949 and in late 1967 became involved in prolonged breeding in the coastal areas, starting on the Short Rains, both cases leading to appearance of plague swarms. In 1952, however, the invading swarms did not breed on the Somali Peninsula until the onset of the Long Rains there in March 1953 (see Summary 3).

7.8 SHORT RAINS BREEDING (OCTOBER TO JANUARY)

Distribution. As can be seen from Fig. 2.7b, breeding may occur in this season over an area extending from the northern coast of Somalia across the Somali Peninsula and northern and eastern Kenya into Tanzania; the full extent of the areas in which it has been recorded since 1940 can be gauged from the hopper band frequency maps for November to January. The actual extent of breeding varies from year to year, and the frequency of its occurrence in any one degree-square is highest in Somalia and south-eastern Ethiopia, decreasing southward through Kenya and Tanzania.

Populations involved. Swarms breeding on the Short Rains comprise Long Rains swarms surviving since the preceeding spring (see Section 7.13), sometimes augmented by spring-early summer immigrants from the North-Central Region, and summer swarms originating in the Region or invading it from the North-Central and Eastern Regions (see Sections 7.15 and 7.7).

Times of breeding. While swarms, and the rains on which they breed, spread over the Region from north to south, the laying, hatching and fledging start progressively later further south. Fig. 7.2 shows that *hopper bands* are about as likely to appear from October as from November on the Somali Peninsula, but in Kenya they appear more usually from November, and in Tanzania from December. The *fledging* and formation of new swarms take place mainly in December and January (though in the Somali Republic (North) and Ogaden it may start in late November), and in most countries sometimes continue till February.

On the northern coastal areas of Somalia, where Short and Long Rains may merge (Sections 7.3 and 7.12), the breeding which starts between October and January sometimes continues without a break and through more than one generation, with fledging until April and May (compare Fig. 7.2; and see, e.g., Sections 2.7.2 and 2.7.3).

7.9 MIGRATIONS OF SHORT RAINS SWARMS

December to February: the initial spread

When young Short Rains swarms are making their appearance between late November and January or February, the ITCZ is near or at its most southerly position and the predominant winds over the Somali Peninsula and East Africa blow from the north-east or east. As a result, the directions of movement of young swarms are mainly between west and south-west, with many swarms from Somalia and south-east Ethiopia spreading into Kenya and sometimes northern Tanzania (see Summaries 14 and 15 for descriptions of such south-westward movements in January-February 1955 and December 1961 – February 1962; and see Case Study 14.1 for an example of associated weather systems).

In addition to the predominant south-westward trend, swarms may be deviated to west or north-west by temporary easterly or south-easterly winds. The westward direction may predominate over the northern Somali Peninsula, where swarms sometimes move out on to the Harar Plateau, from where they may emigrate to the north (see Summaries 10 and 15 for examples of such movements in January 1952 and January-February 1962, and Case Study 10.1 for an example of associated weather systems). The west to north-west movements may develop also elsewhere in the Region: see Summary 14 for an example of the fanning out of young swarms to north-west and to south-west from the southern Somali Peninsula in January 1955, and Case Study 14.1 for the associated weather system; Summary 10 for a description of the west to north-west deviation of young swarms reaching north-east Kenya in January and February 1952, and their subsequent move northward and north-westward into the Ethiopian Highlands and along the Ethiopian Rift; Summaries 14 and 15 for examples of westward deviations from eastern Kenya into Uganda and to the Kenya Highlands in February 1955 and 1962; and summary 14 for a description of the spread of swarms invading northern Tanzania westward into the Lake and Western Provinces in March 1955.

March to June: return to Long Rains breeding areas.

In February or March, the south-westward movement of swarms becomes reversed, and a northward trend gradually becomes general over the Region with the northward advance of the ITCZ. The northward trend becomes apparent first in Tanzania in February-March, when the swarms begin to move into Kenya (as, e.g., in February-March 1962, see Summary 15), and spreads through Kenya, south Ethiopia and the Somali Peninsula from about March to April, with the swarms moving over these areas towards the Harar Plateau and the Somali Republic (North). (See summaries 10 and 15 for examples of northward movement along the Ethiopian Rift in March 1952 and 1962, and Summary 14 for a description of the northward movement across Kenya and the Somali Peninsula in April 1955, with an example of associated weather systems illustrated in Case Study 14.2). A comparatively slow northward movement of a maturing Short Rains swarm through the western Kenya Highlands in April-May 1945 (with the swarm finally reaching the Turkana lowlands, where it bred on the Long Rains) is illustrated by Gunn, Perry *et al.* (1948).

In April-May, the movements of swarms that have reached the more northerly parts of the Region acquire an eastward bias, in association with the development of south-west monsoon winds over the Somali Peninsula, and the daily development of the escarpment convergence zone. The eastward spread over the Somali Peninsula in April-May 1952, May 1955 and April-May 1961 are described in Summaries 10 and 14, and by Betts (1976).

The period March-June, when Short Rains swarms move north and then east, is also the season of the Long Rains, when swarms can mature and breed. Most of the movements described in the preceeding paragraphs are performed by swarms that are maturing, or that have matured and are laying over the traversed areas. The final spread of old Short Rains swarms usually reaches its limit in May-June, with the last of the swarms dying off in June.

Reference must be made to occasional *north-westward* movements which may develop over western Tanzania and Kenya during the northward emigration of Short Rains swarms. Thus, in April 1955 (a year when swarms spread far to west in Tanzania) there was a movement through Rwanda, west Uganda and north-east Zaire (see Summary 14 and Case Study 14.3). In the same month other swarms moved from north-west Kenya to south-west Ethiopia and south-east Sudan. Then in the following month there was an unusual appearance of some swarms between 7° and 10°N in the Bahr el Ghazal Province of Sudan, suggesting that the north-westward movement out of East Africa extended well into Sudan (see Summaries 12 and 14, and Case Study 14.4).

7.10 WINTER AND EARLY SPRING EMIGRATIONS TO OTHER REGIONS, OCTOBER TO MARCH

While summer swarms produced in the northern part of the Region (see Fig. 2.6a) may often be augmented by immigrants from outside (see Section 7.7), they themselves may sometimes move out northward from the Region with the southerly winds which often blow over the southern Red Sea basin between October and May, and join the summer swarms produced in the adjoining part of north-eastern Ethiopia in their movements towards the winter and spring breeding areas. Thus, summer swarms moving northward along the western coasts of the Red Sea in north-east Ethiopia in October 1952 (see Summary 3) probably comprised swarms from the South-Central Region.

Similarly, Short Rains swarms reaching the western Somali Republic (North) and Harar Plateau or the northern part of the Ethiopian Rift in the course of their migrations, may emigrate out of the Region in a northerly direction. For example, immature Short Rains swarms from the Somali Peninsula moved into north-eastern Ethiopia in January, February, and March 1952, February 1955, and February-March 1962 (see Summaries 10, 14 and 15; and Case Study 10.2 for weather systems during the northward move in January 1952). For subsequent histories of the emigrating swarms, see Sections 6.10, 6.11 and 5.10.

7.11 SPRING INVASIONS FROM OTHER REGIONS, FEBRUARY TO MAY

Examples of invasions of the South-Central Region in winter and summer seasons are discussed in Sections 7.7 and 7.15. There are no clear examples of immigrations in the spring season, however, when invasions from north-east Ethiopia or Arabia probably continue to occur.

7.12 LONG RAINS BREEDING (MARCH TO JUNE OR JULY)

Distribution. Long Rains breeding may occur over an area extending from northern Tanzania to the northern coast of the Somali Peninsula. This area largely coincides with the Short Rains breeding area, though it extends further west than the latter in Kenya and Ethiopia (compare Figs. 2.6b and c). The full extent of the areas over which it may occur can be gauged from the hopper band frequency maps for May and June.

The actual extent of Long Rains breeding varies from year to year — according to the spread of laying swarms. The frequency of its occurrence is highest in western Somali Republic (North), and the Harar Plateau and Railway Area in Ethiopia, and diminishes southward through Ogaden, Somali Republic (South), Kenya and Tanzania.

Populations involved. These are mainly the Short Rains swarms originating in the Region but sometimes supplemented by immigrant swarms from the north or north-east (as, e.g., in the winter of 1952 from the Eastern Region — see Summary 3).

Times of breeding. The Long Rains start earliest in Tanzania and southern Kenya and spread gradually northward with the advance of the ITCZ (see Table 7.2). Similarly, maturation and laying by Short Rains swarms (with the exception of those on the northern coast of Somalia) tend to begin earliest in Tanzania and Kenya, and progressively later as one moves northward.

As can be seen from Fig. 7.2, in Tanzania and Kenya *hatching* begins most frequently in March, but may not begin till May or June; in Uganda, south-west Ethiopia and Somalia it may begin between April and June; and in south-east Ethiopia between March and June, but most frequently in April or May.

In Tanzania and Kenya, *fledging* and formation of new swarms may begin and end in April, but may continue till July; further north it may end between May and July or August. Most frequently the last of new swarms are formed in June or July.

On the northern coast of Somalia, spring *hatching* may begin in any month between February and June, and formation of *new swarms* may end in any month between May and August, but most frequently in May or June.

7.13 MIGRATIONS OF LONG RAINS SWARMS, MAY TO SEPTEMBER

At the time of the appearance of Long Rains swarms between late April-May and June-July, south-east to south-west winds predominate over most of their source areas (Section 7.3), and the new swarms move in a general northward direction towards the northern part of the Region, where some may emigrate further north.

Consequent on this northward trend, most of the eastern lowlands of East Africa and the Somali Peninsula become clear of swarms by July-August. But the movements of swarms are slower on the higher ground in Kenya and Ethiopia because of the variable winds and the cool and cloudy weather which prevails there in summer (see Gunn, Perry *et al.* (1948) for an example of a slow displacement of a swarm in the Kenya Highlands in September 1945), and this may result in the separation of the area invaded by swarms into two sections: west and north-west Kenya and adjoining areas; and the northern part of the Region, extending from the northern part of the Ethiopian Rift through the Harar Plateau and the Railway Area to the Somali Republic (North). An example of the northward movement of Long Rains swarms over the Region in June-July 1954, and their separation into two such distinct areas in July-August, is described in Summary 16.

From July to August, those Long Rains swarms which are able to mature and lay become involved in summer breeding, which usually occurs on the lowlands of north-western Kenya, and the Railway Area of Ethiopia and adjoining areas (see Section 7.5). But the majority of Long Rains swarms usually becomes accumulated in the Somali Republic (North) at the narrow semi-permanent convergence zone between northerly and strong south-westerly winds, which in the 'kharif' season (June to September) lies across the northern Somali Peninsula. The movements of swarms at this convergence zone, where they provide particularly suitable targets for aerial control, have been described by Sayer (1962). Most of these swarms remain sexually immature until the end of the 'kharif', in late September-October, and the onset of Short Rains and of southward movement (see Section 7.6).

7.14 SPRING AND SUMMER EMIGRATIONS TO OTHER REGIONS, APRIL TO SEPTEMBER

The Long Rains swarms forming in, or reaching, the northern part of the Region adjoining the western Gulf of Aden or southern Red Sea may emigrate to north-east or to north-west. The south-west monsoon winds over the western part of the Gulf of Aden may favour swarm movement from the Somali Peninsula across the Gulf to south-western Arabia between June and September; examples of such movements in June 1946 and August 1943 are described by Rainey & Waloff (1948).

Movements earlier in the year to the north-west, through north-eastern Ethiopia towards the summer breeding areas of Ethiopia and Sudan, take place on spells of south-east winds over the southern Red Sea like that described in Case Study 11.1. Such movements by young Long Rains swarms occurred, e.g., in April-May 1950 (see Section 2.7.2 and Fig. 2.3g), April-May 1968 (Section 2.7.3 and Fig. 2.15e) and May and June 1955 (see Summaries 12 and 15). Sometimes the northward emigrations from the Somali Peninsula towards the summer breeding belt of the North-Central Region involve old mature Short Rains swarms which had already bred in the South-Central Region, as, e.g., in May 1954 and May 1955 (see Summaries 11, 12 and 14, and Case Study 11.1). For subsequent histories of the emigrating swarms, see Sections 6.11, 6.16 and 8.15.

7.15 SUMMER INVASIONS FROM OTHER REGIONS, JUNE TO SEPTEMBER

Although a proportion of Long Rains swarms may emigrate northward *into* the North-Central Region, the Long Rains populations may, in turn, be augmented during the summer months by immigration of spring or early summer swarms *from* the North-Central Region.

As distinct from local Long Rains swarms which, during the 'kharif', may be blown off the north Somali coast by the strong morning south-westerlies and brought back by the onshore afternoon sea breeze (Rainey & Waloff 1948), Arabian swarms may reach the Somali coast from southern Arabia on the northerly winds blowing above the monsoon (Section 3.3.4); the possibility of such an immigration in July 1945 is discussed by Rainey & Waloff (1948). Or again, the Harar Plateau and Somali Republic (North) may be invaded by spring or early summer swarms moving in from northern Ethiopia with the usual north-westerly winds blowing over the southern Red Sea basin from June to September, as they did, e.g., in August 1968 (see Section 2.7.2 and Fig. 2.15f).

All such immigrants mingle with the Long Rains swarms, and either breed during summer or join the concentration of swarms on the northern Somali Peninsula (Section 7.13) and later move south and breed with them during the Short Rains season (Sections 7.6 and 7.8).

8 THE WESTERN REGION

8.1 POSITION OF THE REGION AND COUNTRIES INCLUDED

This Region occupies northern and western Africa, to the west of the western boundaries of Egypt and Sudan (Fig. 2.4). Its western and northern boundaries run along the Atlantic and Mediterranean shores, though occasionally swarms fly out to the Atlantic and Iberian Peninsula (see Section 2.4, Table 8.1 and Section 8.6). Its southern boundary runs through the countries bordering the Gulf of Guinea.

The countries of the Region are listed in Table 8.1 in order of the annual frequency of occurrence of swarms in them during the period 1940–75. It will be seen that swarms and hopper bands have occurred most frequently in north-western and central parts of the Region, where swarms have been recorded both during plague years (totalling 19 in the considered period), and during recessions. The frequencies decrease sharply to the south of the Sahel. Hopper infestations have probably been considerably under-reported in Western Sahara, where they were likely to have been as frequent as in Mauritania, and the records are undoubtedly also incomplete for Libya and Chad. The absence of hopper band records in Gambia, most Gulf of Guinea States and the Iberian Peninsula, is probably due to the real absence of breeding.

8.2 MAIN PHYSIOGRAPHIC FEATURES

Apart from the western and northern coastal plains, most of the Region is occupied by extensive low plateaux, with an average altitude of 200–500 m (Fig. 8.1). In the Algerian Sahara, large parts of the plateaux are covered by sand dunes of the Great Western and Great Eastern Ergs. Rising above this general level are the central Saharan Highlands, reaching to over 1,500 m in Ahaggar, Mouydir and Tassili n'Ajjer, and extending in the south to the Adrar des Iforas and the Aïr uplands. In the east, the highlands extend into Chad and rise to over 1,000 m in Ennedi and 1,500 m in Tibesti.

In the north-west of the Region, the plateaux are bordered by the folded ranges of the Atlas Mountains, running from Morocco through northern Algeria to Tunisia, while in its southern part the ground rises to over 1,000 m in the Futa Jallon highlands in Guinea, the Bauchi Plateau in Nigeria, and the highlands of Cameroun.

Table 8.1 Number of years with recorded Desert Locust infestations in the Western Region during the 36 years from 1940 to 1975.

	Swarms	Hopper bands
Morocco	26	17
Mauritania	24	19
Mali	24	18
Algeria	23	19
Niger	22	19
Chad	22	14
Western Sahara	22	11
Libya	16	13
Senegal	16	8
Nigeria	14	2
Tunisia	13	10
Gambia	9	0
Upper Volta	7	0
Guinea	6	0
Sierra Leone	6	0
Bissau	5	0
Ivory Coast	5	0
Cameroons	5	0
Ghana	3	0
Benin	3	0
Spain	3	0
Canaries	3	1
Gibraltar	1	0
Portugal	1	0
Cape Verde Islands	1	0
Madeira	1	0
Togo	1	0
Central African Republic	1	0

Fig. 8.1 Physiography of the Western Region. Mean rainfalls at places shown are listed in Table 8.2.

8.3 WEATHER AND CLIMATE

In mid *winter*, when the Inter-Tropical Convergence Zone lies near 10°N, the weather of the Western Region is dominated by *subtropical anticyclones* and *eastward*-moving waves and cyclones (Section 3.3.5). As a result, winds north of about 30°N blow mostly from between west and north, with spells of a day or two from other directions; whereas winds elsewhere are the *tropical easterlies*, or *trade winds*, blowing mostly from between north and east, but sometimes from the south-east when there is a passing wave. In mid *summer*, the subtropical anticyclones still dominate the weather of the north, but passing waves are then often weak; hence winds blow for long spells from between north and east. By contrast, in the south there is a marked change by mid summer: the ITCZ has moved to about 20°N, and to the south of it are *monsoon* west winds (Section 3.3.5), disturbed by *westward*-moving waves (and cyclones on the ITCZ). These monsoon winds form a wedge beneath the tropical easterlies, deepening southward to an average about 3 km deep, 1,000 km south of the ITCZ.

From mid winter to mid summer there is a progressive change in the wind pattern over the Region: the ITCZ and following monsoon winds spread north in surges (sometimes with temporary retreats) from about 10°N in January to about 20°N in July. From mid summer to mid winter there is a reverse and rather faster change. As a result of this change in wind pattern, there are well-recognised seasonal variations of wind direction at each place within the Region. Likewise, there are seasonal variations in rainfall. North of the ITCZ, the eastward-moving disturbances bring most of the rain (Section 4.11; and see, e.g., Fig. 4.6a and c), which therefore falls in winter and spring, whereas summer is largely rain-free. South of the ITCZ by contrast, it is convection in the moist monsoon winds from the South Atlantic Ocean, modified by westward-moving waves, that brings the West African rain, which therefore falls in summer (see, e.g., Fig. 4.6b). It follows from this brief account that annual rainfall amount, and duration of the rainy season, vary with latitude. The *winter-spring rains* of the north weaken southward and more or less disappear south of about 30°N. By contrast, the *summer rains* of the south strengthen southwards, starting at about 20°N. These changes are illustrated by Table 8.2, which shows mean monthly rainfall at selected places along a line near 10°W from Tunis (37°N) to Kano (12°N). Between about 20° and 30°N, over the vast deserts of North Africa, rains are rare and erratic; average annual falls are less than 50 mm, and over wide areas less than 10 mm. Some places have no rain for a year or more, but nevertheless heavy rainstorms do occur from time to time during the winter and spring. All the Saharan highlands receive more rainfall than the surrounding lower-lying areas; run-off, canalised along the wadis, often provides breeding sites in the midst of deserts (see, e.g., Fig. 4.6b).

Table 8.2 Monthly mean rainfall (mm) at selected places along a north-south line near 10°E (see Fig. 8.1 for places named).

	Latitude °N	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Tunis	37	70	47	43	42	23	11	1	11	37	56	57	70	466
Gabes	34	17	17	17	17	9	2	T	1	14	41	30	19	183
*Gadames	30	6	3	5	5	1	T	0	T	T	4	8	4	36
*Djanet	25	6	2	1	2	4	1	T	T	1	1	1	1	20
Bilma	19	T	T	0	T	1	1	2	11	4	2	0	0	21
Agades	17	T	T	0	1	6	8	49	78	20	1	0	0	164
Zinder	14	0	0	0	3	27	55	153	232	71	7	T	0	549
Kano	12	0	T	2	8	71	119	209	311	137	14	T	0	872

T = less than 0.5 mm.

Period: 1931 – 60 (taken from *Climatological normals*, WMO No 117 TP 52) except those marked*, which are for the period 1926 – 50, taken from Dubief 1953).

In the northern part of the Region, low winter temperatures delay maturation and breeding. As can be seen from Fig. 2.6b, throughout the period 1939–75 no hopper bands were reported north of 28°N during November–January.

Day-to-day changes in the weather are a result of the movement and development of atmospheric disturbances (see Section 3.3.5). The eastward-moving disturbances *north of the ITCZ* are mostly variations of the same kind as those in the Eastern and North-Central Regions (Sections 5.3 and 6.3), illustrated in Fig. 3.17a. A cyclone (low, or depression, in the pressure field) lies north of 30°N, and on its southern side is a windshift line (cold front; see Section 3.3.5 and L of Fig. 3.17a), separating mainly southerly winds ahead from mainly northerly winds behind (see, for example, Figs. C11.5b, C11.6b, C17.6b, C17.7b, C17.8b, C17.9b and C19.1c). Sometimes these winds are strong enough to give widespread dust storms (Berenger 1963, Jalu *et al* 1965, Shenk & Curran 1974). The whole disturbance usually moves eastward at 5–10° longitude a day. Sometimes there is no cyclone centre but only a wave, or the centre may lie far to the north over Europe (see Fig. C17.1b). Cyclones sometimes form just south of the Atlas Mountains, and move east-north-eastward to the central Mediterranean Sea, taking up to a few days to do so (see Figs. C11.5b and C17.8b). Early in the life of such a cyclone the wind-shift line may be poorly formed and difficult to find (Fig. C11.3d), but where it is a well-marked cold front a second depression may form on it and move in a similar direction (Fig. C17.4b). Northerly winds behind a cold front spread as far south as the ITCZ, usually turning to north-east on the way. Ahead of a cold front, the ITCZ moves northward temporarily and then southward behind it, the change in latitude being usually up to 5°, but sometimes 10°; for an example, see Fig. C11.6b. Sometimes a cyclone can be slow-moving for several days, particularly over the Atlantic Ocean off the north-west coast of Africa (Fig. C17.5b), and that can lead to a spell of heavy rain. Heavy rains in winter and spring often accompany wave troughs and cyclones in the upper atmosphere (Section 4.11.2; see also Dent & Mason 1972, Gland 1964, Jalu & Damotte 1967, Mayençon 1958, 1961a, 1961b, Pedelaborde & Delannoy 1958, Winstanley 1970 for examples in Algeria and Tunisia; and Casanova 1967, Germain 1959, Vittori 1969 for examples in Mauritania and Western Sahara). On rare occasions they fall as far south as 10–15°N (Matthews 1961, Morell 1973, Ramiarasoa 1969). During spring, small DESERT DEPRESSIONS form near 30°N and move eastward close to the southern shore of the Mediterranean Sea (Fig. C11.4b), often crossing into the North-Central Region (Pedgley 1972, Tantawy 1964a). Between successive cyclones there are anticyclones, again moving eastward but seldom with centres south of 30°N (see, for example, Figs. C11.3d, C11.4b, C11.5b, C11.6b, C17.1b, C17.3b, C17.8b and C17.9b).

South of the ITCZ, the monsoon winds are seldom a uniform flow over the whole length of West Africa. Sometimes there are convective rainstorms that give cool, outward-spreading winds (L of Fig. 3.17b; and see, e.g., Fig. C11.3d) that can reach as far as the ITCZ. At other times the flow becomes complex because there are many small-scale atmospheric disturbances (Figs. C17.1b, C17.2b and C17.3b). Waves in the monsoon, moving westward, can be difficult to find, but where one crosses the ITCZ there is often a cyclone, characterised by hot weather, clear skies, and strong winds (Figs. C11.3d, C11.5b and C17.9b; see also Pedgley & Krishnamurti 1976). Within the circulation of such a monsoon cyclone the ITCZ can oscillate north-south by up to 5° latitude over a few days. Waves and cyclones are most clearly seen on weather maps for heights of 2–4 km above sea level (Aspliden 1974, Carlson 1971, Dhonneur *et al* 1973, Payne & McGarry 1977, Reed *et al* 1977).

A consequence of the seasonal change in wind pattern over the Region is a corresponding change in the dominant directions of swarm movement (see Section 8.4). *North of the ITCZ*, movement is mostly from the east, but daytime temperatures on average do not exceed 20°C north of about 25°N in mid winter, and there may be little or no flight on many days because the weather is too cold. In winter, most flight takes place on the warmest days, which are often those with southerly winds. Overall displacement in winter is therefore mostly from between south and east even though dominant winds are from between north and east. North of about 25°N, there are days when movement is from between south-west and north-west, when winds from these directions are blowing around a passing cyclone, particularly those cyclones that move from south of the Atlas Mountains to the central Mediterranean Sea. The Atlas Mountains, rising to over 2,000 m in Algeria and 3,000 m in Morocco, often form temperature barriers to northward displacements in winter, when swarms tend to move north-eastward along the southern edges of the mountains, or become trapped between their ranges. During spring, daytime temperatures rise and on average exceed 20°C almost everywhere by April, so that swarm movements from then until summer are mostly from between east and north — towards the ITCZ and summer breeding grounds. Because tropical east winds blow above the wedge of monsoon winds, it is possible for high-flying swarms to be taken south of the surface position of the ITCZ. *South of the ITCZ*, movement is mostly from the west (well shown by the Southern Circuit — see Section 8.9), but it is probably slow and erratic in the disturbed monsoon winds.

Along the north-west coast of Africa, continental easterly trade winds are often separated from cooler, oceanic north-easterly trade winds by a semi-permanent front (the TRADE FRONT that helps to prevent low-flying swarms being taken out to sea (see, for example, Figs. C17.1b, C17.2b, C17.10b and C19.1b). When the continental winds are strong, there may be no trade front and easterly winds blow out over the Atlantic Ocean, sometimes taking swarms to the Canary Islands and Madeira (see, for example, Figs. C17.5b and C19.1c).

8.4 SEASONAL BREEDING AND MIGRATIONS: GENERAL COMMENTS

Breeding in the Western Region takes place during the summer, winter and spring seasons. Summer and spring breeding occur in two seasonal belts receiving the summer and the winter-spring rains and running across, respectively, the south-central and the northern parts of the Region (see Figs. 2.6a and 2.6c). In both these seasons, breeding can be heavy and widespread in their zones, and lead to the production of large populations of swarms. Winter breeding is usually more restricted than in the other two seasons, but can sometimes be locally important. Its distribution partly overlaps with the areas of summer breeding but it extends further north than the latter in the countries bordering the Atlantic and in the Sahara, where it occurs on the borders of the Saharan highlands receiving winter rains (Section 8.3).

The greater parts of the summer and spring breeding belts in the Western Region are widely separated from each other, and seasonal migrations of swarms which connect them are usually long-range, involving traverses of several hundreds and sometimes thousands of kilometres across the desert belt.

8.5 SUMMER BREEDING (JULY TO OCTOBER)

Distribution. In the Western Region, summer breeding takes place mainly between latitudes 14° and 21°N in a belt running from southern Mauritania and northern Senegal through Mali, Niger and Chad, where it is continuous with the summer breeding area of Sudan (see Fig. 2.6a and Section 6.5). The total extent of the zone within which summer breeding may take place can be seen on the hopper band frequency maps for August and September, which show that it may sometimes extend into Western Sahara and the Algerian Sahara. These maps also show that the highest frequencies of gregarious breeding in any one degree square in West Africa at this season have been recorded in southern Mauritania, where in one square they reach 10 out of 37 years. In other countries they do not exceed six or seven years, and in general are much lower than the summer frequencies in Ethiopia and Sudan (respective maxima per degree-square: 13 and 16 years). This contrast is probably partly due to under-reporting in West Africa, but it is also possible that it reflects a real difference in the frequency of gregarious breeding between the eastern and the western parts of the African summer belt. The numbers of years with summer breeding from 1939 to 1975 in different West African countries are given on Fig. 8.2.

Populations involved. Following a period in winter and spring when the summer breeding belt is clear of swarms, it begins to be invaded, from May onwards, from several different sources. Whenever swarms have been produced in the spring breeding belt of the Western Region they have migrated southward to the summer belt (see Section 8.14). These spring swarms may be supplemented by any swarms of the preceding summer generation which had performed the Southern Circuit, and are returning to the summer belt (see Section 8.9). Finally, the Western summer belt may be invaded by spring swarms from Arabia (see example forecast, Section 11.5), and by Long Rains swarms from the Somali Peninsula (Section 8.15).

Times of breeding. Maturation of swarms invading the summer belt does not usually begin till late June or July. In all West African countries with summer breeding, *layings and hatchings* may begin from July; but in Mauritania, Mali, Niger and Chad, hopper bands appear most frequently from August, and in Senegal from September (see Fig. 8.2). *Fledging* and formation of new swarms may begin in the second half of August, and continue in the following months; over most of the summer breeding belt, fledging terminates most frequently between late September and late October, continuing occasionally into November, and in southern Mauritania and Chad into December (see Fig. 8.1 and Section 8.10 on winter breeding).

8.6 MIGRATIONS OF SUMMER SWARMS TO WINTER AND SPRING BREEDING AREAS, OCTOBER TO JANUARY

Soon after young swarms appear in the summer breeding belt they begin to leave their source areas and migrate towards the countries in which they will breed in winter or spring, or both (see Fig. 2.6a). The initial emigrations are often to north and north-west or west-north-west, with swarms moving down the advancing southerlies during northward surges of the ITCZ, or more commonly with the south-easterlies associated with the approach of depressions moving in from the Atlantic and eastward over the Sahara. Such movements result in the spread of swarms into the Algerian Sahara, northern Mauritania and Western Sahara, all of which may be invaded from September, though more frequently from October and even from November. Morocco may be first reached between late September and November, though most frequently from October, while Algeria north of 32°N may be invaded between October and December. All the countries of north-western Africa may experience repeated invasions by successive waves of swarms moving in from between south-west and south-east as atmospheric disturbances move from west to east across the Region.

South-western Libya may be first reached in October or November, with swarms moving north and north-east either directly from Chad and Niger, or after crossing the Algerian Sahara. An eastward to north-eastward trend may appear in all the invaded areas, with swarms moving on the west or south-west winds around the southern side of eastward-moving cyclones; this trend may lead to movement of swarms from Mauritania into Algerian Sahara, and from Algeria into Tunisia and north-western Libya, both of which may be invaded either from the south or from the west. In Tunisia, the first invasions may occur in any month between November and as late as March, while north-western Libya may be first invaded between October and December, though most frequently from November, and occasionally not till February.

Swarms reaching the barrier of the Atlas Mountains in Morocco and Algeria tend initially to move east-north-east to the south of the ranges; in Morocco they may become trapped between the ranges in the funnel-shaped Sous Valley (as notably in 1954 and 1960). Eventually the swarms spread across the mountains on to the northern plains, though sometimes not till early spring.

Examples of northward, north-westward and north-eastward movements of the summer swarms between late September and December 1954 and 1958, with consequent invasions of all the countries of north-western Africa are described in Summaries 17 and 18. A northward movement out of the summer belt during a northward surge of the ITCZ in September 1954 is illustrated in Case Study 17.1, and the weather when swarms invaded the countries of north-western Africa from the south-east is described in Case Studies 17.2 (September 1954) and 17.5

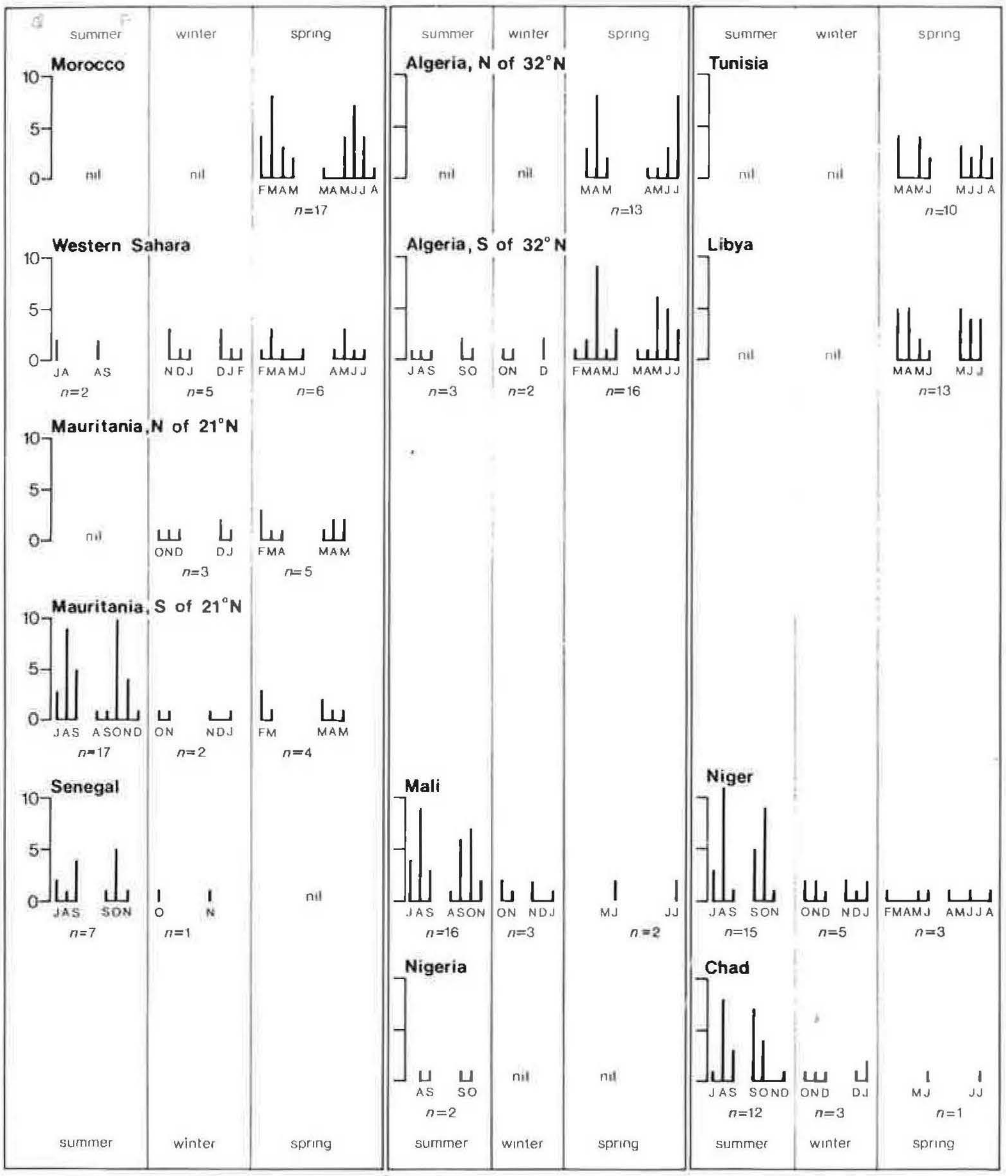


Fig. 8.2 Seasonal breeding in the Western Region: monthly frequencies of beginning and ending of hopper infestations. In each column, the monthly frequency of *hatching of first hopper bands* is shown on the left, and *fledging of last hopper bands* on the right. *n* is the number of years of records used.

(October 1954); see also Gerbier 1965 for discussion of such movements in 1958. Weather systems in which swarms move north and north-east to invade Libya and Tunisia (November 1954, January–February 1955) are described in Case Studies 17.6 and 17.8.

These long-distance movements sometimes take swarms eastward to the North-Central Region or westward to the Atlantic Ocean. An example of an eastward emigration occurred in November 1954, when swarms moved to north and north-east through eastern Algerian Sahara and Libya into north-western and northern Egypt (Summary 17 and Case Study 17.6). In the western part of the Region, swarms moving from the south-east or south over the countries bordering the Atlantic may be blown for great distances out over the ocean and sometimes on to the Atlantic islands. For example, in October 1954 strong south-easterlies and then southerlies associated with a depression over the Atlantic carried several swarms to the Canaries and dispersed some of them over the Atlantic as far north as the Scilly Isles, off the south-western tip of England (see Summary 17 and Case Study 17.5, and Rainey 1954, 1963). In mid October 1958, strong easterly winds blowing off southern Morocco carried a swarm west to Madeira, while some days later a strong southerly current, developing over the eastern Atlantic and the mainland in association with a deep depression over the Canaries, carried swarms from Senegal and southern Mauritania to Western Sahara and the Canaries (Summary 18, Gerbier 1965). Again, in October 1945, swarms were blown out to sea from southern Morocco and then northward to Portugal by strong southerlies associated with an Atlantic depression (Waloff 1946a).

8.7 EARLY WINTER (OCTOBER) INVASIONS FROM OTHER REGIONS

During the early winter, the Western Region is liable to be invaded by young summer swarms, which have formed beyond its limits in the eastern part of the African summer breeding belt, in the same season when they were forming in the west (see Section 8.6). As a consequence, the swarms spreading west and north-west towards the spring breeding belt may include not only the swarms of West African origin but also those from Sudan — as, for example, in October 1954 (see Summary 17). Sometimes the *majority* of swarms invading the spring belt on north-western Africa originate outside the Western Region. Thus, during the spread of the plague in October 1950, when the Western Region west of Chad was virtually clear of swarms, numerous swarms from Sudan and adjoining parts of Chad spread rapidly to the west and north-west through the Region (see Section 2.7.2 and Fig. 2.13h). A similar invasion occurred after the 1967–68 plague upsurge when, in late September–October 1968, numerous swarms originating in Sudan spread over western and north-western Africa (see Section 2.7.3, Fig. 2.15g). Weather systems in which swarms may spread rapidly from eastern to western and north-western Africa are illustrated in Betts 1976 (Figs. 6.3 and 6.4).

The invading swarms subsequently mature and breed in the Western Region in winter and spring.

8.8 WINTER EMIGRATIONS TO OTHER REGIONS, OCTOBER AND NOVEMBER

Reference has already been made to an invasion of north-western and northern Egypt by swarms which had moved north and north-east across eastern Algerian Sahara and Libya in November 1954 (see Section 8.6, Summary 17, Case Study 17.6); the subsequent history of these swarms is described in Section 8.6. The exact origin of the swarms is uncertain; they may have originated anywhere between Mali and Chad, and even in Sudan, whence they may have moved out in a westward direction before swinging to north and north-east, and back into the North-Central Region.

It also appears probable that the eastward movement of summer swarms originating in Sudan, towards the Red Sea and Arabia, which is usual in late September and October (see Section 6.6), may on some occasions include summer swarms drawn into this movement from the eastern part of the Western Region, by late spells of westerly monsoon winds before the ITCZ has moved south across the area.

8.9 THE SOUTHERN CIRCUIT OF SUMMER SWARMS (OCTOBER TO MAY OR JUNE)

Not all the summer swarms forming in, or invading, the Western Region move northward towards the spring breeding areas. In some years (e.g. in 1954–55, 1956–57, 1957–58 and 1958–59 seasons), some of them become involved in the so-called Southern Circuit through the countries bordering the Gulf of Guinea.

During the initial westward movements of summer swarms from Sudan and the eastern part of the Western Region, some may move to the south-west with north-easterly winds during southward surges of the ITCZ, and then appear south of the summer breeding belt in Chad and Niger (e.g., October 1954) and northern Nigeria (October 1954, October 1968) (see Summary 17, Case Study 17.3; and Section 2.7.3, Fig. 2.15g). Such swarms may persist in these areas for a month or two and then disappear, possibly moving again to the north.

By December, swarms remaining to the south of the Sahara are usually found in the western part of the Region: in Mali, southern Mauritania and Senegal, with some appearing in some years further south in northern Ghana, Upper Volta and Ivory Coast. The southward movement continues in January–February, when swarms may spread from Senegal into Guinea and northern Sierra Leone. In March, the movement through the Gulf of Guinea states may become eastward, with a definite north-easterly trend (associated with northward advance of the south-westerly winds as the ITCZ moves north) appearing by April, when swarms may reappear in southern Mali and northern Nigeria. The north-eastward trend continues in May–June, with more swarms reaching southern Mali and appearing in southern Niger and Chad in May, and occasionally reaching western Sudan in June (Section 8.16). As a rule most of the States bordering the Gulf of Guinea become clear after May.

Examples of the Southern Circuit (in 1954–55 and 1958–59) are described in Summaries 17 and 18, while weather systems during the southward spread of swarms from Senegal to Guinea (February 1955), and the north-eastward move from Guinea to Mali (April 1955), are illustrated in Case Study 17.10.

The circuit of *Schistocerca* swarms in West Africa to south of the Sahara resembles the migrations performed in the same area and seasons by swarms of the African Migratory Locust, *Locusta migratoria migratorioides* R. & F. during its plagues (Batten 1967). But in contrast to the *Locusta* swarms, which mature and breed in the course of the circuit, *Schistocerca* swarms do not mature throughout the winter and are still sexually immature when they appear on the southern borders of the summer breeding belt in May. During May and June, they move further north into the breeding belt, where they become indistinguishable in the reports from immature swarms invading the belt from north and east (see Sections 8.14 and 8.15). It is generally assumed that the old summer swarms, which had survived in the immature state for some 8–9 months since the preceding October, mature and lay in July or August, together with the new swarms of the spring generation. Whether they do so has never been investigated, and it remains to be found out whether the swarms which perform the Southern Circuit retain any ability to reproduce in the following summer.

8.10 WINTER BREEDING (OCTOBER TO JANUARY)

Distribution. Fig. 2.6b shows all the degree-squares in which hopper bands have been reported in November–January during the years 1939–75. It will be seen that in the Western Region this breeding may occur in countries bordering the Atlantic, from Senegal to Western Sahara, all of which may receive some winter rains. Further east it may occur more locally, on the borders of Ahaggar in Algerian Sahara, mainly around Adrar des Iforas and the Adrar uplands in Mali and Niger, and in the Tibesti and Ennedi uplands of Chad, in all of which the effect of the sparse winter rains may be enhanced by run-off. It will be seen from the November–January hopper band frequency maps, however, and from Fig. 8.2, that everywhere in West Africa the frequency of winter breeding had been low (though it may have been under-reported). But, in general, the winter breeding in this Region appears to become more important during recessions, when it involves night-flying low-density populations retained in the Sahara by low winter night temperatures. During plagues, the day-flying swarms tend to over-fly the Sahara and reach the main spring breeding belt of north-western Africa.

Populations involved. Swarms which breed in the winter are members of the summer generation forming in West Africa, or invading it from the east, which happen to encounter conditions suitable for rapid maturation and laying (see Chapter 4). When earlier summer swarms experience such conditions in parts of the summer breeding belt in which the rains have happened to continue into early winter, they remain in those parts and breed there. Otherwise, they breed in winter on encountering localised favourable conditions during their movements across the Sahara towards the spring breeding belt (see Sections 8.6 and 8.7).

Times of breeding. As can be seen from Fig. 8.2, *hoppers* of the winter generation may first appear in the West African countries from October or November. In Mauritania and Niger, the first winter hatchings have sometimes occurred in December, and in Western Sahara and Chad in January.

Fledging of this generation has been reported in most breeding areas between November or December and January. In Western Sahara it may continue or even start in February.

8.11 MIGRATIONS OF WINTER SWARMS, NOVEMBER TO JANUARY

There is little direct information on the movements of young winter generation swarms which may form in the winter breeding areas between November and January. This is largely because most of the summer generation swarms are still sexually immature and pink or red at that period, and the swarms of the two generations are not differentiated in the reports. There is little doubt, however, that the winter swarms perform the same movements as the summer swarms and move in a general northward direction to the spring breeding belt (see Section 8.6) or become involved in the Southern Circuit (Section 8.9).

8.12 MIGRATIONS OF SUMMER AND WINTER SWARMS, FEBRUARY TO JUNE

By the end of the year, most of the swarms which subsequently breed in the spring breeding belt of north-western Africa had reached it from the south. Swarms which had crossed the Sahara become separated by a wide desert belt from those remaining to the south of it and involved in the Southern Circuit.

In the course of the next four-five months the area infested by swarms in north-western Africa may expand to the north, as the swarms gradually spread across the Atlas ranges and plateaux in Morocco and Algeria and reach the northern coastal plains (see Summaries 17 and 18). The swarms may also move eastward across the northern Sahara and spread into Tunisia and north-western Libya (see above Summaries, and Case Studies 17.8 and 19.1 for examples of weather systems in which swarms spread east; see also the discussion in the example forecast of Section 11.5).

In the spring breeding belt, swarms may begin to mature and lay. This can happen locally in January (as, e.g., in northern Mauritania in 1955, and in north-western Libya in 1959; see Summaries 17 and 18), but more general maturation and laying does not usually take place until February or March, possibly with the seasonal rise in air temperatures. As a rule, the layings continue in April and May, and frequently into June; in the later part of the breeding season, the rapidly maturing members of the early spring generation may also lay (Section 8.13). The last of the mature swarms usually die off in north-western Africa in June.

8.13 SPRING BREEDING (FEBRUARY TO JUNE OR JULY)

Distribution. Spring breeding, associated with the rains brought by the mostly eastward-moving disturbances, may occur throughout an extensive belt running from Morocco through northern Algeria to Tunisia and north-western Libya, and more locally in Mauritania, Western Sahara, Algerian Sahara and central Libya (see Fig. 2.6c); it may also take place during this season in northern Niger, and probably in the under-reported northern Mali and Chad. Like the winter breeding, spring breeding in the desert belt takes place mainly around the highland areas. The full extent of the areas in which gregarious spring breeding has been recorded over the 37 years from 1939 to 1975 can be seen on the hopper band frequency maps for April to June, which also show that the highest frequencies of breeding in any one degree-square were recorded in northern Algeria, in Libya (up to seven years in both) and in Morocco (up to eight). The numbers of years in which spring breeding has been recorded in different countries of the Region are given on Fig. 8.2.

Populations involved. The populations taking part in this breeding are summer swarms originating in the summer breeding belt of West Africa. In some years they are supplemented by summer swarms from the North-Central Region, which can provide the bulk of the breeding swarms (see Section 8.7). Finally, swarms breeding there may comprise West African winter swarms (see Section 8.11), and the swarms of the local early spring generation (see next paragraph).

Times of breeding. As can be seen from Fig. 8.2, *early spring breeding*, with hatchings and formation of bands in February (and fledging in March–early April), may occur in Mauritania, Western Sahara, Algeria and occasionally Niger; it has also been recorded in Morocco, where, however, hopper development is usually more protracted, due to moderate spring temperatures, and fledging may not begin till May.

The *main spring breeding*, in which hatchings and band formation may begin in any month between March and May or June, occurs over most of the spring breeding belt, with the onset of hatching taking place most frequently in March in Western Sahara and Morocco, in March and again in May in Tunisia, in March or April in Libya, and in April in Algeria. In Mauritania, however, no hatchings have been recorded after April, while to the south of the Sahara in Niger there is an apparent gap which may be due to under-reporting between recorded hatchings in February and May–June. In Mali and Chad there are no records of gregarious hatchings till June – i.e. until the late spring season. These late spring hatchings to south of the Sahara may be associated with the early summer rains, and the *fledging* from them takes place between late June and August. Over the rest of the spring breeding belt, the fledging of hoppers from March onwards may start in the second half of April, become general in May and June, and continue into July. In Tunisia and Morocco, it has occasionally continued into early August.

8.14 MIGRATIONS OF SPRING SWARMS

March to April. Swarms of the early generation, forming in north-western Africa in March and early April, may move to the north and east over the spring breeding belt, rapidly reach sexual maturity, and breed together with the swarms of their parent summer generation during the later stages of spring breeding.

An example of movements by early spring swarms in April 1955, when they migrated from northern Mauritania northward towards Morocco and then eastward across northern Algerian Sahara, is described in Summary 19, with the associated weather systems illustrated in Case Study 19.1. These young swarms most likely moved further north into the spring breeding belt and took part in the protracted 1955 spring breeding.

May to July or August (Fig. 2.6c). From May onwards, the spring swarms forming in north-western and northern Africa begin to move southward and to appear to south of the Sahara. In all West African countries in which they breed in summer, they may first appear in any month between May and July: most frequently from May or from June in Mali, Niger and Chad, and from May or from July in southern Mauritania.

The southward migration of young swarms can usually be clearly traced only through Mauritania; elsewhere in the Sahara their sighting has been rare. This may be because they move south-westward on the dominantly north-easterly winds across very sparsely inhabited country (see Fig. 2.6c). Another reason may be the very high day temperatures which prevail over the source areas and most of the Sahara during the southward migration. In such weather, swarms may fly *by night* (Section 8.3) and remain unseen. Over Mauritania, day temperatures remain less extreme and there the swarms are more likely to fly by day and be observed.

Examples of the southward movements from north-western Africa to the western part of the summer belt in May–June 1954 and 1955 are described in Summaries 11 and 19, with the associated weather systems illustrated in Case Studies 11.5 and 11.6. In 1955, when spring breeding was protracted and hopper infestations persisted till late July, the movements across Mauritania and probably across Algerian Sahara continued in July and early August, after which all swarms disappeared from the spring breeding belt (Summary 19).

In May and June, when the western summer belt is being invaded from the north, it is also being reached from the south by old summer swarms which had originated in the preceeding year and had become involved in the West African Southern Circuit (see Section 8.9). At the same time it may be invaded from the east by swarms originating in the North-Central and the South-Central Regions (see Section 8.15, from which it will be seen that the situation in both these Regions must thus be of direct concern to the forecaster of possible developments in the Western Region). All these different populations of swarms become intermingled and indistinguishable in the reports from the western summer belt, where they mature and begin to breed from July (compare Section 8.5). The breeding swarms usually survive till September–October, and some of them may occasionally become involved in the initial northward movements into the Sahara, before dying off (compare Summary 11).

8.15 EARLY SUMMER INVASIONS FROM OTHER REGIONS, MAY TO JUNE

In May or June, Sudan may be invaded by (a) spring swarms originating in Arabia, some having crossed Egypt and others having come directly across the Red Sea, and (b) swarms from the Somali Peninsula, having crossed north-eastern Ethiopia, and comprising both old mature swarms of the preceding Short Rains generation and young swarms of the subsequent Long Rains generation (see Section 6.16). The swarms from these different sources become intermingled in Sudan and may move west beyond it into the summer breeding belt of the Western Region.

Examples of invasions of the Western Region by Arabian and Somali swarms, having crossed Sudan in May–June 1950, May–June 1954 and May–June 1955 are described in, respectively, Section 2.7.2 (Fig. 2.13g), and Summaries 11 and 12; in 1950 and 1955 they spread as far as Niger, and in 1954 possibly to Mali. In 1968, Arabian spring swarms invading Egypt and Sudan in early June, spread westward to Niger, Mali and southern Algeria in the course of the month, and apparently as far as Mauritania by early July (see Section 2.7.3 and Fig. 2.15e). The weather systems in which the westward movements took place in 1954 and 1968 are illustrated in Case Studies 11.3 and 11.4. See also the example forecast in Section 11.5.

The old Somali swarms of the preceding Short Rains generation which reach West Africa have usually been breeding since March (Section 7.11) and are apparently too old and exhausted to continue breeding, so they die off there without doing so. But young spring swarms, from Arabia or the Somali Peninsula, mature in West Africa and breed in the western summer belt together with spring swarms from north-western Africa.

8.16 EARLY SUMMER EMIGRATIONS TO OTHER REGIONS, JUNE AND JULY

During late spring or early summer, when the western summer breeding belt is being invaded by new spring swarms from the north (Section 8.14) and by swarms of the preceding summer generation from the south (Section 8.9), situations may sometimes arise in which swarms move east from the Western Region into the summer breeding belt of Sudan. This occurred, for instance, in 1951, when on 13 June two swarms were reported in western Darfur Province of Sudan, after the country had been clear of confirmed swarms since the preceding December. There were further reports from western Darfur in the second half of June and in July.

During spring 1951, swarms had been produced in several localities of north-western Africa between northern Mauritania and Libya, and by 20 May some of them had moved southward across Mauritania and had reached Senegal. Further east, some swarms on the Southern Circuit (see Section 8.9) were reported in late May to the south of the ITCZ in southern and western Niger and southern Chad. Other young swarms were present in the period May to early June on the Arabian Peninsula, in Somalia, and in Kenya, but these potential sources can be ruled out on the grounds that movements from them would almost certainly have been reported from Ethiopia and from elsewhere in Sudan.

The most likely source of the Darfur invaders was the swarms which had been on the Southern Circuit, for the ITCZ had been lying over northern Darfur for at least four days before 13 June, and they could have arrived with south-westerly winds. It is also possible that they were derived from swarms originating in north-western Africa which had initially moved south, and then east to south of ITCZ, during some three weeks between their arrival in Senegal and the appearance of swarms in Darfur.

Finally, it is also just possible that the swarms came from Libya, where they had been forming in May and early June, but movement would then have had to have been at one or two kilometres above sea level, where westerly winds would have just reached western Darfur on some days.

Although at this season movement of swarms *from the east* into the Western Region is apparently more frequent and is better documented (Section 8.15), the possibility of migrations in the *reverse direction* must also be kept in mind.

SUMMARIES AND CASE STUDIES

List of Summaries

SUMMARY 1

MOVEMENTS OF SWARMS OF 1950 MONSOON AND 1951 EARLY SPRING GENERATIONS IN THE EASTERN REGION

This Summary deals with the spread into the spring breeding area of the Eastern Region by swarms originating in the monsoon breeding area of India and Pakistan in a year when breeding was protracted and the formation of new swarms continued from late August to November, and possibly to December.

The earlier swarms moved out mainly to the west, through Pakistan and southern Iran, and a few of them reached the eastern part of the North-Central Region. As the season advanced they moved in a general northward direction through west Pakistan, Afghanistan and Iran; in Iran they were joined in the northward movements by their progeny produced in the coastal areas.

Many of the later monsoon swarms did not emigrate to the west, but moved mainly in a northerly direction and overwintered in northern Pakistan and adjoining parts of north-west India.

In addition to these westward and northward displacements, the season provided examples of eastward incursions by monsoon swarms into central and eastern India.

Sources

The considered swarms were produced in the summer breeding areas of India and Pakistan during and following the 1950 monsoon rains. Breeding was quite widespread and protracted, with the earliest hatchings in early July and the latest in early November: it is likely that at least two successive monsoon generations were produced. The breeding areas (Fig. S1e) have been divided according to recorded or estimated dates of fledging, which took place from late August in Rajasthan, and from September in Punjab and Kutch in India, and Las Bela, Sind and Bahawalpur in Pakistan. In October and November, fledging continued in Sind, Rajasthan, Punjab and Kutch, and extended into Gujarat and Kathiawar. It is possible that in north Rajasthan and Punjab, and in Kutch, where last hatchings took place in early November, the formation of young swarms continued in December.

Movements in the last quarter of 1950 (mainly to the west)

The first indication of westward movements was the appearance in September of young swarms in the western part and just to the west of the source area (cf. Figs. S1 a and e). A notable and rapid westward movement developed in October, when young swarms were reported in Sind on 5th–6th, in Makran (at 27°N 66°E) on the 11th, on the western border of Pakistan (at 26°N 64°E) on the 13th, and near Jask (at 25°N 57°E) in south Iran and in Oman on the 17th (Figs. S1 b and e). For discussion of weather systems in which such westward movements take place see Case Studies 2.4, 4.4, 4.5, 5.1 and 5.3. In the second half of October, swarms moved west in Punjab of Pakistan and in Quetta, while in southern Iran they spread to west of Bandar Abbas (27°N 56°E) and northwards towards Baft (29°N 56°E). The westward movements continued in November, when southern Iran became invaded west to 51°E, more swarms reached Oman, and a swarm appeared on the Qatar peninsula (at 25°N 51°E). No notable changes in the distribution of swarms that had moved out to west of the source area occurred in December (compare Figs. S1 c, d and e).

To the east of the source areas, some swarms moved south-eastwards from Rajasthan into Madhya Pradesh in October, a swarm appeared near Bombay (at 19°N 72°E) in November, and some young swarms moved north-east from Rajasthan through Uttar Pradesh towards the Nepal border in December (compare Figs. S1 b, c, d and e).

Movements in the first quarter of 1951 (mainly to the north)

There was some further extension of the invaded areas during this quarter in south-east Arabia, where a swarm appeared to west of Oman (at 22°N 51°E) in January, and in south-western Iran, where they spread to southern Khuzistan (to 30°N 49°E) in January and as far as Dizful (32°N 47°E) in March (compare Figs. S1 f, g, h and i).

At the eastern end of the affected area, in India, some swarms moved south and east through southern Rajasthan and the adjoining states, as far as 21°N and 77°E in January, while in February an eastward movement took some swarms across Madhya Pradesh as far as 23°N 85°E in Bihar (compare Figs. S1 f, g and i). There were no further reports of these swarms after February.

The main spread during the quarter was in a general northward direction. In India during January there were further north-eastward movements towards the Nepal border, and to north or north-west into Punjab. The northward trend continued in February so that in March the country was apparently clear of swarms except for north-western Punjab. Similarly, in Pakistan in January, swarms spread north in Sind and Bahawalpur into Quetta and Punjab of Pakistan, and through Baluchistan and Chagai towards the Afghanistan border. In February, they reached the North-West Frontier Province in Pakistan and appeared in Kandahar Province of Afghanistan. In eastern Iran, they spread in January to 30°N in Kerman and to 32°N 57°E in southern Khurasan, where more swarms appeared at 32°N 60°E in March.

1951 early spring breeding

Monsoon swarms invading coastal areas of southern Iran began to mature and to lay from January 1951, and in February hopper infestations appeared near and to north-west of Bushehr (between 28 and 31°N), near and to west of Bandar Abbas (between 54 and 57°E) and in Iranian Makran (between 59 and 62°E) (Fig. S1 i). Young swarms of the early spring generation appeared in southern Iran in April 1951. Most of them apparently spread to the north, matured rapidly (becoming indistinguishable in the reports from old monsoon swarms), and contributed to the layings which occurred in central and north-eastern Iran in May and June. Those which remained immature became indistinguishable in the reports from numerous young swarms of the main spring generation which appeared in Iran and Pakistan from May onwards, and have not been considered in this Summary.

Final movements to west and north (Figs. S1 g, k and m)

In April–May, there was a slight westward extension of the invaded area, with swarms spreading from south-west Iran through the Basrah area in Iraq (30°N 47°E) into Kuwait and the Neutral Zone. This spread may have extended further south-west, for in April mature swarms appeared in the Riyadh area of Saudi Arabia (at 25°N 45°E and 24°N 46°E); these could have been derived, however, from swarms that invaded north-west Arabia from Africa in January, or from swarms produced in south-west and west Arabia in the 1950–51 season.

The final spread north occurred in Iran and Afghanistan. In Iran, monsoon and early spring swarms moved in April–May north to about 32°N in the central part of the country, and to about 35°N in Khurasan. In west Afghanistan, swarms reached 34°N in May.

Breeding by monsoon swarms

The westward and northward movements of the 1950 monsoon swarms took them into and across the spring belt of the Eastern Region, where in 1951 they were able to breed widely and heavily.

The early spring breeding in southern Iran has been referred to in Section 4 of this Summary. In February–March, maturing and laying swarms became widespread over southern and south-eastern Iran, with the layings spreading into central, eastern and north-eastern Iran between April and June, and into western Afghanistan in April–May; as noted in Section 4 of this Summary, the early spring swarms participated in layings in May and June.

In Pakistan, in addition to the more usual spring breeding in the southern and western parts of the country, monsoon swarms which had overwintered in the centre and north began to mature and lay from February and March; at the same time swarms were laying in north-western Punjab of India. In Bahawalpur, Punjab, Quetta and North-West Frontier Province the layings continued in April, and locally in May.

As a result of breeding by monsoon swarms, serious hopper infestations developed in all affected areas, and were particularly heavy in northern Pakistan. Numerous spring generation swarms made their appearance over the spring belt between May and July, and began to move east and invade India from May.

Re-invasion of India by mature swarms in late spring–early summer 1951 (Figs. S1 j, k, l and m)

In India, some mature swarms spread east through northern Punjab in April, and in May the waves of immature swarms moving into Punjab and Rajasthan from the west included a number of mature swarms. In June, mixed populations of immature and mature swarms invaded the whole of north-western India and spread across central India and east as far as 22°N 86°E in Bihar.

It is possible that these immigrant mature swarms were residual members of the late 1950 monsoon generation (some members of which were still immature in central and northern Pakistan in March 1951) or they were members of the early spring generation (in which case some of them perhaps survived to take part in the 1951 monsoon breeding, which began in India in the second half of July).

SUMMARY 2

MOVEMENTS OF 1951 MONSOON GENERATION SWARMS IN THE EASTERN REGION

This Summary considers the movements undertaken by swarms of the monsoon generation in India and Pakistan during 1951. The late arrival of the seasonal rains prevented any substantial breeding before the end of July and an early cessation of the rains prevented the customary production of a second generation. Although immature swarms were reported by mid September, winds in India prevented a westward movement out of the monsoon breeding area until November and swarms were not reported in the Makran before early December. The westward emigration was therefore later than normal and low temperatures within the uplands of western Pakistan may have prevented swarms from reaching the winter and spring breeding areas of Iran.

Sources

The passage of a monsoon depression at the end of July concentrated swarms that had been produced during the widespread 1951 spring breeding in the Eastern Region into the southern part of the monsoon breeding area, and also provided sufficient rainfall for egg laying to commence. Up to then there had been little rain and, although rainfall at Barmer (26°N 71°E) was adequate for breeding to occur in early July, the limited extent of egg laying facilitated the control of hopper bands.

Widespread monsoon breeding did not begin until late July–early August, 3–4 weeks later than normal; egg laying in India was initially restricted to the southern and central districts of Rajasthan and the Banaskantha district of Bombay. After the first week of August, the reported incidence of egg laying progressed into northern districts of Rajasthan as mature swarms moved under the influence of the south-westerly winds. By the end of the month, egg laying had been reported throughout West Rajasthan and southern districts of Haryana. At the end of August, reports of mature swarms declined and egg laying was reported from only Churu district in the first week of September. There were hopper infestations in all localities where there had been egg laying, but despite control operations new generation swarms appeared in the second fortnight of September. Estimates of development periods suggest fledging continued throughout October and, in some northern districts, into early November.

In Pakistan, breeding was more restricted: apart from isolated incidents of egg laying in Khaipur and Bahawalpur, it was confined to the southern Sind in the first half of August and Las Bela district later in the month. Estimates of development periods suggest fledging should have commenced by mid September, although the absence of immature swarms in either area before the westward migration in November suggests that control against hopper bands may have been successful.

After August, there was little rain in the breeding area and no breeding by the new generation swarms.

Movements

Immature swarms began to appear in southern Rajasthan in the second half of September (Fig. S2a). Although the reports were confined within the source areas (Fig. S2e), making it difficult to discern movements, it is likely that the prevailing south-westerly winds prevented any emigration into Pakistan.

In the first ten days of October all swarms were reported concentrated in the northern districts of Rajasthan, Haryana and Bahawalpur, with the exception of a single report in Jalore district, and it is likely that the majority of the swarms came from those areas, although the swarms reported in southern Rajasthan the previous month may have moved northward. Fledging continued in Rajasthan and swarms began to move beyond the limits of breeding (Fig. S2e), first northward into north-eastern Pakistan (Case Study 2.1) and then east and south-east to reach Uttar Pradesh by 21 October (Case Study 2.2).

At the beginning of November, almost all the swarm reports were from northern India, although some were from south-east Rajasthan and in western Pakistan during the first week of the month. It is likely that this initial westward migration was caused by the passage of a western disturbance across Pakistan (Case Study 2.3). Those swarms remaining in eastern Pakistan and India then returned to the east and south-east, replicating the movement of late October (see Case Study 2.2) as westerly winds returned to northern Rajasthan.

In the second fortnight of November, more swarms were reported in the upland areas of western Pakistan, and by 6 December a single swarm was reported at Turbat (26°N 63°E) in the Makran, followed by a further report in south-east Iran on 10 December. This movement into the Makran (Fig. S2e) almost certainly took place when there were easterly and north-easterly winds over northern India and Pakistan whilst an Arabian Sea depression moved northward to the coast of Kathiawar in mid November, followed by the onset of the north-east monsoon at the end of the month (Case Study 2.4).

Although swarms entered the Makran, none was reported continuing westward towards the winter and spring breeding areas of Iran. The failure of swarms to cross Iran can perhaps be attributed to the delay to emigration caused by the late start to breeding and by the subsequent movements of swarms into northern Rajasthan and adjacent areas. By mid December, daily maximum air temperatures within the Makran and Baluchistan rarely exceeded 23°C, and the lower temperature over high ground may have prevented swarm movements. Only scattered populations continued to be reported in Baluchistan and it would appear likely that swarms of the monsoon generation had broken up within the upland areas.

With the exception of a single report of a small immature swarm in Rajasthan in February 1952, no further swarms were reported after December until the immigration of swarms from the Somali Peninsula into Pakistan in April and to India in May 1952 (Summary 10). The origin of this isolated swarm is not known although the aggregation of scattered remnants of the monsoon generation would appear most likely, suggesting that some of the locusts survived the winter within India and Pakistan.

CASE STUDY 2.1

NORTHWARD SPREAD OF IMMATURE SWARMS IN PAKISTAN, OCTOBER 1951 (J.D.)

On 8 and 9 October, immature swarms were reported in Multan and Dera Ghazi Khan districts of Pakistan, followed by further reports in Lyallpur and Sahiwal districts between 17 and 19 October (Fig. 2.1a). Although enough rainfall for breeding had fallen in these areas in August (Multan 61 mm, Lahore 85 mm), the absence of reports of egg laying or subsequent hopper infestations suggests that these swarms had moved north after forming within the main monsoon breeding area to the south. This movement was the first by monsoon generation swarms in 1951, and it took place three to four weeks after the usual time that swarms begin to leave the breeding area.

Breeding during the monsoon season in 1951 had commenced later than normal: the first reports of widespread laying in Rajasthan and adjacent areas were on the last day of July, after the passage of a monsoon depression and the start of the seasonal rain. Immature swarms of the new generation did not appear until the second fortnight of September, when reports were at first restricted to Barmer, Jaisalmer and Jodphur districts of Rajasthan. Following these early reports, swarms were seen throughout west Rajasthan and southern Bahawalpur in the first week of October although, being confined to the breeding area, movements by the first-fledged swarms cannot be distinguished from those fledging later.

After the passage of another monsoon depression in mid September, the monsoon over India and Pakistan weakened and winds became generally light, except in coastal areas, with frequent calms over northern India.

Winds along the Indo-Pakistan border were predominantly from the south-west throughout early October (e.g. Fig. C2.2b), backing to south-east over northern Pakistan. With these winds there could have been a northward movement from Rajasthan to Bahawalpur and Multan. The displacement of swarms deduced from reports suggests very limited movement — consistent with the lightness of the winds.

In the first half of October, it is also possible that swarms from later fledging in Rajasthan moved into northern districts of the state, judged by the absence of reports in southern Rajasthan after 19 October.

CASE STUDY 2.2

EASTWARD SPREAD TO DELHI AND WESTERN UTTAR PRADESH, OCTOBER 1951 (J.D.)

From 23 to 25 October 1951, immature swarms spread eastward, mostly in a broad tract of land orientated north-west to south-east along the boundary between Rajasthan and Haryana (Fig. C2.2a). Swarms were seen also near the northern end of the Indo-Pakistan border — all on the Indian side, with the exception of one immature swarm in Sahiwal district and another swarm of unknown maturity north of Lahore on 23 and 24 October. Several swarms were reported in central Rajasthan from 20 to 23 October, but afterwards there were no reports in that state south of latitude 28°N until 28 October, when an immature swarm was reported at Ajmer (see Case Study 2.3). This eastward spread of swarms delayed the usual westward migration out of the breeding area.

By 22 October, the monsoon had withdrawn from northern India and during the previous two days a ridge of high pressure had extended inland from the Arabian Sea. The development of the ridge was accompanied by a change in winds over India and Pakistan, and a weak anticyclonic circulation was established over Rajasthan (Fig. C2.2b). Although winds over coastal Pakistan and south-western Rajasthan continued from the south-west, light westerly winds predominated at the surface over the extreme north-west of India, veering to north or north-east over central and southern India. These winds persisted until 26 October, when a western disturbance approached Baluchistan (see Case Study 2.3).

The eastward extension of swarms beyond the breeding areas into Delhi and Uttar Pradesh probably resulted from movement on the westerly or north-westerly winds over northern Rajasthan and Haryana. The lightness of the winds, however, undoubtedly restricted the range of movement, and large-scale displacements were impossible. Immature swarms which previously had been moving towards the north in Pakistan may also have moved towards the main area of reports, although some swarms remained, as shown by the reports in Sahiwal and Lahore districts. The possibility that more swarms remained unreported in north-eastern Pakistan and in southern Rajasthan cannot be discounted, although a clearance of these areas seems more likely.

CASE STUDY 2.3

WESTWARD MOVEMENT OF SWARMS OUT OF THE MONSOON BREEDING AREA, 26 OCTOBER TO 4 NOVEMBER 1951 (J.D.)

On 3 November 1951, two immature swarms were reported in the eastern foothills of the Sulaiman Range in central Pakistan, and on the following day a further swarm was reported in the Indus valley, south of Dadu (Fig. C2.3a). Swarms were also seen entering Bahawalpur at the beginning of November, although the exact date is unknown. In India, immature swarms remained in northern districts of Rajasthan and in Haryana, although areas of Delhi and western Uttar Pradesh that had been invaded earlier (see Case Study 2.2) reported no swarms. On both 28 and 29 October an immature swarm was seen at Kekri (Fig. C2.3a) in Ajmer district, and on 4 November two further swarms were seen in Gwalior and Mandasor districts of northern Madhya Pradesh. This spread of swarms into Pakistan was the first westward migration in 1951, but it was four or five weeks later than normal.

On 26 October, a western disturbance crossed into Baluchistan from the west and the wind pattern over India and Pakistan changed as the ridge of high pressure, which had been responsible for the westerly winds that had taken swarms into Delhi (see Case Study 2.2), withdrew towards the Arabian Sea. Wind directions over north-western India became easterly, and as the disturbance travelled eastward to central Pakistan by 28 October (Fig. 2.3b) a cyclonic circulation persisted over lowland parts of the country until the centre of the circulation moved northward and weakened over Punjab in the first two days of November. Throughout the passage of the disturbance, winds remained light.

The entry of swarms into Pakistan, well beyond the limits of reported breeding, indicates that a westward migration occurred during the passage of the disturbance, and this is supported by the absence of reports from western Uttar Pradesh and Delhi between 26 October and 5 November. The two reports in the Sulaiman Range on 3 November, some 300 km west of the Indo-Pakistan border, would require a daily displacement of less than 50 km and could have happened even in the light winds at the time, suggesting that these swarms are likely to have formed within the monsoon breeding area. The origin of the swarm near Dadu on 4 November is perhaps less clear because, although the cyclonic winds around the disturbance would have allowed a movement from Bahawalpur or Rajasthan, a fairly rapid displacement from the northern districts of these states would have been necessary. An origin elsewhere in Pakistan can perhaps be dismissed because of the lack of previous reports in the areas where egg laying had occurred. Estimates of egg and hopper development periods in Pakistan suggest that fledging began five to six weeks before the first reports of swarms in central parts of the country. An alternative possibility is that unreported swarms moved west from later fledging in southern Bahawalpur or central Rajasthan, for swarms had been reported in these areas earlier in October.

The movement of swarms to Ajmer and Madhya Pradesh does not seem to have been downwind, and although the swarm in Ajmer on 28 and 29 October may have come from breeding nearby, the other reports may represent a southward displacement. If this is so, the swarm at Gwalior must have begun moving before the passage of the disturbance, and continued after it had disappeared and high pressure had been re-established on 3 November, giving winds similar to those on 22 October (Fig C2.2b). A similar movement may also account for the swarm in Mandasor district, although it may have come from Ajmer.

CASE STUDY 2.4

WESTWARD SPREAD INTO WESTERN PAKISTAN, LATE NOVEMBER AND DECEMBER 1951 (J.D.)

On 19 November 1951, an immature swarm was reported in the uplands of eastern Baluchistan, and during the following ten days further swarms were reported in the uplands of central Pakistan. Then in the first week of December, two swarm reports came from the southern Makran, followed by a single report near Qasrqand in south-eastern Iran on 10 December (Fig. C2.4a).

In India, although an eastward movement had taken place in the first half of November, swarm reports after 19 November were confined to Haryana and Rajasthan. Most of these were in the north but several were reported in central and southern districts of Rajasthan between 26 and 30 November. By the beginning of December the number of reports had declined, and after 5 December only scattered populations of low density continued to be reported in Rajasthan, with none elsewhere.

The reports of swarms entering the uplands of Baluchistan indicate a westward spread from the breeding area after mid November, although swarms had been present in central Pakistan at the beginning of the month (see Case Study 2.3). The appearance of swarms in the Makran, however, and the disappearance of swarms from India, support a westward migration.

On 12 November, a depression formed in the southern Arabian Sea and moved northward to cross the coast of Kathiawar on the 17th. The depression weakened whilst travelling north and became stationary over Kathiawar until 20 November, when a weak anticyclonic circulation had become established over Rajasthan. These winds were only temporary for, on 23 November, the depression deepened and moved inland across Rajasthan, bringing rainfall to much of the state before weakening over the Punjab on 27 November. During the northward passage of the depression to Kathiawar, a high existed over eastern Iran leading to mostly north-easterly or easterly winds over north-western India and Pakistan after 14 November (Fig. C2.4b). Winds backed to northerly as the depression moved inland on the 23rd. After the disappearance of the depression, the high over Iran persisted throughout the first fortnight of December and winds became light from the north-east.

The persistent north-easterly or easterly winds from 15 to 19 November and after 27 November must certainly have allowed the westward spread of swarms indicated by the reports, but the movement probably started several days before the first report in central Pakistan on the 19th.

Temperatures fell rapidly after the end of October, however, and 1200 GMT temperatures below 25°C were frequent by late November. The cool weather and light winds would have reduced the speed of movement, and low temperatures may also explain why swarms failed to mature and breed following the abnormal rainfall in November. By early December, 1200 GMT temperatures in Baluchistan were often below 20°C, and swarms may not have been able to cross the highland areas, thus explaining the lack of reports further west.

SUMMARY 3

MOVEMENTS OF 1952 MONSOON GENERATION SWARMS FROM THE EASTERN TO THE NORTH-CENTRAL AND SOUTH-CENTRAL REGIONS

This Summary deals with movements of the 1952 monsoon generation swarms between September and December 1952. In addition to infesting the Eastern Region, many swarms spread to the Arabian and Somali Peninsulas, where they augmented the local swarming populations and contributed in due course to breeding in the following spring.

Sources

South-Central Region

In October 1952, Long Rains swarms were maturing and moving south across the Somali Peninsula to breed on the Short Rains (see Summary 16 and Figs. S3 b and d). By November, most of these swarms were south of 6°N. The first scattered fledglings of their progeny (Short Rains generation) began to appear on 25 November in the northern Somali Peninsula, with fledgling swarms in the Ogaden from 2 December.

North-Central Region

Summer breeding took place in Ethiopia, near Gondar (13°N 38°E) in the Takazze valley (13°N 38 and 39°E), and at Debra Sina (10°N 40°E) (Fig. S3c). Fledgling from this breeding could have occurred in August and, although no fledgling swarms were reported, there was a population of *mixed maturity* swarms in the Awash area (9°N 40°E; Fig. S3a) in September, which could have included locusts of the summer generation. There were a number of swarms of the summer generation moving in northern Ethiopia in October. These swarms probably crossed the Red Sea to Saudi Arabia in late October or during the first three weeks of November (see Summary 10), for none was reported in Eritrea after 21 November.

In 1952 there was no other summer breeding in Sudan until laying took place in late October and gave rise to a fledging swarm reported on 30 November in the Northern Province, outside the limits of the area considered in this Summary.

In south-west Arabia, there was also some summer breeding, with hoppers in the Peoples' Democratic Republic of Yemen (P.D.R. Yemen) in July, and in the P.D.R. Yemen and the Yemen Arab Republic in August (Fig. S3c). Most of the hoppers in the P.D.R. Yemen were reported to be controlled, and no fledgling swarms were reported. The area was clear of both swarms and hoppers in September (Fig. S3a).

Eastern Region

Monsoon breeding in the Eastern Region began with laying in July in the Punjab, Las Bela and eastern Sind of Pakistan, and in Rajasthan of India. Laying continued throughout August and during the first week of September, extending the infested area of Pakistan and spreading to the Punjab, Haryana, and western Gujarat in India. Fledging started in mid August, and continued until the last week of October. These areas of breeding are shown in Fig. S3c.

Movements of monsoon and summer generations swarms in the North-Central and South-Central Regions

In September in the North-Central and South-Central Regions, the only adult populations were the maturing Long Rains swarms on the Somali Peninsula, and mixed maturity swarms in the northern Rift Valley of Ethiopia (Fig. S3a).The first movement of monsoon swarms west towards the North-Central Region from the Eastern Region took place at the end of September, when a swarm was reported in eastern Iran on 28 September (Figs. S3 a and c). During the first fortnight of October, scattered locusts were reported along the Batinah Coast of Oman (9 and 10 October), and there was an immature swarm report from Masirah Island (20°N 59°E) from 10 to 12 October. Swarms had reached Wadi Hadramout by 18 October, and the western P.D.R. Yemen by the 20th. At the end of October, swarms were also reported in southern Yemen Arab Republic (Figs. S3 b and c).

In the Persian Gulf area, there was a later westward movement with the first swarms reported in the Fars district of Iran on 23 October, and then Kuwait and the western coast of the Gulf on 29 and 30 October (Figs. S3 b and c). During November there was a second wave of swarms from India and Pakistan moving west and south-west. These were reported at Jask (26°N 58°E) on 2 November, in Oman between 3 and 5 November, and at Wadi Hadramout on 2 November.

Monsoon generation swarms also crossed the Gulf of Aden from the P.D.R. Yemen to Somali Republic (North), where they appeared from 14 November (Figs. S3 d and f). They are also likely to have arrived on Socotra in mid November. The weather and possible routes taken by swarms during the migration to Socotra are discussed in Popov 1959.

After the beginning of December, when the first Short Rains fledgings were appearing in the northern Ogaden of Ethiopia, immature immigrant monsoon swarms could no longer be distinguished from young swarms of local origin. In December, monsoon generation and Short Rains generation swarms on the Somali Peninsula extended as far south as the Kenya border, beyond the limits considered in this Summary (Figs. S3e and f).

In south-west Arabia during November, monsoon generation swarms moved northward through the Yemen Arab Republic to the southern Red Sea Coast of Saudi Arabia, where they mixed with summer generation swarms that had come across the Red Sea from Eritrea (Figs. S3 d and f).

Along the Persian Gulf in the first half of November, swarms were reported further west in eastern Arabia than during October, and at the end of the month some had spread north-westward in Iran.

In December, there was a spread of swarms into south-eastern Iraq and across northern Saudi Arabia (Figs. S3 e and f). Jordan was invaded between 3 and 9 December, and again from 23 to 29 December. The movements in December probably involved both monsoon and summer generation swarms (Fig. S3f).

Movements of monsoon generation swarms in the Eastern Region

During August, all reports of young swarms were in the breeding area. In September, there were widespread reports of immature swarms in the breeding area, and some swarms had begun to move east into India (eastern Rajasthan and western Uttar Pradesh). In Pakistan in September, swarms moved north to northern Punjab, and west to Quetta, eastern Baluchistan and Las Bela. There was also a report of a swarm of unknown maturity in eastern Iran on 28 September. These movements in the Eastern Region are shown on Figs. S3 a and c.

By 14 October, swarms in Pakistan reached the Afghanistan border (Figs. S3 b and c), although there had been reports of *scattered* locusts inside Afghanistan on 9 October. In India, there was little movement eastward beyond the limits reached in September, but there was a movement southward to the Rann of Kutch in the first week of October. In the second week of October, swarms were carried far out over the Arabian Sea by northerly winds: there were several reports from ships of locusts floating in the sea between 11 and 13 October (Fig. S3b), and some swarms were eventually carried to the Kerala coast of southern India between 12 and 14 October (Fig. S3c), but in a few days they had been eaten by birds. The weather at the time of this movement is discussed in Rao 1954. There was further movement into Kutch from 16 October, and swarms were reported in Kutch until early November.

During November, there was a south-eastward movement into Uttar Pradesh as far east as 79°E, and into north-west Madya Pradesh as far south as 22°N. Swarms remained in these areas during the first week of December (Figs. S3 e and f), but no swarms were reported north of 31°N in Pakistan or India in November (Fig. S3d).

During December, there were fewer monsoon generation swarms reported in India (Fig. S3e), but in Pakistan, swarms were again found in the Indus valley as far north as 32°N.

Movements in the North-Central, South-Central and Eastern Regions in early 1953

In the *North-Central Region* during January, February and March 1953, there was little further spread of the monsoon and summer generation swarms from the areas they had reached at the end of 1952, although early spring breeding was taking place in the Arabian Peninsula and in Iran. In April and May 1953, these swarms moved north from their positions in Iraq and Jordan to extend the 1953 spring breeding over the whole of Iraq and Syria and into southern Turkey.

In the *South-Central Region*, monsoon generation swarms bred (together with the 1952–53 Short Rains generation swarms) on the Long Rains of the Somali Peninsula, north of 5°N, from late March.

In the *Eastern Region*, a few swarms remained in India and Pakistan in January and February until breeding took place in the spring breeding areas of the Eastern Region.

SUMMARY 4

MOVEMENTS OF THE 1960 MONSOON GENERATIONS SWARMS IN THE EASTERN REGION

This Summary considers the movements by swarms of the 1960 monsoon generations in the Eastern Region and their subsequent distribution in early 1961. Widespread breeding in early July 1960 gave rise to new swarms in late August, some of which remained along the Indo-Pakistan border to breed in September and October while others moved out of the breeding area. In September and October, the earliest of these monsoon generation swarms first moved into central and southern India before moving north-eastward to arrive in Bangladesh and Assam in December. Later fledging produced swarms that moved towards the west in October, and reached the head of the Persian Gulf in November. Following the appearance of second generation swarms in November, a further westward movement into the Makran took place in December.

Sources

Swarms had been present in Iran and Pakistan throughout the winter of 1959–60 and, after extensive spring breeding in Pakistan and southern Iran, spring generation swarms concentrated within the monsoon breeding area of the Indo-Pakistan border in late June. The coming of monsoon rains at the end of June led to rapid maturation of these swarms and breeding had been seen in some districts of Rajasthan by the first week of July, followed in the next week by widespread egg laying throughout West Rajasthan, Haryana, the Punjab of India as well as Las Bela and the eastern desert regions of Pakistan. Estimates of egg and hopper development rates suggest that fledging from these earliest layings may have started in mid August; this suggestion is supported by reports of immature swarms in Rajasthan in the last week of the month.

Egg laying continued over much of the breeding area throughout August and September, and it is likely that maturation of the first monsoon generation, and subsequent egg laying, may have started by mid September although the almost continuous reports of egg laying in many districts prevent any satisfactory division of subsequent generations. In areas where egg laying was more restricted, however, breeding swarms which can only be attributed to the spring generation had disappeared in early September.

With the exception of areas of breeding in Haryana and the Punjab during the first fortnight of October, egg laying appears to have stopped by the end of September, and estimates of development rates suggest that fledging of the second monsoon generation swarms may have begun in late October or early November. In Haryana and the Punjab, fledging from egg laying in early October could not be expected before mid December, and the absence of hopper bands in these areas after mid October suggests that breeding may have been unsuccessful — perhaps as a result of breeding sites being too dry or as a result of effective control.

Movements

In 1960, swarms leaving the monsoon breeding area of India and Pakistan moved both eastward and westward.

Eastward and circular movements

Immature swarms of the first monsoon generation were first reported in West Rajasthan in the last week of August. Together with the residual swarms of the spring generation, they remained within the breeding area until the end of the first week of September (Fig. S4a). By this time some of the new swarms may have matured and, although subsequent breeding would have reduced mobility, new swarms were reported east of the areas of breeding. By the middle of the month swarms were observed throughout East Rajasthan. This eastward trend appears to have continued until about 20 September (Case Study 4.1), when swarms invaded Jhansi and Hamirpur districts of Uttar Pradesh and northern districts of Madhya Pradesh. In the last week of September, movements by these swarms appear to have been more southward (Fig. S4d), and by early October, swarms were reported in western Madhya Pradesh, Maharashtra and northern Karnataka (Fig. S4c). A southward movement of swarms still within the breeding area also resulted in the invasion of Gujarat, leaving few swarms in Rajasthan (Case Study 4.2).

Following the rapid southward extension of reports in September and early October, the swarms in central India moved eastward and north-eastward (Fig. S4d). Swarms in Karnataka state moved into adjacent Andhra Pradesh and then progressed north-east along the coast into Orissa, where swarms moving east from eastern Maharasthtra may also have been present (Case Study 4.3). Further north, in central Madhya Pradesh, a north-east movement also occurred and by the end of October swarms had been observed in south-east Uttar Pradesh and Bihar (Case Study 4.3). The two groups of swarms continued to move towards the north-east separately in November (Fig. S4g) — in the south through north-east Orissa, and in the north into north-east Uttar Pradesh — but by the end of December the two groups had almost amalgamated in Bangladesh and Assam (Fig. S4g). Swarms continued to be reported in these areas during the first three months of 1961 (Figs. S4 h, i, j), after which the absence of reports suggests they eventually died out.

Westward movements

After the initial movement out of the breeding area in early September, there was further fledging of the first monsoon generation in Rajasthan and Pakistan. Although some of these swarms may have matured and remained to breed in late September and early October, others moved westward into Baluchistan and the Makran in the first fortnight of October (Fig. S4a). Swarms continued to be reported in western Pakistan during the second half of the month and they were reported by 22 October near Jask (26°N 58°E), in southern Iran (Case Study 4.4). In early November, movements within Iran appear to have been limited although the westward progression continued (Fig. S4g): by the last week of the month, swarms had reached Khuzistan district of south-west Iran (Case Study 4.5).

Fledging continued in the breeding area into late October and early November, probably representing a second monsoon generation. In the first fortnight of December, swarms resulting from this later breeding also moved westward into Baluchistan and the Makran when north-easterly winds prevailed over north-western India and Pakistan (for example, see Case Study 4.4). By the end of December, India and Pakistan were reported free from swarms, except those that had moved eastward to Assam and others that had remained in Gujarat following the southward movement in October (Fig. S4f; Case Study 4.2). The latter swarms disappeared in January 1961, and it is possible that they may have dispersed and given rise to the extensive scattered populations reported in Rajasthan before the monsoon breeding in 1961 (see Summary 8).

Swarms that had moved westward remained in southern Iran until April (Figs. S4 h–k). Breeding in the winter and spring breeding areas by these swarms, and by others originating in the Central Regions provided the new generation that moved back into India in June and July 1961 (see Summary 8).

CASE STUDY 4.1

EASTWARD SPREAD ACROSS INDIA, 8–17 SEPTEMBER 1960 (J.D.)

From 8 to 17 September 1960, swarms were reported east of the monsoon breeding area of the Indo-Pakistan border: first in East Rajasthan during the second week of the month, and then in northern districts of Madhya Pradesh and southern Uttar Pradesh (Fig. C4.1a). These swarms seem to have formed within the breeding area.

Although remnants of swarms of the previous generation may still have been present within India and Pakistan, it is probable that they represent the first monsoon generation, for fledging began in mid August.

Although spring generation swarms had been present throughout northern India during June, they had returned westward to breed in July, so that swarms had become restricted to the monsoon breeding area before the second week of September, except for two isolated reports in northern Uttar Pradesh in August. Many of the swarms within the breeding area in August and early September cannot be satisfactorily divided into two successive generations, but in areas where it is likely that earlier reports referred to spring generation swarms these had disappeared by September.

In the first three weeks of September, there were no monsoon depressions over northern India, with the exception of a shallow, short-lived low which crossed from Orissa on 9 September to Uttar Pradesh before filling up on 13 September. Winds over coastal areas of north-western India and Pakistan were predominantly south-westerly, veering to westerly inland (Fig. C4.1b). At the surface, winds were generally light but the persistent westerly direction probably enabled a steady eastward displacement of swarms.

CASE STUDY 4.2

SOUTHWARD SPREAD ACROSS INDIA, LATE SEPTEMBER 1960 (J.D.)

Most swarms had cleared from the monsoon breeding area in India and Pakistan during September 1960. From 20 to 25 September, they were reported in western Madhya Pradesh, some 200 km south of the limit of reports on the 17th, and by 2 October there were reports from western Maharashtra, northern Karnataka and Gujarat states (Fig. C4.2a). Before swarms moved south of the breeding area in September, they were confined to north of latitude 22°N. These swarms originated within the monsoon breeding area, moving south after the eastward migration earlier in the month (Case Study 4.1).

In mid September, the monsoon over India weakened and the formation of a shallow low pressure centre over Andhra Pradesh was accompanied by the development of northerly winds over west and central India on 18 September (Fig. C4.2b), and these winds persisted until early October. In general, surface winds were light, although towards the end of September speeds were often stronger than 10 kt.

The persistent northerly winds from 18 September to early October provided opportunities for a southward movement. Swarms were not present in Gujarat, however, until early October, and this later arrival is likely to have been because the eastward movement in early September involved many of the swarms present in the breeding area, and only a few from later fledging were able to migrate south on the northerly winds.

CASE STUDY 4.3

SPREAD TO EASTERN INDIA, OCTOBER 1960 (J.D.)

During October 1960 there was an impressive spread of swarms from north-western and central India into eastern parts of the country. Reports from south of latitude 20°N before 2 October show that swarms were present in a north-south area through Maharashtra and Karnataka states (Fig. C4.3a). During the next week, there was an eastward spread into Andhra Pradesh, eastern Maharashtra and Madhya Pradesh. In the next ten days, further reports from southern Madhya Pradesh, southern Orissa and coastal Andhra Pradesh show a continued eastward or south-eastward movement across central India. Swarms which had arrived in Andhra Pradesh along the coast by 8 October moved towards the north-east to join others moving across central India.

These movements can be related to the winds at the time. The low pressure centre which had given rise to northerly winds at the end of September (Case Study 4.2) had moved inland and persisted over central India during the first week of October, producing predominantly westerly or south-westerly winds south of 20°N (Fig. C4.3b). After 8 October, the low disappeared and winds over central parts of the country became more northerly, whilst south-westerly winds predominated along the Andhra Pradesh coast (Fig. C4.3d). Winds over India would therefore have enabled swarms to move east out of central and southern states, although further north this is perhaps less certain.

An unconfirmed newspaper report on 10 October stated that swarms had moved as far east as Hazaribagh (Fig. C4.3c), in Bihar, and this would suggest a substantial eastward migration some time before the 10th. Swarms had been present in Bihar in July, but it is probable that they returned westward to breed within Rajasthan, for it is unlikely that swarms could have remained unreported in Bihar since July. Westerly winds prevailed over northern India in the first half of September (Case Study 4.1), but the low over India after 18 September had created generally easterly winds over north-eastern India and these persisted until after the first ten days of October, when winds again became westerly or north-westerly (Fig. C4.3d). Therefore, if swarms really were present in Bihar on 10 October, they would have been involved in a movement during the first half of September, remaining unreported for at least three or four weeks. This is unlikely, so it is possible that the newspaper may have been referring to the previous swarms in July. Other swarms moving east across the northern states were not reported until after 18 October, by which time westerly winds were again blowing over northern India.

CASE STUDY 4.4

WESTWARD SPREAD TO THE MAKRAN, OCTOBER 1960 (J.D.)

On 2 and 3 October 1960, swarms were reported in south-eastern Pakistan, and during the following three weeks there was a westward spread of swarms, first into the Pakistan Makran by the 9th and then into south-eastern Iran in the second fortnight of the month (Fig. C4.4a). No swarms had been reported in these areas since August, and the movement in October was the first westward migration in 1960. First reports were restricted to areas where fledging may have occurred in September and October. Some of the reports, however, were of mature and maturing swarms, suggesting that fledging had taken place at least two or three weeks before. In the second week of the month, there were swarms beyond the breeding areas, so it is probable that they had moved west.

In late September, winds over the breeding area were predominantly south-westerly, but as the low pressure centre which had caused the movement of swarms to Andhra Pradesh (Case Study 4.3) moved inland during the first week of October, weak north-easterly winds blew over north-western India and Pakistan (Fig. C4.4b). These winds persisted until 8 October, when westerlies returned to Pakistan, but northerly or north-easterly winds continued to blow over south-eastern Iran.

The westward movement out of the breeding area must have started during the period of north-easterly winds in early October, but the return of westerlies by the 8th suggests that swarms may have reached the Iranian border some days before the first reports in that area. Swarms could have continued to move westward in southern Iran in the weak north-easterly flow which continued until the end of the month.

CASE STUDY 4.5

WESTWARD SPREAD TO KHUZISTAN, NOVEMBER 1960 (J.D.)

Up to 24 November, monsoon generation swarms in Iran had been reported only from central southern parts, but on that day swarms and groups of immature locusts were seen along some 600 km of coastal Fars Province, and there was also a swarm at Ram Hormuz in Khuzistan (Fig. C4.5e). Because it is unlikely that locusts could have moved so far in one day, the westward spread must have begun some time before.

In mid November, a depression entered the eastern Mediterranean, leading to south-easterly winds along the Gulf coast of Iran by the 17th (Fig. C4.5b). This south-easterly flow persisted until the 20th, so it is possible that locusts reached south-western Iran several days before they were reported on 24 November. In the last week of November, another depression crossed the eastern Mediterranean, and renewed south-easterly winds between 26 and 28 November may have taken swarms further into western Iran, although there were no reports beyond Ram Hormuz until 2 December, by which time the more usual north-westerly winds had returned to Khuzistan.

By late November and early December it is also possible that the monsoon generation swarms moving west through Iran had been joined by swarms moving north-east from summer breeding areas of the North-Central Region. Swarms had been reported in central Saudi Arabia in mid November, and westerly and south-westerly winds over the northern Arabian peninsula during the passage of the depression would have enabled swarms to move towards western Iran. Such a movement is perhaps supported by a report of an immature swarm in north-eastern Saudi Arabia in late November, although the exact date of the report is unknown.

SUMMARY 5

MOVEMENTS OF THE 1961 MONSOON GENERATIONS SWARMS IN THE EASTERN REGION

This Summary considers the movements undertaken by swarms of the two monsoon generations bred in the Eastern Region during 1961. In late 1961, successive emigrations took place towards the west although some swarms remained in India and Pakistan. In December, swarms spread northward and reached Soviet Central Asia by April the following year. In March 1962, some swarms moved eastward to reach Assam in eastern India.

Sources

Scattered populations had remained in India from the monsoon season of 1960, and after their re-aggregation, together with large numbers of immigrant 1960 spring generation swarms arriving from Iran in late June (Summary 8), they began breeding within India and Pakistan from the end of the month. The unusually heavy monsoon rainfall in June, associated with the passage of a monsoon depression, provided early opportunities for egg laying, and the first swarms of the new generation were reported from mid August. Breeding during July was extensive throughout Rajasthan, the border states of Pakistan, and Las Bela. Despite attempts to control hopper infestations, reports of the first monsoon generation swarms were widespread. At the end of July, egg laying over much of the breeding area was temporarily interrupted by a break in rainfall which persisted until the second half of August. When breeding resumed in the last ten days of August, it is likely that the initial reports of laying swarms related to residual spring generation swarms, but by early September it may well have been supplemented by first monsoon generation swarms. Breeding continued throughout September, and a southward movement of swarms in late August extended the breeding area into Gujarat. In the first week of October, egg-laying swarms continued to be reported from a few localities in Rajasthan and Sind although after this time, with the exception of a single report in Banaskantha district of Gujarat, breeding appears to have ended, following the withdrawal of the monsoon. The division into successive generations in the Eastern Region during 1961 is made difficult by the possible overlap of breeding populations in early September, although estimates of development rates suggest that *first* monsoon generation swarms may have been fledging between the second week of August and mid October, and *second* monsoon generation swarms between mid October and early November.

Movements

Following the appearance of first monsoon generation swarms within the breeding area of India and Pakistan in mid August (Fig. S5a), a westward movement beyond the limits of breeding appears to have occurred at the end of the month, when swarms were reported in Karachi (25°N 67°E) on 27 August. The source of these swarms is not certain, although it would appear probable that they came from the main monsoon breeding area (Case Study 5.1). Reports suggest that the westward trend continued in early September: during the first week of that month further swarms were reported at Turbat (26°N 63°E); on the 14th a single mixed maturity swarm was seen in south-east Iran; and there were further reports from Oman the following day. It appears likely that these last reports represent swarms which crossed the Gulf of Oman during the passage of a monsoon depression. Before such a crossing to Oman, the northerly winds ahead of the depression were also responsible for a southward movement into Kutch and Gujarat (Case Study 5.2). Some swarms may even have been carried out to sea, because groups of locusts were reported by shipping off the coast of Kutch. On 30 September a single swarm was reported in southern Iran near Bandar Abbas (27°N 56°E) (Fig. S5d); this report may represent a northward movement from Oman across the Strait of Hormuz.

In October, swarms within Iran appear to have continued moving westward through the western Zagros, although first monsoon generation swarms that had remained within India and Pakistan were reported largely within the breeding area, except for a northward extension of reports along the eastern foothills of the Sulaiman Range (Fig. S5c). In the second half of the month, the appearance of the second monsoon generation swarms may also have contributed to the reports.

In November, the westward movement in Iran continued, with swarms reported as far as 48°E in Khuzistan. This movement probably took place on south-easterly winds associated with the passage of a Mediterranean depression (for example, see Case Study 4.5). In mid November, a second wave of swarms, possibly of the first and second monsoon generations, appears to have moved westward out of the breeding area into western Pakistan and adjacent Iran, although the extent of this movement cannot be certain due to other swarms having already been present in these areas (Case Study 5.3). In the last week of the month, swarms that had remained in the breeding area moved towards the north-east, and by the end of November swarms were reported in Delhi and western districts of Uttar Pradesh (Case Study 5.4; Fig. S5h).

In December, the widespread distribution of reports within the previously infested areas (Fig. S5f) prevents any satisfactory examination of movements. It is likely that the second wave of swarms towards Iran continued, with swarms reported throughout the Makran and Baluchistan of Iran. Within India and Pakistan, swarms continued to be reported and in the second fortnight of December they moved northward into northern Pakistan. It is probable that some of these latter swarms then moved into Afghanistan late in the month, when a general northward movement of swarms took place from Baluchistan (Case Study 5.5; Fig. S5h).

In early 1962, the widespread infestations continued although little change in distribution is evident before March, except for the appearance of immature swarms in eastern central Iran in January (Figs. S5 g, i, j). The reports relating to these swarms in central Iran are vague, and it is not certain whether they represent a westward extension from Afghanistan or a northward spread from southern Iran; the latter may be more likely as swarms reported in Afghanistan were mature.

In February, swarms remained within the areas where they had been reported in January (Figs. S5 g and i), and no further movements can be discerned.

After mid March, swarms in western Iran continued to move towards the north-west (Case Study 10.7), whilst in India some swarms moved progressively eastward through Uttar Pradesh and Bihar, and by the end of the month swarms had been reported in Assam (Case Study 5.6). In Afghanistan, a northward movement may also have occurred, with swarms reaching the Turkmenistan border before breeding (Fig. S5l).

In April there were few movements in the Eastern Region, perhaps as a result of widespread breeding. Even so, swarms in western Iran continued north-westward into Iraq (Case Study 10.8) beyond 45°E. After mid April, swarms were no longer reported in eastern India and they may have died. Breeding by the monsoon generations continued into May, by which month there were widespread reports of the new spring generation, and the latter gave rise to the extensive infestations within the Eastern Region before the monsoon breeding in 1962.

CASE STUDY 5.1

WESTWARD SPREAD ACROSS PAKISTAN, LATE AUGUST AND EARLY SEPTEMBER 1961 (J.D.)

Reports of immature swarms at Karachi (Fig. C5.1a) between 27 and 29 August 1961, followed by successive reports of swarms within the Makran during the first week of September, provide an example of a particularly early westward migration out of the monsoon breeding area.

The early start to monsoon breeding at the end of June 1961 resulted in the appearance of new swarms along the Indo-Pakistan border by mid August. Limited breeding had also occurred in mid July within the dunelands or 'reks' near Sonmiani and may provide an alternative source for the swarms which subsequently arrived at Karachi. It was believed, however, that control operations against hopper bands near Sonmiani were successful, and it seems more likely that the origin of the Karachi swarms was the monsoon breeding area.

In the last ten days of August, a monsoon depression had formed over the Orissa coast of eastern India, and after the 22nd it moved north-west across India. Instead of recurving towards the north over north-west India, the depression took a south-westward track upon reaching Rajasthan, and on 27 August crossed the Arabian Sea coast near Karachi (Fig. C5.1b). While the depression was crossing Rajasthan between 25 and 26 August, easterly and north-easterly winds were blowing over the monsoon breeding area, thereby giving swarms a chance to spread to south-eastern Pakistan. On 28 August, the depression moved into the northern Arabian Sea and weakened. Some swarms were reported to fly north out of Karachi, consistent with the southerly winds behind the centre of low pressure.

On 2 September, an immature swarm was reported near Hoshab (Fig. C5.1a), in the western Makran, followed by a further report from Turbat on the 6th. It is probable that these swarms entered the Makran on easterly winds associated with the depression, for westerly or south-westerly winds blew over the Makran during the first week of September. The disappearance of the depression on 30 August (and therefore the ending of opportunities for a continued westward movement) suggests that swarms may have been present two or three days before the first report on 2 September. This is not unreasonable in an area of complex relief.

CASE STUDY 5.2

SOUTHWARD SPREAD TO GUJARAT, LATE AUGUST AND SEPTEMBER 1961 (J.D.)

From 24 to 30 August 1961, immature and mature swarms were reported in the Rann of Kutch, followed by a report of a swarm at Rajkot (Fig. C5.2c) on 1 September. Further reports in north-eastern Gujarat (first week of September) and then in coastal districts of the state (from 9 to 13 September) suggest successive movements out of the monsoon breeding area. Swarms may even have been carried out to sea, for groups of mainly mature adults were observed some 30 km from the shore on 10 September.

The reports of swarms in the Rann of Kutch were the first since July. While there may have been unreported local breeding, it seems probable that the swarms had come from widespread breeding to the north. The earliest reports, on 24 August, included *mature* swarms. These were probably residual parent generation swarms, for it is unlikely that fledging could have taken place before the second week of August. *Mixed-maturity* and mature swarms reported in *late* August may, however, have consisted of both parent and first monsoon generation, although it is likely that many of the former would have died following breeding, or may even have already bred before moving south.

Three monsoon depressions crossed India in late August and early September, and it is likely that these enabled swarms to move southward because the usual monsoon south-westerly winds over India and Pakistan were interrupted by brief spells of northerly winds ahead of the low pressure centres (for example, see Fig. C5.2b). For the periods 24–26 August, 3–5 and 9–12 September, northerly winds persisted. In general, these periods agree with new reports within Gujarat.

CASE STUDY 5.3

WESTWARD SPREAD OF SECOND MONSOON GENERATION SWARMS INTO BALUCHISTAN, NOVEMBER 1961 (J.D.)

In the first fortnight of November 1961, immature swarms were reported in Baluchistan, followed by reports in south-east Iran on the 20th. Swarms had previously been reported in these areas before mid October, but it is likely that the later reports indicate a second movement out of monsoon breeding area (Fig. C5.3a).

Fledging of second monsoon generation swarms had continued in late October and early November, and swarms had been recorded in eastern Baluchistan, beyond the limits of breeding, by the end of the first week of

November. Swarms had not been reported there since late September and early October. Although it is possible that some of these earlier swarms may have remained within the upland areas, unreported until early November, a more probable source for the November swarms is the main breeding area.

During the first three weeks of November, winds were predominantly north-easterly or easterly, providing opportunities for a westward displacement (Fig. C5.3b). This movement seems to have continued into south-eastern Iran after mid November, although its extent is uncertain because swarms of the first monsoon generation were already in southern Iran and Oman. While it is likely that swarms of the second monsoon generation reached as far as south-eastern Iran, further migration towards the west may well have been restricted by cold weather. After mid November, 1200 GMT surface temperatures within the upland areas fell rapidly and were frequently below 20°C by the end of the month. It is possible, therefore, that swarms remained within the area, unable to cross the higher ground.

CASE STUDY 5.4

MOVEMENT OF SECOND MONSOON GENERATION SWARMS TO DELHI AND UTTAR PRADESH, NOVEMBER 1961 (J.D.)

In the last ten days of November 1961, immature swarms were reported in several states of India — Haryana, Punjab, Delhi and western Uttar Pradesh (Fig. C5.4a). Their absence in these areas since September suggests that swarms had moved north-east out of the monsoon breeding area.

Earlier in November, immature swarms had been reported in many districts of Rajasthan, as fledging of second monsoon generation swarms continued within the breeding area. The first of these swarms had moved westward early in the month (see Case Study 5.3) but, after the 20th, swarms began to be reported beyond the northern and eastern limits of breeding. First reports were close to areas of breeding and may represent fledging. After 25 November, however, reports were more widespread towards the north-west, and by the 30th swarms had moved into western Uttar Pradesh, beyond 78°E (Fig. C5.4a).

On 24 November, a western disturbance crossed from Iran into Pakistan, and by the 26th had progressed eastward to lie over Rajasthan before moving northward over the Punjab on the 27th (Fig. C5.4b). The passage of the disturbance interrupted the prevailing north-easterly winds over the monsoon breeding area, for between 25 and 27 November south-westerly winds were experienced ahead of the low pressure centre. These winds provided an opportunity for the north-eastward displacement revealed by the reports, although any large-scale displacement was prevented by a return of northerly winds on the 28th.

CASE STUDY 5.5

NORTHWARD SPREAD TO AFGHANISTAN, DECEMBER 1961 (J.D.)

On 22 and 27 December, two swarms were reported from Farah Province in Afghanistan, and during the same month swarms were also reported in Herat, Kabul and Kandahar Provinces (Fig. C5.6a). These reports from Afghanistan indicate an extensive northward movement of monsoon generation swarms, later giving rise to widespread breeding throughout the Eastern Region in early 1962 as far north as southern Turkmenistan.

Swarm reports in the previous month within the Eastern Region were largely confined to coastal areas of Iran and Pakistan and the monsoon breeding area. In December, however, a progressive northward movement appears to have occurred in eastern Iran, Pakistan and India, with swarms entering northern Baluchistan and central Pakistan in the first two weeks of the month. Reports in Afghanistan were vague but swarms in eastern parts of the country appear to have arrived after 21 December. In Kabul and Kandahar Provinces, swarms may have been present earlier, because reports in adjacent parts of Pakistan indicate there was an extensive northward spread at the end of the first week.

In early December, winds over India and Pakistan were predominantly weak north-easterlies, although south-easterly winds had blown over Pakistan on 6 and 7 December as a ridge of high pressure extended over northern India. North-easterlies were also frequent later in the month, but periods of southerly winds were experienced over Baluchistan and central Pakistan ahead of western disturbances from 9 to 16 and from 20 to 24 December (Fig. C5.5b). It is probable that most swarm movements took place during these periods of southerly winds, when temperatures rose by 5 or 6°C. When winds were from the north-east, temperatures frequently fell below 20°C, particularly in Baluchistan, and may have prevented a southward return into coastal areas.

CASE STUDY 5.6

EASTWARD SPREAD TO ASSAM, MARCH 1962 (J.D.)

At the end of March 1962, *mature* and *unknown-maturity* swarms were reported as far east as western Assam (Fig. C5.6a) — the first reports in that state since the previous year (see Summary 4). This appearance of swarms in Assam followed the rapid spread of reports across northern India during March. It is likely that *most* swarms were mature, although many of the reports did not indicate maturity. This large movement shows that mature swarms can at times be highly mobile.

The swarms were undoubtedly part of the monsoon generation which had remained within India and Pakistan since the previous year, for rainfall in northern Pakistan and India had resulted in the maturation of most reported swarms by early March. At the beginning of that month, swarms were largely restricted to Pakistan and north-western India. Then during the first fortnight a limited eastward movement appears to have taken place, with swarms reported along the Nepal border on the 14th. Reporting within Nepal is generally poor, so swarms may have been present also within that country. During the second fortnight, a more extensive movement seems to have happened, with swarms crossing eastern Uttar Pradesh and Bihar into Bangladesh (although no reports were received from the last of these) before reaching Assam on 29 March.

Throughout March, north-westerly or westerly winds prevailed over northern India. Although light, the persistent direction would have enabled a progressive eastward displacement of swarms (Fig. C5.6b). By the end of March, many of the swarms in India and Pakistan had begun breeding, and little further movement occurred until the appearance of the resulting spring generation.

SUMMARY 6

MOVEMENTS IN THE EASTERN REGION, APRIL TO AUGUST 1954

This Summary deals with:

April and May migrations by *mature* monsoon 1953 generation swarms into Pakistan and India;

spring breeding in the Eastern Region and parts of the North-Central Region, followed by typical eastward migrations, between late May and July, of young swarms towards the monsoon breeding area;

the alternating eastward and westward displacements of immigrant swarms over northern India in June and July before the occurrence of rains adequate for breeding.

Return eastward migrations of mature monsoon swarms in April and May 1954

Most of the monsoon generation swarms produced in Pakistan and India in the summer of 1953 moved westward in the autumn of 1953. The few swarms that over-wintered in Pakistan and India had disappeared by February and March 1954, so that by March, India, Pakistan, Afghanistan, and most of eastern Iran were reported free of swarms (Fig. S6a). In early April, *mature* swarms reinvaded the spring breeding areas of eastern Iran, Pakistan and Afghanistan, and some reached India (Figs. S6 b and d) in the middle of the month. Breeding by these swarms took place in Iran, Afghanistan and western Pakistan, and there were two reports of laying from Jaisalmer district in India. Because this laying took place before the onset of sufficient rains for breeding in Sind or Rajasthan it is likely that no hoppers emerged.

In May, further *mature* swarms from Pakistan and Afghanistan moved into India, and were reported as far east as Jammu (33°N 75°E) on 14 May, and Dehra Dun (30°N 78°E) and Alwar (27°N 77°E) on 19 May (Figs. S6 c and d). This movement was associated with north-west winds on 8 and 9 May, and from 12 to 19 May. Some of these swarms survived in Pakistan and India into June, but they could not be distinguished from the rapidly maturing spring generation swarms that were arriving in India at the same time.

Spring breeding in the Eastern Region and parts of the North-Central Region

Spring breeding took place in many parts of the North-Central Region in 1954, and was also widespread in the Eastern Region throughout southern Iran, Afghanistan, western and northern Pakistan. Laying began in January in some areas of central Saudi Arabia and south-west Iran. In February, there was laying in Kuwait, while in March it also began in southern Iraq. In April, as mature swarms spread eastward, laying spread to Baluchinstan of Iran and Pakistan, and to Afghanistan. In May, there was laying in northern Pakistan and the Punjabs of both Pakistan and India. The earliest fledging of the spring generation was in March in south-west and south-central Iran (Fig. S6e), and some of the swarms from this fledging could have moved east in the invasion of India by mature swarms in the first half of April (Fig. S6d) because an *immature* swarm was reported in Jodhpur district of Rajasthan on 12 April (Fig. S6b). Fledging in April and early May was widespread, occurring in central and north-eastern Saudi Arabia, in Kuwait and the Neutral Zone, and in southern Iran (Fig. S6e). The early fledglings in Arabia moved first north and then south-west to enter Africa in the second half of May (Summary 11). Fledglings from around the Persian Gulf area, however, are more likely to have gone east in late May. In the second half of May and in June, fledging occurred in the areas shown in Fig. S6i and it continued in northern Pakistan and the Indian Punjab into July.

Eastward migrations of spring generation swarms

On 30 May, an immature swarm was reported in the Indus Valley, north-east of Karachi (25°N 67°E) after a swarm (reported as probably immature) had been seen on the Mekran of Pakistan on 25 May (Figs. S6 c and e). These swarms represented the start of the main eastward movement of the spring generation from the North-Central and Eastern Regions, which at this time of year is associated with west and north-west winds blowing from Arabia and Iraq towards Pakistan. Immigration into Pakistan continued in June with swarms from Iran, Iraq and Arabia being augmented in the middle ten days of the month by young swarms from Afghanistan coming into northern and central Pakistan. Immature swarms entered India in early June, one of them being reported as far east as Nohar (29°N 75°E) on the 2nd. In the first half of June, most of these swarms were confined to west of 75°E (Fig. S6j) but they spread further east in the second half of the month.

Swarms were reported on the coast of Kathiawar in the third week of June (Fig. S6f). It is possible, but unlikely, that they had entered India on a more southerly route, on the south-west monsoon winds which blew continually from the south-east coast of Arabia in the second week of the month (Case Study 6.1). There were also reports of locusts flying over the Arabian Sea (in squares 18°N 67°E and 17°N 68°E) in the last week of June; they had probably been carried south on northerly winds associated with a depression in the Arabian Sea (Case Study 6.1).

During July, swarms were still entering northern Pakistan from Afghanistan and were probably being augmented by fledglings from breeding in northern Pakistan itself. Some swarms were still coming in from Iran, as indicated by reports from the eastern Mekran of Pakistan between 11 and 15 July and by an isolated report in Iran on 25 July (Fig. S6g).

Alternating eastward and westward movements over northern India in June and July

During June, swarms that had entered India from the west did not stay in the monsoon breeding area but continued to move east over northern India. At the time there had been very little rainfall in the monsoon breeding area and soils were probably unsuitable for breeding. Before 15 June, all swarms remained west of 75°E (Fig. S6j), but between 16 and 19 June there was a limited eastward movement to 77°E, followed by a more extensive movement to reach Ambikur (23°N 83°E) on 26 June (Fig. S6i). Between 27 and 29 June, however, the swarms appeared to have retreated west, as there were no reports east of 80°E. At the beginning of July, swarms were again to be found as far east as 84°E, whereas between 6 and 11 July they were again only recorded west of 80°E. These oscillations of the area infested, backward and forward across northern India, can be related to wind changes involved in the passage of depressions moving westward along the Ganges valley from Bengal towards Rajasthan (see Case Study 6.2). On reaching Rajasthan, these depressions usually brought rain that made soils more suitable for breeding. From 10 July, swarms in India were maturing rapidly and movement eastward was no longer as evident as it had been previously (Fig. S6j), although westerly winds were established over the whole of northern India for the last ten days of the month. Breeding was now taking place in Rajasthan, Punjab and western Uttar Pradesh in India, and in Sind and Punjab of Pakistan. This pattern persisted in August (Fig. S6j).

CASE STUDY 6.1

SWARMS ON THE KATHIAWAR COAST OF INDIA, JUNE 1954 (J.P.)

The 1954 invasion of Pakistan and India started in late May, and swarms continued to arrive from the spring breeding areas of the North-Central and Eastern Regions thoughout June. All swarms in India were north of 28°N until one was seen on the Kathiawar coast at 22°N in the third week of June, and another on 25 June (Fig. C6.1a). Following this, 'pink fliers' were seen from a ship in the Arabian Sea at about 18°N 68°E on the night of 27–28 June. These more southerly reports suggest swarms may have taken a route into India different from that of earlier swarms, or they may have come from a different source. The evidence for and against such suggestions is now examined.

There were three possible sources for these locusts (Fig. C6.1a):

> Afghanistan and Pakistan, where fledging started in the first half of June;
>
> around the Persian Gulf, where fledging started in April and continued into June;
>
> central and south-western Arabia, where fledgling swarms and continued fledgling were reported in the first half of June.

Surface winds along the Kathiawar coast from 10 June until the day of the sighting were persistently west or south-west, thus suggesting a source in Arabia, and therefore a sea crossing of 1,000–2,000 km. Such a movement could have been either direct from Arabia, or from the Persian Gulf after first crossing the interior of eastern Arabia. Although there were no reports from eastern Arabia, swarms could have moved undetected through this large, poorly reported area.

A source in Iran or Pakistan certainly cannot be ruled out, however, if movement took place on winds *above* the monsoon south-westerlies. Such winds are often from the *north*-west, and they sometimes reach as low as 1 km above sea level along the Kathiawar coast. North-westerlies at 600 m would have reached the Kathiawar coast above surface westerlies on 25 June (Fig. C6.1b), but on no other day before then until 15 June. Hence, if the swarm seen on the 25th came on winds above the monsoon it is most likely to have done so on the very same day as it was reported; otherwise, it would have had to stay nearby for 10 days before being seen on the 25th — possible but unlikely in the presence of persistent west and south-west winds, although their great strength on some days may have stopped flight. The upper north-west winds last present on 15 June may well have brought the Kathiawar swarm reported in the third week.

The 'pink fliers' seen at sea between 1530 GMT on the 27th and 0330 GMT on the 28th of June may well also have come from the north on winds (above the monsoon) that were part of the cyclonic circulation around a weak depression that had moved westward across India from Orissa on the 26th and crossed the western coast on the 28th at about 18°N — the same latitude as that where the locusts were seen at sea.

On balance, the evidence points to a source in Iran—Pakistan, judged by the number and nearness of swarm reports in Pakistan and India in June, their absence in Arabia, and the presence of favourable winds on the same day as that of the swarm sighting. But movement would have been *above* monsoon south-west winds — a kind of movement which may be common and which would allow a crossing of the ITCZ by swarms coming to Pakistan and India from Iran and Afghanistan.

CASE STUDY 6.2

EASTWARD SPREAD ACROSS INDIA, JUNE AND JULY 1954 (J.P.)

The spread of swarms across northern India during June and July 1954 illustrates the reversals that occur with changes in wind direction associated with westward-moving monsoon depressions. This spread involved both young swarms from spring breeding and some mature swarms of the previous generation.

Throughout the first half of June, swarms moved no further east than 75°E (Fig. C6.2a) because winds on most days over east Pakistan and Rajasthan blew from between north-east and south-east on the northern side of a persistent low pressure area lying from Rajasthan to central India (illustrated by Fig. C6.2b, which shows north-east winds even reaching Sind). During the next five days there was some swarm movement to the south-east (Fig. C6.2c) in a spell of north-west winds over Rajasthan ahead of a depression moving westward across the Ganges valley (illustrated by the weather map for 18 June, Fig. C6.2d). By 26 June, swarms had reached furthest east for that month (83°E in Madhya Pradesh, Fig. C6.2e), after a spell of six days with west winds over northern India (illustrated by the weather map for 23 June, Fig. C6.2f). During the following four days there were no reports east of 80°E (Fig. C6.2g) — a retreat that coincided with a spell of east winds on the northern side of a depression (such as that shown in Fig. C6.1b). North winds on the western side of the same depression may have taken locusts over the Arabian Sea on the 27th (Case Study 6.1).

Swarms moved eastward again at the beginning of July, reaching as far as 84°E after the return of west winds, but between 6 and 11 July swarms were reported mainly west of 80°E during a spell of east winds over northern India on the north side of yet another depression. By mid July, the young swarms were beginning to mature and become less mobile; they spread no further east than 81°E between 12 and 15 July, even though west winds had returned. Between 16 and 20 July, reports were confined to west of 77°E and winds were again easterly as a fourth depression moved westward. Subsequently, swarms moved no further eastward, even though west winds returned on 21 July, for by this time there was breeding in Punjab, Sind and Rajasthan, following widespread rains brought by the last two depressions.

SUMMARY 7

MOVEMENTS OF 1950 SPRING GENERATION SWARMS IN THE EASTERN REGION

This Summary deals with a typical invasion of monsoon breeding areas of the Eastern Region by spring generation swarms. It provides examples of the repeated movements into these areas by swarms originating to north-west and west; of the eastward spread of swarms beyond the limits of the summer breeding area; and of the westward return to the latter.

Sources

There is no indication that in 1950 the source areas of spring generation swarms invading the eastern monsoon breeding areas extended into Arabia. They were apparently confined to the Eastern Region, and lay to the east of 55°E (Figs. S7 e and f).

Information on the early spring breeding in 1950 is very incomplete. Some hopper infestations occurred in the coastal areas of southern Iran, between 55 and 57°E and south of 28°N, and on Khishm Island (26°N 55°E) in February–March, and a few young swarms apparently appeared there in early April. Only scattered populations were reported in Oman, but some small immature and maturing swarms of unknown origin were found there in April. The fate of all these April swarms is unknown; it is possible that they moved north and contributed to the May layings which gave rise to June hatchings and July fledgings in source area D (see below).

The main spring breeding was protracted, and the resultant young swarms were fledging from May to July. From the recorded dates of first appearances of hoppers or fledglings, or both, it has proved possible to divide the source areas as follows (see Figs. S7 e and f).

A *Fledging in May*

Coastal areas of southern Iran, where hopper infestations and production of some young swarms continued into May; parts of northern and north-western Pakistan, where there had been early layings by 1949 monsoon swarms that had overwintered there.

B *Fledging from May to July*

North-central part of Pakistan, where protracted hopper infestations led to protracted formation of young swarms.

C *Fledging in June*

South-eastern Iran and adjoining parts of south-western Pakistan.

D *Fledging in July*

Northern Baluchistan in Pakistan, north-eastern Kerman and south-eastern Khurasan in Iran.

Eastward and south-eastward spread of swarms

In the second week of *May*, and before swarms began moving out of the source areas in northern Pakistan, there were reports of two swarms in Kathiawar (between 70 and 72°E, and 22 and 23°N). These may have arrived, possibly across the sea, from source area A in southern Iran. In northern Pakistan, swarms began to move out of their source areas in the third week of *May*, when they crossed the border into Rajasthan. By the end of May they had reached eastern Rajasthan and Indian Punjab (Figs. S7 a and e). During *June* there were further movements into eastern Pakistan and north-western India of new swarms originating in north-central Pakistan (source area B) and south-eastern Iran (source area C), with some of the latter possibly moving part of their traverse over the sea (Fig. S7e). Eastward movements continued right across northern India, with some of the swarms reaching western Bihar (Figs. S7 b and c; the eastward movements in India may have occurred in two waves, 6–14 and 15–20 June). Finally, in the first half of *July*, the last of the swarms originating in source area B, and swarms forming in source areas D, moved to north-western India, augmenting the immigrant swarms that had arrived there in May and June (Fig. S7f).

Return westward movements

In the first ten days of July a pronounced westward to north-westward trend developed over northern India that led to a clearance of the country to the east of Rajasthan. Then in the last week of July a pronounced westward trend developed in eastern Rajasthan (Fig. S7f).

Distribution at the start of the 1950 monsoon breeding season

As a result of the eastward emigations from the source areas and of the return westward movement, the swarms, which were maturing and beginning to lay by the end of July, became concentrated in a comparatively narrow zone running through north-western India and south-eastern Pakistan (see their distribution in August, Fig. S7d).

SUMMARY 8

MOVEMENTS OF 1961 SPRING GENERATION SWARMS INTO THE EASTERN REGION

This Summary deals with a characteristic eastward spread of swarms, originating in the spring breeding areas of the western part of the Eastern Region and the north-eastern part of the North-Central Region, into the monsoon breeding areas of the Eastern Region.

Sources

In 1961, spring breeding was restricted, in the Eastern Region, to southern Iran west of 58°E, but was widespread in the North-Central Region, where it took place on both shores of the Red Sea, and in central and northern Saudi

Arabia, Kuwait, Jordan, Israel, Syria and Iraq. Spring generation swarms, from most of the breeding areas on the Arabian Peninsula and in the Middle East, moved south-west and south to the summer breeding belt in Africa and south-western Arabia, but swarms from central and north-eastern Saudi Arabia and Iraq also moved to the *east* and these areas are the ones shown in Fig. S8e.

From recorded dates of layings, and estimated and recorded dates of hoppers, of fledging and of young swarms, the source areas can be divided according to periods of fledging (Fig. S8e). From the middle of *April*, fledging began on the southern coast of Iran and in north-central Saudi Arabia, and then in *May* it continued in these areas and spread to Kuwait, southern Fars and Khuzistan in Iran, and to southern and central Iraq. Fledging continued in *June* over most of these areas, becoming more widespread in Iraq, where it probably continued into July.

Pakistan and India before the arrival of spring generation swarms

In late 1960, following a westward movement from Pakistan and India, some swarms moved east across northern India to reach Bangladesh and Assam (see Summary 4). Scattered locusts remained in Rajasthan in early 1961, probably the remnants of swarms that did not move out. In May and June, the numbers of scattered locusts increased until there was a report of a swarm at Jaisalmer (27°N 71°E) on 21 June, followed on 23 June by a swarm report 150 km further south. These swarms were too early to have come from spring breeding further to the west, for immigrants did not arrive in this area until 27 June, and it is most likely that they formed from the scattered populations already in India (see Cochemé 1966 and Case Study 8.1).

Eastward movements from May to August 1961

In May, young swarms were present only within the boundaries of the source areas (compare Figs. S8 a and e). Eastward movements from there began in June; in early June, swarms were reported in Kerman Province of south-central Iran between 5 and 8 June, and in Fars Province both inland and on the coastal plain and around Bandar Abbas (27°N 56°E). By 17 and 18 June, swarms had reached eastern Iran at Zahedan (29°N 61°E) and Bampur (27°N 60°E). Although these swarms could have come from a southern Iranian source it is also possible for them to have come from early fledging in north-central Saudi Arabia and in Iraq (see Siddiqi 1965).

In Pakistan, the first immigrant swarm was reported at Panjgur (27°N 64°E) on 23 June. During the next few days, swarms were reported in Las Bela District and north-west of Karachi (25°N 67°E). At the end of June, swarms were reported in the lower Indus valley of central and northern Sind (Fig. S8c), and a fresh wave of swarms from the west reached south-western Pakistan.

In India, the first immigrant swarms were reported in Kutch on 25 June, having crossed the Arabian Sea from Pakistan within the north-westerly airflow on the south-west side of a depression that was moving northward into Rajasthan from the Arabian Sea (see Siddiqi 1965, Cochemé 1966, and Case Study 8.1). There were seven reports of mainly immature swarms in the Rann of Kutch between 25 and 29 June. From this area they apparently moved northward and were seen in southern Sind (Pakistan) and southern Rajasthan (India) between 27 and 29 June (see Figs. S8 b and c, and Case Study 8.1).

In July, there were some swarms in central Saudi Arabia during the first ten days of the month, and swarms were reported in southern Iran in the first half of the month (Fig. S8c). In Pakistan and India, the number of swarm reports during the first week of July greatly increased, suggesting further influxes from the west. Most swarms at this time were in Sind and Rajasthan, west of 72°E (Case Study 8.2). Between 9 and 16 July, swarms moved north in Pakistan as far as Sargoda (32°N 73°E), while in India swarms moved north-east to reach 75°E. After 16 July there was little further movement to new areas, although one swarm was reported in southern North-West Frontier Province in Pakistan (see Figs. S8 c and e, and Case Study 8.2).

Swarms arriving in the monsoon breeding areas in late June and July 1961 rapidly matured, and started laying in early July, so that by the end of July laying was widespread over the infested area. By August, the distribution of swarms was more restricted and became confined to Sind and Bahawalpur in Pakistan, and to western Rajasthan in India (Fig. S8d).

CASE STUDY 8.1

SWARMS IN PAKISTAN AND INDIA, LATE JUNE 1961 (J.P.)

Swarms from the spring breeding areas of North-Central and Eastern Regions were first reported from the Makran of Pakistan on 23 June. By 30 June they had reached the lower Indus valley in Pakistan, and also nearby India, mostly in the Rann of Kutch between 25 and 29 June (Fig. C8.1a). Although a swarm of *mixed maturity* had been reported from Jaisalmer district of Rajasthan (27°N 71°E) on 21 June, as well as a *mature* swarm 150 km further south on 23 June, both these swarms seem to have been too early to have been part of the invasion from the west.

The first swarm in Pakistan, on 23 June, was likely to have come from spring breeding in the North-Central Region after passing through south-east Iran. Surface wind patterns across south-east Iran and the Makran of Pakistan are difficult to find because of the combined effects of lack of data and the complex winds near coasts and mountains, but locusts had moved into south-east Iran near the Pakistan border by 17 and 18 June, although further eastward movement into Pakistan appeared unlikely on the latter day, when there were northerly winds over Southern Baluchistan and the Makran. Westerly winds returned on 23 June, however, and movement into Pakistan was again possible.

Immature swarms were first reported in the Rann of Kutch on 25 June and it is likely that they reached there from the sea on west winds to the south of a strengthening cyclone that had first moved north-west over the Arabian Sea and then turned north-east to cross the coast of India on the 23rd, to be over Rajasthan by 25 June (Fig. C8.1b). If swarms had been near the Makran coast on 23 and 24 June they could have been carried out to sea on north winds to the west of the cyclone, the winds later changing to westerly as the cyclone moved inland. The first land to be reached by these swarms would have been the Rann of Kutch.

These swarms in Kutch are likely to have been the first to have reached India from the west. By contrast, the swarms in Rajasthan on 21 and 23 June were possibly formed by crowding of a scattered population that had been reported in the area throughout June and earlier. They became more numerous as the month progressed, possibly as the result of immigration from mid June onwards.

Later swarms, on 27 and 28 June at Mithi (25°N 70°E) and on 29 June at Barmer (26°N 71°E), however, could have come either from the west via Rann of Kutch, or from local populations by crowding. The airflow over the Rann of Kutch at the time was south-westerly, so swarms could have moved from there (Fig. C8.1a). From 28 to 30 June, swarms were reported in the western Makran of Pakistan and these swarms represented a fresh wave from the source areas.

Finally, swarms that were reported in the lower Indus valley on 28 and 30 June had most likely come earlier from the west and then moved up the valley when southerly winds returned on 27 June after the decay of the cyclone.

CASE STUDY 8.2

SWARMS IN PAKISTAN AND INDIA, LATE JUNE AND JULY 1961 (J.P.)

Spring generation swarms that had entered Pakistan and India in late June and July 1961 were confined to the Rann of Kutch and the desert areas west of 72°E up to 7 July, although the greatly increased numbers of reports implied continued invasion from the west and perhaps breaking up for egg laying (Fig. C8.2a). From 8 to 16 July, however, there was considerable movement east and north, but during the remainder of the month there was little further movement.

During the first week of July, mainly east winds on the north side of a cyclonic circulation centred over Gujarat (Fig. C8.2b) appeared to stop the eastward spread of swarms. Then from 7 to 16 July, during the period of maximum swarm movement, the more usual south-west and south winds blew over Pakistan and north-western India on every day, taking swarms to 74°E in Rajasthan and to 32°N in the Indus valley (Fig. C8.2c illustrates these winds for 14 July).

East winds returned to northern Rajasthan from 17 to 26 July, on the north side of an extensive area of low pressure over Rajasthan and central India, and they seem to have stopped further eastward movement of swarms. By mid July most swarms had matured and started to breed (and had therefore become less mobile), for there had been rain in the desert areas since 19 June. When westerly winds, similar to those illustrated in Fig. C8.2c, returned at the end of July, there was a further eastward spread of laying swarms into early August, but thereafter swarms of the spring generation seemed to die out.

SUMMARY 9

MOVEMENTS OF 1958 SUMMER GENERATION AND 1958–59 WINTER–EARLY SPRING GENERATION SWARMS FROM THE NORTH-CENTRAL REGION TO THE SPRING BREEDING AREAS OF THE NORTH-CENTRAL AND EASTERN REGIONS

In the summer of 1958, numerous swarms were produced from breeding in the North-Central Region (in Sudan, Ethiopia, and, over a less extensive area, in the People's Democratic Republic of Yemen (P.D.R. Yemen). This contrasted with the summer breeding in the Eastern Region, which was of limited extent and from which only low-density populations arose. Thus, the appearance of swarms in the winter and spring breeding areas of the North-Central and Eastern Regions in 1958–59 can be related clearly to movements from the summer breeding area of the North-Central Region. Further swarms, resulting from the winter and early spring breeding along the Red Sea Coast, became indistinguishable from the summer swarms in their later movements to the main spring breeding area, and they have therefore been included in this Summary.

This Summary deals with the changing swarm distribution from September 1958 (when the first fledging occurred in the summer breeding area) until June 1959 (when the last of the 1958 summer generation swarms and of the 1958–59 winter generation swarms were reported).

The area considered is delimited by 24°E in the west and 12°N in the south. The 1958 summer breeding to the west of 24°E and the migrations of resultant swarms (and possibly also of some swarms from the western Sudan breeding areas) are examined in Summary 18. The 1958 summer breeding in eastern Ethiopia extended southward to 10°N, and some of the Ethiopian summer swarms apparently moved southward in October and November 1958 on to the Somali Peninsula (in the South-Central Region), joining the 1958 Long Rains swarms already present in that area. The characteristic seasonal developments in that Region are discussed in Chapter 7 and are not considered here.

Early sources: 1958 summer breeding

The areas of summer breeding in the North-Central Region in 1958 are shown in Fig. S9e, with areas where fledging occurred during September only distinguished from areas where fledging continued into October. Where there were no direct observations, fledging dates have been estimated from laying and hopper reports. Fledging commenced at the beginning of September in central Sudan; some swarms were thus most probably ready for flight by mid September. The last report of a fledging swarm was in the P.D.R. Yemen, on 30 October.

Distribution and movements from September to December 1958

There were many reports of young swarms during September 1958 (Fig. S9a). None of these swarms was reported outside the breeding areas (Fig. S9e), but by 2 October a young swarm was reported in eastern Egypt at 26°N, over 700 kilometres away from the nearest part of the breeding area. It is unlikely that a swarm could have covered a distance of 700 kilometres in only the first two days of October so it is probable that this northward movement commenced at the end of September, by which time there were many swarms ready for flight in the breeding areas. In Fig. S9e, however, the northward spread of swarms into Egypt is shown as taking place in October, the month with the first *recorded* swarm appearance north of the breeding areas. During the last 20 days of October, swarms continued to spread northward, and by the end of the month at least one swarm had crossed the Gulf of Suez into southern Sinai (Figs. S9 b and e).

Also during the second half of October, swarms appeared on the northern Red Sea Coast of Sudan, where the first report was on 20 October. Some of these swarms may have moved northward from the breeding areas (where they may have fledged later than those involved in the earlier northward movement), but others may have moved south-eastward on to the Red Sea Coast, having earlier moved northward into eastern Egypt.

A third movement during this period was northward into south-west Saudi Arabia from the breeding area in the P.D.R. Yemen. Some swarms may have crossed the Red Sea from northern Ethiopia for, although there were no reports of locusts at sea to provide added evidence of such a movement, the many swarms reported near Gizan (16°N 42°E) from 11 October suggest that swarms may have moved north-eastward from northern Ethiopia (where there had been many reports of swarms throughout October), combining near Gizan with the fewer swarms reported moving north from the P.D.R. Yemen. By 30 October, a swarm was reported as far north as 21°N in the uplands of west-central Saudi Arabia (Fig. S9e).

Figs. S9c and e show the spread of swarms into central and northern Saudi Arabia during November. By the end of the first ten days, swarms had reached 31°N 37°E in north-western Saudi Arabia, and 29°N 44°E in southern Iraq, suggesting that a fairly rapid movement northward and eastward took place in early November. There were no reports of swarms in Egypt between 2 and 22 November, so it is probable that swarms had moved eastward from there into north-western Saudi Arabia in early November. If west-to-east crossings of the central Red Sea did not, in fact, occur, then this may have been the main pathway during the year for swarms moving from the summer breeding areas towards the spring breeding areas of the North-Central Region. The reappearance of swarms over a broad front in eastern Egypt during the last ten days of November suggests that they returned on north-easterly winds from north-western Saudi Arabia; this south-westward movement is illustrated by broken arrows in Fig. S9e.

During the first ten days of November, over the southern Red Sea there were reports of locusts, including one swarm, between 17°N and 20°N. It is not clear whether these locusts were moving eastward or westward, but by the middle ten days of November swarm emigration from the Red Sea coastal areas of Ethiopia, Sudan and Saudi Arabia apparently decreased as swarms began to mature in the winter breeding areas.

The spread northward and eastward in Saudi Arabia is shown on Fig. S9e with a broken limit over central Saudi Arabia. This limit is uncertain as it borders the Rub-al-Khali area of Saudi Arabia, where swarms may pass totally unreported. Similarly, in the south of the Arabian peninsula, following an initial eastward spread of swarms from the P.D.R. Yemen breeding area during the first ten days of November, a continuation of the movement eastward in early December towards the Rub-al-Khali area is shown on Fig. S9e with an 'uncertain' limit.

Coincident with the eastward spread of swarms in the south of the Arabian Peninsula, there was a strong eastward movement from the north-east of the Arabian Peninsula, carrying swarms as far as 55°E in the United Arab Emirates and 57°E on the Gulf Coast of southern Iran by 6 December. Swarms were reported at sea over the south-eastern part of the Gulf (Fig. S9d) but, as with the limits drawn round the Rub-al-Khali, the limits drawn over the sea must be 'uncertain' because reporting is inevitably incomplete. By the beginning of the last ten days of December, swarms had crossed the border from Iran into the Makran area of Pakistan (Figs. S9 d and e).

Subsequent to the eastward movement of swarms from north-*eastern* Saudi Arabia in early December, swarms spread northwards during the last 20 days of the month from north-*western* Saudi Arabia and probably also Egypt (where there had been no reports after the first ten days of December) into Jordan, Israel and Syria (Figs. S9 d and e). Hence, by the end of December, swarms from the summer breeding areas in the North-Central Region had spread northward and eastward, reaching as far north as 32°N and as far east as 63°E. Young swarms were also beginning to appear during December in the winter and early spring breeding area along the east coast of the Red Sea. The breeding that led to these swarms is discussed next.

Later sources: 1958–59 winter and early spring breeding

Swarms from the 1958 summer breeding areas in the North-Central Region began to mature along the eastern Red Sea Coast in the Yemen Arab Republic during October; the first laying was reported on 18 October. Swarms along the Red Sea coasts of Sudan, Ethiopia and Saudi Arabia began to mature and lay in November. Fledging from this winter and early spring breeding along the Red Sea Coasts occurred from December to March. It is included in this Summary because the emergent swarms matured rapidly and became indistinguishable from swarms that had come from the 1958 summer breeding.

Fig. S9h shows areas where there was fledging from December to February, and Fig. S9j in March. Fledging dates were estimated from laying and hopper records where no direct observations were available. Most breeding on the *west* coast of the Red Sea was successfully controlled: there were no fledging swarms reported in Sudan and only two in Ethiopia, during early January. It is not clear what became of these swarms, but they may have matured locally to contribute to spring breeding there.

There were more escapes from the breeding areas on the *east* coast of the Red Sea, in spite of control measures. Fledging commenced in mid December and continued to mid March; the last report of fledging from this breeding was on 15 March, on the coast of Saudi Arabia. Swarms from the east coast of the Red Sea moved into the interior of Saudi Arabia and matured quickly, becoming indistinguishable from the summer swarms by April 1959.

Distribution and movements from December 1958 to February 1959

Fig. S9h shows that the changes in swarm distribution from December to January and February were small compared with the changes during the previous months. During the first ten days of January, swarms moved westward from Jordan to western Sinai, where the last report had been in November. These swarms were reported to be controlled, and from Fig. S9g it can be seen that there were no swarms reported in Sinai in February.

In Syria, there was some northward spread of swarms during the first ten days of January, but this was followed in February by a decline in the reported swarming population in Jordan, Syria and Israel (compare Figs. S9 f and g), probably due to emigration east or south.

The north-westward spread of swarms across the Tigris-Euphrates plain in Iraq commenced in the second half of January, and swarms reached 31°N by 24 January. A further spread was not reported until the end of February, when swarms reached 33°N by the 28th.

Further east, swarms spread northward in extreme south-eastern Iran (Fig. S9h). Swarms were reported at 27°N 60°E during the last ten days of January, and reached the same latitude near the Pakistan border during the middle ten days of February. Thus, there was a gradual spread of swarms over south-eastern Iran.

In the Arabian peninsula, swarms appeared in the Hajjar mountains of Muscat and Oman during the middle ten days of January. It is possible that they had come from the south-west, passing unreported across the Empty Quarter, but they were *mature* and this suggests that the movement had been south-eastward from the Trucial Coast, where there were also *mature* swarms, and not north-eastward from the P.D.R. Yemen, where *immature* swarms continued to be reported until the last ten days of January.

Comparison of Figs. S9 f and g shows that the P.D.R. Yemen became free of swarm reports by February. It is probable that there was a movement north-eastward into central Saudi Arabia from the south-western parts of the Arabian Peninsula — as there had been in January and February 1952 (cf. Summary 10).

Distribution and movements in February and March 1959

Fig. S9j shows the limit of the recorded distribution of swarms in February and the changes in distribution that occurred during March. The previous section mentioned the fewer swarms in Jordan, Syria and Israel in January compared with February, and by March (Figs. S9 g and i) there were fewer still.

Further east, however, the north-westward spread of swarms across the Tigris-Euphrates plain continued, and swarms also moved northward into south-western Iran (Fig. S9j). These movements, and the somewhat smaller northward spread of swarms in southern Iran at 57°E, all took place during the last ten days of March.

On the other side of the Gulf, swarms on the Oman peninsula spread south-eastward, although it is not known whether this occurred during March or April. Comparing Figs. S9 g and i, it can be seen that the main change in swarm distribution between February and March was the almost complete disappearance of swarms from the eastern Red Sea coast, apart from a few young swarms which resulted from the last of the early spring breeding and which became indistinguishable from the previous summer's swarms by April.

In March, in the P.D.R. Yemen and north-eastern Ethiopia, the last reports were received of swarms which may have been part of the 1958 summer generation. These swarms may have contributed to the subsequent production of spring swarms in these areas.

Distribution and movement from April to June 1959

The March swarm distribution (Figs S9 i and n) showed an almost total absence of reports in the countries bordering the eastern Mediterranean. During April, however, swarms spread into Jordan, Israel, Syria and northern Iraq, and across the border into southern Turkey from the population in north-central Saudi Arabia and Iraq (Figs. S9 k and n). By the middle of April, there were no more reports of swarms in north-central Saudi Arabia, and swarms had reached 36°N 37°E in northern Syria by 14 April.

During the last ten days of April, swarms also spread further north in western Iran (Figs. S9 k and n).

By May, there were no further reports of swarms from the summer or winter—early spring breeding anywhere on the Arabian peninsula (Fig. S9l), whereas in the northern areas the swarm distribution was not significantly different from that in April. The only major change was a re-invasion of Sinai (free of swarms since January) during the first ten days of May, with swarms extending to the Nile Delta by the beginning of the middle ten days of May (compare events in 1952 — Summary 10).

In the Eastern Region, swarms spread slightly further east in southern Pakistan during April, but the northward movement shown on Fig. S9n into eastern Iran and western Afghanistan may have been in April or May. Reports did not specify in which of the two months swarms were seen in Afghanistan, and the spread into eastern Iran is drawn on the basis of a June hopper report (with fledging at the end of the month) which may relate to the presence of breeding swarms in either April or early May.

Fig. S9n also shows the possibility that swarms spread into central Pakistan during May. Swarms reported there were of unknown maturity but, because there was at least one report during the first week of the month (before young swarms appeared in southern Pakistan), and because there had been no reports of spring breeding in central Pakistan, it seems probable that these swarms belonged to the 1958 summer or 1958—59 winter—early spring generations. In Iraq in June, there were two reports of mature swarms (Fig. S9m) which may have been part of the summer or winter—early spring generations. Elsewhere, however, there were no reports of swarms from these generations after May 1959 and it can be assumed they died.

It has been seen that swarms moving from the North-Central Region 1958 summer breeding areas, and others joining them from the 1958—59 winter—early spring breeding areas, moved over large parts of the North-Central and Eastern Regions.This led to widespread spring breeding in the Middle East and the Arabian Penisula.

SUMMARY 10

THE SPREAD OF 1951—52 SHORT RAINS SWARMS OVER THE NORTH-CENTRAL, EASTERN AND SOUTH-CENTRAL REGIONS

This Summary deals with the migrations across the North-Central, Eastern and South-Central Regions by the swarms produced on the Somali Peninsula during the 1951—52 Short Rains breeding season. It illustrates the very wide range of the migrations of the Desert Locust, and the way in which swarms originating in a single Region may give rise to extensive hopper infestations over three Regions.

Sources

By the end of 1951, both the Eastern and the North-Central Regions appeared to be free of swarms. The events preceding the disappearance in the Eastern Region of the 1951 monsoon generation swarms are discussed in Summary 2.

In the North-Central Region, no swarms were produced during the 1951 summer breeding in Sudan, and the few swarms produced in north-eastern Ethiopia and P.D.R. Yemen, during the very restricted breeding in these countries, disappeared by December, possibly moving to, and breeding on, the Somali Peninsula. Thus, the only source of a large population of swarms was the Somali Peninsula. Here, the 1951 Short Rains breeding was heavy, extending from the north of Somali Republic (North) southward to about 1°N, and it was widespread in Ogaden and eastern Sidamo and Borana Provinces in Ethiopia, as well as over Somali Republic (South) (Fig. S10c). Hatching began in the last ten days of October in the north, and continued till late November in the south. In spite of intensive control operations, large areas remained uncontrolled and numerous young swarms made their appearance. These were formed between about 11 and 6°N in the first half of December, and between 9 and 1°N in the second half of the month, with the formation of swarms continuing into the first half of January between 6 and 3°N (Fig. S10c).

During December 1951, all the young swarms were reported within the source area (Figs. S10 a and c), but during January 1952 they began to move both northward and south-westward. Wind patterns at the time of similar contrasting movements are illustrated for 1955 in Case Study 14.1. Movements in these opposite directions are described separately below.

Movements to the North

Swarms first moved to the west and north of the source area in the first half of January 1952 — westward to the Harar Highlands of Ethiopia, and then northward to the Dessye escarpment (11°N 39°E) and to near Aden in the P.D.R.Yemen (12°N 44°E and 13°N 45°E; see Case Study 10.1). A further northward spread took place in the last ten days of January, first through Afar, Danakil and coastal Eritrea, across the southern Red Sea to south-western Arabia (north to about 20°N; see Figs. S10 b and c, and Case Study 10.2), and then rapidly northward with swarms reaching Hail (26°N 42°E) on 5 February, as far as Israel (at 31°N 35°E) by the 6th, and the southern border of Iraq (at 29°N 44°E) by the 8th (Case Study 10.3).

This direction of movement over Arabia is typical for the winter–spring season, when it usually involves swarms produced in summer breeding areas of the North-Central Region; its speed, during some of its stages (e.g. Bishah 2 February to Ansab 8 February — 1,150 km, about 190 km a day) was rapid, and comparable to some rapid displacements of young swarms across the Sahara (compare Summary 18, or Betts 1976) or from India to Iran and Oman.

After further crossings to the southern Red Sea in early February, swarms had spread over central and northern Arabia to reach Iraq, Kuwait and southern Iran by the 23rd (Case Study 10.4). Further spread, late in February and early in March, took swarms eastward on both sides of the Gulf, reaching to Oman, and to near Jask (26°N 57°E) in Iran on the 5th, but in the second half of March the spread was more to the north and north-east across Iran, reaching the Pakistan border (at 29°N 61°E) by the end of the month. During April there was a spread to Baluchistan and Quetta, and during May to Sind and western Rajasthan. Finally, in June, young swarms of the 1952 spring generation, moving west to east across Pakistan and into north-west India, were joined by some old Short Rains swarms, but they were probably too senile to take part in 1952 monsoon breeding (compare Summaries 1, 6 and 8). It will be seen that on this occasion Iran and Pakistan were invaded by swarms moving in from the west and spreading to the east — in contrast to the more frequent invasions by monsoon swarms which move from east to west. The east-to-west displacements occur earlier in the season, however, usually between September and November. For wind systems in which the eastward movements take place see Case Studies 6.1, 8.1 and 8.2. Meanwhile, other swarms which had moved north from the Somali Peninsula did not cross the Red Sea to Arabia. Some moved north through eastern Eritrea to the Sudan border by the end of February, and as far as about 20°N in coastal Sudan in March, but yet others moved onwards to the Ethiopian highlands, appearing in February near Lake Tana (12°N 37°E) (Figs. S10 d, e, f and g).

The northward spread across Iran in March continued in April and May, reaching Afghanistan and north-east Iran as far as Mashad (36°N 45°E). Further west, swarms in March spread both northward into western Iran and Iraq as far as Khanaqin district (34°N 45°E), and north-westward across northern Saudi Arabia and Jordan. In April, the spread continued to Israel, Syria and north-western Iraq; and in May, swarms reached as far north as Mosul (36°N 42°E) (Figs. S10 f, h, i and k). These movements took place in wind systems of the kind described in Section 6.3 and illustrated in Case Studies 10.1 to 10.9.

At the time of the invasions of Jordan and Israel in April, some swarms moved into Sinai and one reached as far as the Egyptian coast of the Red Sea at about 30°N. There were similar invasions in May, but there were no more reports from Sanai and Egypt after 24 May and the swarms had most probably moved south-westward to central Sudan, mixing there with other mature swarms that had moved into Sudan from the south-east, as described below. Analogous movements into Sudan from Arabia took place in May 1954 and May 1955, both involving young spring generation swarms (Summaries 11 and 12). Case Study 11.2 describes such a movement.

The swarms spreading across Arabia and the Middle East began to mature and lay from February onwards. Hatching started in March, and from then until June there were widespread hopper infestations, leading to the appearance of new swarms between May and July 1952.

Movements to the south-west

The first wave of young swarms to move south-westward from the source area was in early January 1952. It reached north-east Kenya, but then turned north-westward to southern Ethiopia, and then north-eastward in February to the Rift Valley of Ethiopia. A second wave took a similar track in February (Figs. S10 d and e). In March, swarms from the Rift Valley moved north-east across eastern Ethiopia, some going onward to the northern Somali Republic (North) as far as Erigavo (10°N 48°E) by the end of the month, and some going to north-eastern Ethiopia to join the swarms already there (Figs. S10 f and g). Swarms continued to spread eastward and southward across the Somali Republic (North) and eastern Ethiopia during April, laying as they went, and they reached Somali Republic (South) during May (Figs. S10 h, i and k). Subsequently there were widespread hopper infestations of the Long Rains generation in eastern, south-eastern and southern Ethiopia and in the Somali Republic, followed by new swarms in June and July.

Meanwhile, the northward movement in northern Ethiopia continued in April and May, when it involved mature swarms. In May, swarms moved westward across the highlands of northern Ethiopia into central and eastern Sudan, joining others that had probably come across Egypt from Saudi Arabia, as described above (Figs. S10 h, i and k). Similar movements by mature swarms from the Somali Republic across northern Ethiopia to Sudan and countries to the west are described in Summaries 11 and 12, and in Case Study 11.1.

CASE STUDY 10.1

NORTH-WESTWARD SPREAD OF SHORT RAINS GENERATION SWARMS, EARLY JANUARY 1952 (J.P., J.R.)

Swarms first appeared to west of their source area from 5 to 9 January — on the Harar Plateau and in the Railway Area (Fig. C10.1). Sightings on the 5th and 6th may represent slow westward movement over many days across the Harar highlands, where day maximum temperatures were about 20°C. The sighting on the 9th, further west, may show part of the same movement, but the 9th was the first day in January with afternoon temperatures greater than 25°C over the Somali highlands (as represented by Hargeisa) in a spell lasting until the 13th. During this spell, movement would presumably have been more rapid. There were north winds each day at Hargeisa but these are likely to have been local, judged by the synoptic pattern, which would have given east winds over the highlands and south-easterlies over the southern Red Sea. The onset of higher temperatures at Hargeisa coincided with a spell of strong south-easterlies at Assab, associated with a weakening cold front moving south-east across Arabia between 9 and 12 January.

The first extension northward occurred during 13–15 January, when swarms were reported in south-west Arabia near Aden, and near Dessye in Ethiopia (Fig. C10.1). The Dessye report on the 15th possibly shows a further westward movement of swarms across the southern Afar lowlands, but the reports near Aden on the 13–14th came after unbroken winds from the east and south-east at Aden during January. If the Aden swarms had crossed the Gulf they would not have come from the south or south-west, but from the eastern Horn of Africa. The small day-to-day changes in wind and temperature at 1,000 mbar (about 150 m) over Aden (taken to represent the air in which flight probably took place) do not suggest a particular synoptic event associated with arrival of swarms, which may have been set more by their readiness to fly at source.

CASE STUDY 10.2

NORTHWARD CROSSING OF THE SOUTHERN RED SEA, LATE JANUARY 1952 (J.P., J.R.)

There was little change in the distribution of swarms until the striking northward spread of 23–25 January. On the 23rd, swarms were reported flying north-eastward in the Marsa Fatma area on the Red Sea coast of Ethiopia, and a swarm flew north-eastward on the Tihamah coast near Qunfidhah. On the 24th, swarms were reported to south and west of the Republic of Djibouti, as well as within that country, and on the 25th they appeared on the Eritrean coast between Marsa Fatma and Edd. On the Tihamah coast, a large swarm was reported to south of Qunfidhah on the 24th; more swarms flying north-eastward came onshore between Qunfidhah and the Yemem border on the 24th and 25th; and a swarm was reported flying from the south-east over Kamaran Island on the night of 25th–26th. On the Yemen coast, swarms were seen coming onshore between the northern border and Hodeida (about 15°N) some time in the last week of January (Fig. C10.2).

The striking northward spread of 23–25 January coincided with:

> a warm spell at Hargeisa from the 22nd onwards, with afternoon temperatures greater than 24°C, and sometimes 28°C;
>
> a spell of 15–25 kt south or south-east winds, 19th onwards, at Assab and Kamaran Islands, a common event at this time of year.

Throughout the remainder of the month, pressure was high over eastern Arabia, with persistent south or south-east winds over the southern Red Sea. It therefore seems that rising temperatures over the Somali highlands allowed more extensive flight than earlier in the month, and hence renewed emigration, followed by rapid northward movement, probably along with a similar movement by swarms already over the Afar lowlands.

On 28–29 January, more swarms came onshore in the Tihamah near Gizan (17°N), and altogether some 18 swarms were estimated to have reached the Saudi coast between the 23rd and the 29th. The flight of the immigrant swarms continued northward and north-eastward: on the 26th some were reported in the northern Asir mountains, by the 29th to south of Bishah, and on 3 February to north of Bishah (Fig. C10.2).

In February, swarms continued to be reported in Somali Republic (North), in Ogaden and in northern Ethiopia, where they spread into the Gondar area and upper Takazze valley and in the coastal area northward to the Sudan border. Similarly in south-west Arabia they were reported in coastal areas and foothills of Yemen, in P.D.R. Yemen (mainly within the area invaded in January), and in Saudi Arabia.

CASE STUDY 10.3

NORTHWARD SPREAD ACROSS ARABIA, EARLY FEBRUARY 1952 (J.P., J.R.)

Several swarms flying north-eastward crossed the Tihamah coast between Qunfidhah and the Yemen border between 6 and 9 February. Meanwhile the earlier invaders continued to spread northward over Saudi Arabia, and on 5 February were reported to south of Hail, while on the 6th a swarm reached Israel, near Jerusalem (where there was another report on the 9th). On the 7th, there were first reports of swarms in the Buraydah area and to east of Hail, and on the 8th to west of Hail, and near Ansab on the southern border of Iraq just west of the Neutral Zone. On the 9th, further swarms were reported to south and south-east of the Neutral Zone, and on the 11th some swarms flew northward across the Neutral Zone into southern Iraq, where one was reported north of 31°N to west of Al Amara (Fig. C10.3a).

On 2–3 February, a cold front moved south-eastward over north-west Arabia; by the 4th it was over Bahrein. South winds ahead of it (Fig. C10.3b) probably extended the swarm movements of late January from the Tihamah and Asir into central Arabia. From 4 to 7 February, there was high pressure over eastern Arabia and the resulting south-east winds (Fig. C10.3c) probably took swarms across north-central and north-west Arabia to Israel. Swarms were seen in those areas on the 5th and 6th respectively. From 8 to 10 February another cold front moved south-eastward over north-west Arabia. A renewal of south winds ahead of it (Fig. C10.3d) could have taken swarms from central Arabia to south-east Iraq, north-east Arabia and the Neutral Zone. Cold air had already flooded Iraq by the 10th, so movement to that country was most likely to have taken place on the 9th. Swarms were seen near the border on that day, but not until the 11th over Iraq, probably showing a two-day lag in sighting after arrival.

CASE STUDY 10.4

SPREAD TO KUWAIT, IRAQ AND IRAN, LATE FEBRUARY 1952 (J.P., J.R.)

The period 14–18 February was apparently one of active flight in northern Saudi Arabia: from the 14th to the 16th flying swarms were seen to east and south of the Neutral Zone; on the 17th and 18th there were several reports from the Buraydah area; and the invaded area extended eastward on to the Hasa, south of Kuwait, on the 17th and 18th (Fig. C10.4a). From 11 to 18 February, north-west winds, with afternoon temperatures not greater than 20°C, blew over Iraq and northern Arabia, gradually turning to north-east. There was probably a little flight on each day, taking swarms slowly south-eastward across north-east Arabia, as illustrated by the reports from near Kuwait on the 17th.

A spread to the north-west began on the 21st, when swarms flying with a strong south-east wind appeared in Kuwait. On the 22nd more flying swarms were reported to south of the Neutral Zone and scattered locusts appeared near Bushehr on the coast of south-west Iran. On the 23rd, swarms appeared to west and north-west of Basra, in south-east Iraq, and in the coastal areas of south-west Iran between the Iraq border and Bushehr, and inland at Borasjun (29°N 51°E).

By the 21st and 22nd, a deepening low over Iraq caused strong south-east winds over the northern Gulf (Fig. C10.4b), but a cold front moved south-eastward to pass Bahrein by the 23rd, when Iraq had become covered by north-west winds with the afternoon cooler than 20°C. Swarms at Kuwait on the 21st, and south of the Neutral Zone on the 22nd, probably represent widespread movement on south winds from north-east Arabia back to south-east Iraq, but also into south-west Iran (Bushehr locusts on the 22nd). This movement would have stopped by the 23rd because of the passage of the cold front, although swarms were widely reported on that day (i.e., there was a lag in sighting of about a day).

A few days later the movement on both sides of the Gulf may have become towards the south-east, for on the 25th and 26th swarms were reported in the Hofuf area and on Bahrein (arriving on the 25th) while in Iran they were reported on the 27th on the coast near Daiyir (Fig. C10.4a). Up to the 27th, cool north-west winds covered the Gulf. Swarms reported on the 25–27th were probably part of a slow south-eastward spread after the 23rd.

CASE STUDY 10.5

NORTHWARD SPREAD ACROSS THE MIDDLE EAST, LATE MARCH 1961 (B.P.)

By March 1961, swarms were beginning to leave their winter locations to move on to areas in which spring breeding commonly occurs. Between 24 and 29 March 1961 depressions crossing the Middle East brought two periods of warm, southerly winds and temperatures became temporarily high enough for active flight. As a result, a number of swarms moved northward and were reported in areas previously clear of locusts (Fig. C10.5a). Swarms were reported in southern Syria on 26 and 29 March in districts which were north-east of those infested earlier in the month. On 27 March there was a report of a mature swarm near Lake Tiberias in northern Israel; swarms in Israel had previously been confined to southern districts. In Iran, immature swarms were reported on 27 and 28 March in the Kermanshah district of Lorestan, close to the Iraq border (Fig. C10.5a). These were about 850 km north-west of the nearest breeding areas in Iran where fledglings might have been expected before 25 March, and 750 km north-east of the nearest immature swarms in Saudi Arabia (reported rather imprecisely as 5–10 and 24–31 March).

On 24 March, west to south-west winds became established in southern Syria ahead of a low over Cyprus. Temperatures were 23–28°C at 1200 GMT. During 25 and 26 March there were westerly winds over Syria and Iraq as a cold front moved away eastward, and temperatures fell to 15–21°C, thereby reducing swarm movement over those countries. Thus, the swarm reported in southern Syria on 26 March is likely to have moved north-eastward on 24 March but had not been reported until two days later.

On 25 March, strong, warm (about 30°C at 1200 GMT) southerly winds had spread to the lowlands of western Iran ahead of the cold front, which by then was lying southward through eastern Iraq into northern Saudi Arabia, but on the next two days cooler westerly winds had spread across western Iran, with temperatures about 20–25°C over the lowlands. The swarms in Kermanshah district therefore probably arrived from the *south* on 25 March (although not reported until 27 March), but they could have come from the *west* on 26 or 27 March (on winds still warm enough for some flight), after having moved north from Saudi Arabia on the 25th or the previous few days.

While the cool, westerly winds were blowing over western Iran on 27 March, south to south-east winds became established over Jordan, Israel and western Syria as a desert depression moved into north-west Egypt. 1200 GMT temperatures were 20–25°C over those countries and it was on that day that the swarm was reported from northern Israel. On the next day, 28 March, south to south-easterly winds had spread to the rest of Syria and to Iraq with 1200 GMT temperatures 23–25°C; the former desert depression was centred over Cyprus with its cold front lying south along the Levant Coast into Sinai and Upper Egypt (Fig. C10.5b). Swarms would again have been able to begin moving northward in Syria (more swarms were reported on 29 March), and also in the lowlands of western Iran with the renewed onset there of warm, south-east winds.

With the passage of the cold front on 29 March, 1200 GMT temperatures fell to 16–22°C over the Levant and Syria, with winds again becoming westerly. On 30 March, the cold front was crossing western Iran; westerly winds then blew over most of the Middle East, temperatures were mainly below 20°C, and it was cloudy with widespread rain. In this weather, large-scale swarm movements stopped for a few days; no more swarms moved northward in the Middle East until the next spell of warm, southerly winds in early April 1961 (see Case Study 10.6).

CASE STUDY 10.6

NORTHWARD SPREAD IN EGYPT AND SYRIA, EARLY APRIL 1961 (B.P.)

In the south-eastern desert of Egypt there were many reports of swarms, mostly immature, between 3 and 7 April 1961. Some were reported north of Quseir on 6 and 7 April (Fig. C10.5a) — further north than the young swarms previously reported in March 1961 — suggesting that a northward movement had taken place.

During the first few days of April 1961 a shallow desert depression crossing North Africa deepened as it reached Sinai and northern Saudi Arabia (Fig. C10.6b). This disturbance brought a spell of weak southerly winds to south-eastern Egypt on 3 April and early on 4 April, the first such spell since 27 March. 1200 GMT temperatures there rose from about 32°C on 3 April to 36°C on the following day.

By 1200 GMT on 4 April, the centre of the depression was moving over Sinai towards northern Arabia and its cold front had almost crossed south-eastern Egypt. Ahead of the front, light southerly winds were probably still blowing over the south-eastern corner of Egypt, but the front was followed by north-westerly winds and falling temperatures. The locusts were most likely, therefore, to have moved northward on 3 and 4 April and the swarm reports on the following few days probably indicate a time-lag in swarms being seen after arrival.

This same desert depression gave warm south to south-east winds over Syria (Fig.C10.6b). Mature swarms had already infested the southern part of that country, but a swarm was reported on either 2 or 3 April (the report is not clear) north-west of previously reported locusts (Fig. C10.6a), having presumably moved on the south-east winds. (On 2 April, winds over Syria were westerly and 1200 GMT temperatures were below 20°C, unaffected by the desert depression which had not then reached Egypt, so it is more likely the swarm was seen on 3 April.)

No more swarms were reported further north in Egypt until 13 April, a day after the next spell of warm southerly winds blew across south-east Egypt. In Syria, there were warm south-east winds on 26 April, but no further northward movement of swarms took place throughout April.

CASE STUDY 10.7

NORTHWARD SPREAD ACROSS THE MIDDLE EAST, EARLY MARCH 1962 (B.P.)

During their northward spread over the Arabian Peninsula in early 1962, swarms had reached about 25°N in the west, and as far as Kuwait (about 30°N) in the east, by the end of February (Fig. C10.7a). Over a few days in early March 1962, swarms were reported in several places further north: at Sakakah in northern Saudi Arabia on 7 and 8 March, Jordan and Israel on 8 and 10 March, and Lorestan in eastern Iran on 10 March (Fig. C10.7a). Movement of swarms took place in a tongue of warm southerly winds ahead of the cold front of a desert depression which was joined by another deep depression moving south-eastward from the Balkans (Fig. C10.7b).

The desert depression moved from south-west Libya on 6 March to be centred over northern Egypt on 7 March. The 1200 GMT temperature on 7 March in northern Saudi Arabia was about 24°C as the warm air ahead of the cold front began spreading there. This was about 2°C higher than the temperature at 1200 GMT on the previous two days. On 8 March the deep depression from the Balkans joined the desert depression, which had in the meantime moved north-eastward from Egypt. The cold front lay from Syria across Jordan and north-west Saudi Arabia into Sudan. Ahead of this front winds became southerly over Iraq and northern Saudi Arabia, and temperature rose to 28–29°C. Behind the cold front, cooler air had spread rapidly east and south-east into Egypt and across the Levant. Strong westerly winds blew over the eastern Mediterranean and more cold air spread southward across western Turkey behind the low, now over south-western Turkey. There was widespread rain on this day over much of Turkey, Syria and northern Jordan.

The partly mature swarm reported reaching southern Jordan on 8 March probably arrived there or nearby the previous day. After the passage of the cold front, temperatures had probably fallen low enough (22–23°C at 1200 GMT) to inhibit much flying. The swarm in Israel is likely to have come north also on 7 March, moving to near Eilat by 10 March. In Iran, the swarm which arrived and laid in the Kuhdasht area of Lorestan on 10 March could have moved northward on either 9 or 10 March, when warm southerly winds were blowing there ahead of the cold front, which had reached about 50°E by 10 March.

CASE STUDY 10.8

NORTH-WESTWARD SPREAD TO SYRIA AND TURKEY, APRIL 1962 (B.P.)

By the middle of April 1962, swarms over the Middle East had moved north into Jordan, southern Iraq and western Iran (Fig. C10.8a). Then came reports that swarms had reached the Deir-ez-Zor district of south-eastern Syria on 15 April, and Mardin Province of Turkey on 18 April, while in Iraq swarms became widespread in central and northern districts from 14 April onwards.

On 14 April, a depression moving from the Balkans deepened on arrival over western Turkey. Its associated cold front extended southward through western Syria and Jordan (Fig. C10.8b). Southerly winds were blowing ahead of the front over northern Saudi Arabia and Syria, with temperatures 29–32°C at 1200 GMT. Winds had become easterly over northern Iraq. On 15 April there were well-marked south-easterly winds over eastern Iraq ahead of the cold front, which had by that day moved into western Iraq.

The swarm that was reported from Syria probably arrived on the warm southerly winds of 14 April. The small mature swarm reported on 18 April in south-eastern Turkey may well have entered the country on 15 April, because on that day warm south-easterly winds blew across Iraq as far north as the Turkish border.

The depression moved eastward into Iran on 16 April (Fig. C10.8b), and south-west winds became established in its rear over Syria and southern Turkey. Temperatures initially dropped to 23–24°C after the passage of the cold front. The following day a desert depression moved across northern Egypt, bringing a return to a southerly airstream over Syria, Iraq and southern Turkey. Temperatures rose to 30°C over central Iraq, where there were several swarm reports that day from areas previously clear of locusts (Fig. C10.8a). By 18 April, the desert depression had shifted to the Levant, giving east and south-east winds over northern Syria, neighbouring Iraq and southern Turkey. Temperatures would have just been high enough (about 22°C at 1200 GMT) for locusts to fly in southern Turkey, though the swarm reported there was more likely to have come on 15 April when the winds were also south-easterly but a few degrees warmer. There were no more reports of swarms in Turkey until the following month.

CASE STUDY 10.9

WESTWARD SPREAD IN SYRIA AND TURKEY, MAY 1962 (B.P.)

By the end of April 1962, swarms had moved northward over the Middle East to become widespread in Iraq and eastern Syria, and a swarm had entered south-eastern Turkey. Swarm movement continued into May, and on the 4th and 5th there were several reports in new areas of central and north-eastern Syria. The swarms were mature, some of them stopping to lay eggs. Also on 4 and 5 May there were mature swarms reported from southern Turkey in districts of Mardin Province which had previously been uninfested (Fig. C10.9a). Swarms had apparently been migrating fairly rapidly in a north to north-westward direction.

In early May, a vigorous desert depression, which had started south of the Atlas Mountains, moved eastward into northern Egypt and on to eastern Syria (Fig. C10.9b), bringing with it a strong surge of warm southerly winds. When the depression was centred over Sinai on 3 May it gave south-easterly winds over Jordan and easterlies over Syria, with 1200 GMT temperatures about 30°C. On 4 May, the depression deepened and moved quickly across to northern Syria (Fig. C10.9b). There were then strong south-east winds over Iraq and temperatures 34–39°C. With the passage of the cold front there was a change to westerly winds over Syria and temperatures fell to about 28°C.

Weather maps show that downwind movement of swarms would have been ahead of the cold front on 3 May or early on 4 May, though some swarms were not seen until 5 May, by which time the cold front had moved to north-western Iran (Fig. C10.9b). Westerly winds were blowing across Syria and southern Turkey on 5 May and temperatures by then had fallen to 24–25°C. There were subsequently no reports of swarms from areas further west or north in both Syria and Turkey until the last week of May; during this interval there were no more spells of warm south-east winds.

SUMMARY 11

MOVEMENTS OF 1953–54 SHORT RAINS AND 1954 SPRING GENERATIONS SWARMS IN THE 1954 SUMMER BREEDING AREAS OF THE WESTERN AND NORTH-CENTRAL REGIONS

During May and June 1954, the summer breeding belt in the Western and North-Central Regions, which had been free of swarms since February 1954, was invaded by both mature and immature swarms. There were three main components for this invasion: *mature* swarms of the Short Rains generation that moved in from the Somali Peninsula, and *immature* swarms that moved in from the 1954 spring breeding areas in North-West Africa and the Middle East (Fig. S11 d). There was a similar pattern of movements in 1955 (Summary 12). The area concerned is bounded by 9°N in the south, to include the northern part of the Somali Peninsula where mature swarms of the Short Rains generation were reported during April, but this Summary is not concerned with details of movements within the South-Central Region (Summary 16). To the east, the area is bounded by 52°E, to include all the mature swarms reported in northernmost Somalia in April 1954. The movements of spring swarms from the Arabian Peninsula into the Eastern Region are dealt with in Summary 6.

Sources

Somali Peninsula and the Yemens

Short Rains swarms, produced by breeding in the South-Central Region from October 1953 to early 1954, had matured by April and were spread over a wide area in the northern part of the Somali Peninsula, and almost certainly also in the Yemens, having crossed the Gulf of Aden (Fig. S11 a). There were no reports of Short Rains swarms after 23 May in these areas. Fledging from spring breeding in the People's Democratic Republic of Yemen (P.D.R. Yemen) commenced during April (Fig. S11 d), but the main swarm production in south-west Arabia was at the end of May and in June, and spring swarms continued to be reported in the breeding area until September.

Red Sea Coasts of Sudan and Ethiopia

There were only two reports of mature swarms at the beginning of April in northern Ethiopia, and these were almost certainly part of the generation which took part in the spring breeding along the Red Sea Coast (Fig. S11 d) and then died. This spring breeding was reported to be mostly successfully controlled, and there were only four reports of immature swarms in the whole of May.

South-Western Saudi Arabia

As in northern Ethiopia, there were a few mature swarms reported in south-western Saudi Arabia during April, and these also seemed to be the last of a generation which died out. Fledging from the breeding area (Fig. S11 d) was late, commencing at the end of May.

Central and northern Arabian Peninsula, Israel, Jordan and Iraq

Unlike northern Ethiopia and south-western Saudi Arabia, where the last mature swarms of the old generation were reported in April, mature swarms continued to be reported in northern Saudi Arabia during the first ten days of

May. *Mature* swarms were reported at 29°N 39°E on 3 and 5 May, and swarms of *mixed maturity* were reported from 8 to 10 May at 29°N 43°E. The earliest fledging from spring breeding is estimated to have commenced at the end of April in central and north-eastern Saudi Arabia, Kuwait and the Neutral Territories (Fig. S11 d), but *swarms* were not reported until May (Fig. S11 b). By June, central and northern Saudi Arabia were free from swarms (Fig. S11 c).

North-West Africa

Fledging in North-West Africa is estimated to have commenced in mid May (Fig. S11 d), and the first swarm that was almost certainly part of the new generation was reported on 18 May in Western Sahara. Although fledging was estimated to continue until August, the last report of a young swarm in the North-West African spring breeding areas was on 15 July. *Mature* adults continued to be reported in these breeding areas until 1 July.

Movements in May and June 1954

Swarm movements during May were associated with the source areas in the North-Central Region and the Horn of Africa (Fig. S11 d). During the middle ten days of May, *immature* swarms appeared in northernmost Saudi Arabia in areas where fledging is estimated not to have commenced until June, suggesting a north-westward spread during early May from the spring breeding areas in central and north-eastern Saudi Arabia, Kuwait and the Neutral Territories, where fledging had commenced at the end of April (Fig. S11 d). Also during early May, *mature* swarms spread northward from the populations on the Somali Peninsula (Figs. S11 a and d) into northern Ethiopia (Case Study 11.1), and from there westward into Sudan by 15 May (Case Study 11.2). Further north, *immature* swarms crossed the Red Sea from the Arabian Peninsula into north-eastern Africa, reaching the Red Sea Coast of Egypt from northern Saudi Arabia by 18 May (Case Study 11.2). Thus, there were two main sources involved in the invasion of north-eastern Africa during May. Some mature swarms from northern Saudi Arabia may have crossed the Red Sea with the immature swarms, and it is not possible to tell whether mature swarms reported in northern Sudan at 21°N 31°E and 21°N 32°E (Fig. S11 b) on 19 May came from the Arabian Peninsula or from the Horn of Africa (Case Study 11.2).

The first Red Sea crossings were into *Egypt*, but from 23 May young swarms also appeared on the Red Sea Coast of *Sudan* at 19°N and 20°N (Fig. S11 b). These had probably crossed the Red Sea from Saudi Arabia, where swarms were reported near Jeddah (21°N 39°E) from 19 May (Fig. S11 b). There is no evidence that Red Sea crossings were made from the Arabian Peninsula to the African coast *further south*.

A swarm reported in north-eastern Sinai at 30°N 34°E (Fig. S11 b) on 28 May most probably came from the spring breeding area in Israel and western Jordan, where fledging was estimated to have commenced in the last ten days of May. Breeding there was reported to be mostly successfully controlled, so this swarm appears to have been the only escape. It probably also moved south-westward into Egypt. Those swarms from the breeding areas in north-eastern and central Saudi Arabia, Kuwait and the Neutral Territories which did not take part in the north-westward spread into northern Saudi Arabia during early May, and the subsequent south-westward spread into Egypt, were most probably involved in an eastward movement, together with other swarms from breeding areas in the north-east of the Arabian Peninsula, Iraq and Iran — see Summary 6.

The westward spread of swarms into the summer breeding belt of Africa continued throughout May, and by the end of the month mature swarms had reached western Sudan and immature swarms were reported in central Chad (Figs. C11.3 b and d). A few immature swarms spread westward from the Red Sea coast of Sudan during the last ten days of May, the most westerly of these swarms being reported at 16°N 33°E. Apart from these and an immature swarm reported in western Sudan on 29 May (Case Study 11.3), the general distribution was of *mature* swarms in central Sudan, but *immature* swarms to the north and west from Egypt to Chad. By the end of the first ten days of June, however, *immature* spring generation swarms had also spread across central Sudan and as far west as Niger (Fig. S11 c).

Also during early June, the westward spread of *mature* Short Rains swarms continued, and a report of a swarm of 'yellow grasshoppers' in western Chad at 13°N 15°E on 10 June (Fig. S11 c) may have represented the westernmost recorded limit of the spread of these swarms across the summer breeding belt of Africa. There was no reports of *mature* swarms in the summer breeding belt in Chad or Sudan between 22 and 29 June, at a time when there was consistent reporting of *immature* swarms, and it seems that the Short Rains generation of swarms had died. General maturation of the spring generation swarms began at the very end of June, and there were no completely immature swarms reported in the breeding belt after 22 July.

During June, swarms also began to spread southward from the spring breeding areas in North-West Africa (Fig. S11 d). On 5 June, a swarm of mixed maturity, which almost certainly included adults from the spring breeding, was reported outside the breeding areas in southern Western Sahara and provided the first evidence of the general southward spread of swarms during June (Case Study 11.5). Several of the swarms reported outside the North-West African spring breeding areas were of *mixed maturity* and it seems probable that individuals from the parent generation spread southward with the young swarms, since general maturation of the immature swarms in the summer breeding belt of Western Africa did not commence until mid July.

By 9 June there were reports of mature and immature swarms in eastern Mali. The origin of these swarms is uncertain and the arrows shown on Fig. S11 d suggest that swarms may have moved into the area from the east or the north-west (Case Study 11.6).

Away from the African summer breeding belt, in the south-west of the Arabian peninsula, swarms from the spring breeding areas in south-western Saudi Arabia and the Yemens became more widely spread during June (Fig. S11 d). No major movement of swarms away from the south-west of the Arabian Peninsula can be discerned.

Movements from July to September 1954

By July (Fig. S11 e), swarms were concentrated into the summer breeding belt of Africa with only a few young swarms remaining in the spring breeding areas of North-West Africa. The last report of a swarm within these breeding areas was on 15 July.

The swarm limit is shown as uncertain across eastern Niger and Chad in Fig. S11 h because the only survey during July in this area was in central Chad, between Fada (17°N 21°E) and Largeau (17°N 19°E), and thus it is not known if the absence of reports between western Niger and Sudan really means the absence of swarms (contrast Fig. S11 e with Figs. S11 c and f). The swarm distribution across the summer breeding belt did not change much from July to August (compare Figs. S 11 e and f) except that there were fewer reports of swarms in the western part of the belt, which may be due to under-reporting. In the central part of the belt, swarms were reported in Chad and further south in north-eastern Nigeria (Figs. S11 f and h). In the eastern part of the breeding belt, there were many reports of mature swarms in eastern Ethiopia (Fig. S11 f); some of these may have been part of the newly-maturing Long Rains generation from the South-Central Region, but it is not possible to distinguish these from the mature swarms of the spring generation from the North-Central Region (Summary 16). In the Yemens, there was a small eastward spread of swarms (Fig. S11 h).

By September there were even fewer reports of spring generation swarms in the western part of the summer breeding belt. In western Mauritania, there were only two reports of swarms, at 18°N 15°W, at the beginning of September (Fig. S11 g), but the presence of fairly widespread hopper bands (Summary 17) that began to hatch during September suggests that there may have been more spring generation swarms involved in breeding there than were reported at the end of August and beginning of September. No mature swarms were reported in Mali or Niger during September, but in Chad swarms spread north-westward in the prevailing easterly and south-easterly winds to 19°N 16°E and 20°N 16°E by 19 September (Figs. S11 g and h) and gave rise to late breeding there (Summary 17). The appearance of mature swarms in the Hoggar region of Algeria from 25 September was almost certainly related to the continued north-westward spread of some swarms from northern Chad or under-reported parts of eastern Niger (Case Study 17.1). A mature swarm — probably the last reported swarm of the spring generation — was seen at 26°N 1°E on 2 October, suggesting a further north-westward spread.

In the breeding belt to the east, there were no reports of 1954 spring swarms after 16 September, except for a single report on 27 September in central Sudan at 14°N 29°E (Fig. S11 g). Generally, it seems that the spring generation of swarms had died by mid September across most of the summer breeding belt.

CASE STUDY 11.1

SWARMS IN NORTHERN ETHIOPIA, EARLY MAY 1954 (E.P.)

Sometimes swarms that have formed within a country become mixed with others coming from afar. This may well have happened in northern Ethiopia in early May 1954, where *locally produced* swarms probably mixed with *mature* swarms taking part in a larger movement from the Horn of Africa to Sudan (Case Study 11.2).

Although there had been widespread reports of adult swarms in February and March, by early April there were only three (two *immature* swarms on the coast, and one *mature* swarm in the highlands), and by the second half of the month only one (a large *immature* swarm in the highlands on the 18th). It therefore seems likely that most of the May swarms came from elsewhere. Outside northern Ethiopia there were three sources of swarms (almost all *mature*) during the second half of April: the Horn of Africa, the coastal plains of the P.D.R. Yemen, and the highlands of the Yemen Arab Republic and south-western Saudi Arabia (Fig. C11.1 a). Because there was no large outside source of *immature* swarms, those reported in northern Ethiopia in early May almost certainly formed there, even though the only known breeding (along the Red Sea coast of Ethiopia from December 1953 to April 1954) was reported to be mostly controlled in early instars. Widespread rain along the Dessye escarpment could have triggered some maturation, but weather maps for early May show that *mature* swarms could have come from the south.

From 1 to 4 May, the RSCZ oscillated between 15°N and 20°N, so that southerly winds blowing as part of the Red Sea Rift Valley flow (Section 6.3) could have brought swarms northward from eastern Ethiopia and Somalia. Fig. C11.1 b shows the map for 8 May, the date when the first fully mature swarms were recorded in northern Ethiopia. Whereas the swarms reported in eastern Ethiopia were over open country of the Danakil, to the east of the escarpment, those in the north were in the highlands, where they were most likely taken by daytime upslope winds. From 9 May, a broad-scale easterly flow set in over the highlands (as shown by 3,000m winds), allowing a further westward spread as shown by two swarm reports on 11 May to the west of those on 6 and 8 May (Fig. C11.1 a).

Although the southerly winds may well have brought swarms northward, the same flow would have prevented a low-level crossing of the Red Sea by swarms from the coastal plains of P.D.R. Yemen, particularly near the Bab el

Mandab, where the winds tend to be strongest. Moreover, there is no evidence from locust reports that swarms did cross the sea, even on days, such as the 5th, when the RSCZ moved south and the southerly winds failed.

During the second half of April, swarms were also reported from the highlands of the Yemen Arab Republic and south-western Saudi Arabia (Fig. C11.1a). These swarms were probably old and dying, and part of the 1953 summer or 1953–54 winter-early spring generations. Not just their age makes these swarms an unlikely source for swarms in northern Ethiopia in early May, because they would have had to cross mountains where the weather would have been hardly warm enough for flight on most days. Mean daytime maximum temperatures at Nimas and Abha are about 22–23°C in late April–early May. Even if there had been some warm days with east winds above the low-level Rift flow, it is likely that few swarms (if any) crossed the Red Sea.

It has been shown that whereas the *immature* swarms in northern Ethiopia during early May 1954 almost certainly formed nearby, some if not most of the *mature* swarms could well have come from elsewhere, most likely from eastern Ethiopia and Somalia.

CASE STUDY 11.2

INVASION OF EGYPT AND SUDAN, MID MAY 1954 (E.P.)

By early May 1954, both mature and immature swarms were present in northern Ethiopia (Case Study 11.1), while in northern Saudi Arabia immature swarms of the spring generation were forming amongst the last mature swarms of their parent generation (Fig. C11.2 a). This study examines the subsequent westward spread of *mature* swarms into central Sudan and of *immature* swarms into eastern Egypt, and discusses alternative explanations for the appearance of *mature* swarms in *northern* Sudan on 19 May (Fig. C11.2 a).

From 12 to 14 May the Inter-Tropical Convergence Zone (ITCZ) lay at about 13°N over Sudan (Fig. C11.2 b). Swarms moving westward across the highlands of northern Ethiopia at 14°N (Case Study 11.1) would have been carried into the north-easterly flow to the north of the ITCZ. Thus the appearance of a mature swarm on 15 May in the Blue Nile region of central Sudan (a country having been reported free of swarms for six weeks) most likely shows the first westward and south-westward spread from the highlands of northern Ethiopia.

On 15 and 16 May, the ITCZ had moved north in eastern Sudan (east of 35°E), reaching as far as 17°N on 16 May. Winds on these two days were light and variable near the highlands and there was probably little further westward movement of swarms into central Sudan. By 17 May, south-westerlies dominated the airflow to the east of 35°E (see winds for 19 May — Fig. C11.2 c) and westward swarm movement from northern Ethiopia was prevented altogether. Swarms which had moved westward during the previous few days, however, and which were in the north-easterly airflow to the north of the ITCZ continued their westward progress, reaching as far as 30°E by 17 May (Fig. C11.2 a).

Only *mature* swarms were reported in central Sudan up to 19 May and so it seems that the *immature* swarms which had been present in northern Ethiopia in early May (Fig. C11.2 a) either remained there or they matured and accompanied the other mature swarms moving into Sudan. Further north, however, in Egypt (which had been free from swarms for five months) only *immature* swarms were reported in the invasion, the first being on 18 May.

Throughout much of May there were north-easterlies blowing across northern Saudi Arabia on which the swarms in the north of that country would have moved south-westward towards the Red Sea. During early May, winds over Egypt were mainly north-westerly to northerly (Fig. C11.2 b), but by 16 May they had veered to north-easterly following the slow eastward passage of an anticyclone from northern Libya on 14 May (Fig. C11.2 b) to the eastern Mediterranean on 19 May (Fig. C11.2 c). The north-easterlies over Egypt and Saudi Arabia were continuous over the Red Sea — above a shallow layer of north-west winds which often form part of the low-level Red Sea Rift Valley flow (Figs. C11.2 b and c; the surface winds along the Red Sea Coast are affected by sea breezes and therefore do not directly show the low-level north-westerly flow over the open sea). Thus there were opportunities for swarms to cross from northern Saudi Arabia to eastern Egypt by 18 May.

On 19 May, there were two reports of *mature* swarms in the Nile region of northernmost Sudan (Fig. C11.2 a). North-easterly winds extended from Egypt into northern Sudan up to 18 May, but by 19 May a more easterly flow was present across northern Sudan. This followed a northward shift of the Red Sea Convergence Zone (RSCZ) to about 21°N (Fig. C11.2 c), thus allowing the Red Sea Rift Valley south-easterlies to blow inland across the coast of Sudan, turning to easterlies across northern Sudan. The mature swarms in northern Sudan can be related not only to those in Saudi Arabia (by moving with their offspring into northern Sudan on the 18th, and then westward into the Nile region on the 19th) but also to those in northern Ethiopia. Swarms which had moved westward from the north Ethiopian highlands in mid May could have come under the influence of south-westerlies as the ITCZ moved north. These winds were intermittent on 15 and 16 May but were more persistent from 17 May. Swarms moving north-eastward on these south-westerlies would have been carried towards the Red Sea coast of Sudan and from there into the South-easterlies blowing inland from the Red Sea on 19 May (Fig. C11.2 c). In this way they would have been carried inland once more to the Nile region of northern Sudan.

While the invasion of Egypt by *immature* swarms can be related clearly to the source in northern Saudi Arabia, and the invasion of central Sudan by *mature* swarms can be related to the source in northern Ethiopia, the swarms in northern Sudan cannot be so clearly related to a single source and seem to mark the first possible meeting point of the two populations invading North-East Africa in May 1954.

CASE STUDY 11.3

WESTWARD SPREAD INTO WESTERN LIBYA, CHAD AND NIGER, MAY–JUNE 1954 (E.P.)

Following the invasion of central Sudan and eastern Egypt by mature and immature swarms in mid May 1954 (Case Study 11.2), swarms continued to spread westward during the rest of the month. Progress in central Sudan was at first slow so that by 28 May the most westerly reports of mature swarms, at 27°E, were only 300 km west of swarms reported up to 17 May (Case Study 11.2). (The report of 'remnants of a swarm' on 25 May in Darfur (Fig. C11.3 a) was related to a *scattered* population and because there were no other reports of swarms this far west before 29 May, it is not considered to have represented a major westward displacement of the *swarming* population before that date.) However, on 29 May, mature swarms appeared in western Darfur (Fig. C11.3 a), some 450 km west of swarms reported up to 28 May, indicating a renewed surge in the westward spread of mature swarms across the African summer breeding areas. On the same day, *immature* swarms were also reported in western Darfur and swarms appeared in Chad (Fig. C11.3 a), where only very low-density populations had been reported for three months. Niger had been free of swarms for over six months when swarms appeared there in early June (Fig. C11.3 c).

The westward spread of mature swarms across *central* Sudan had been slowed down from 20 to 28 May with the development of southerlies over this area. Further north, however, easterly and north-easterly winds persisted over southern Egypt and Libya during the last ten days of May, and the report of immature swarms at Cufra, in Libya, for a period of 'five days in May' can almost certainly be related to westward and south-westward swarm movement from Egypt.

On 29 May, a more northerly flow developed over western Egypt and eastern Libya, and north-easterlies blew into central Chad and northern Darfur (Fig. C11.3 b). The appearance of north-easterlies in Darfur followed the eastward movement of a small low at about 25°N, and an accompanying southward shift of the ITCZ to between 14°N and 15°N on 29 May from a position between 17°N and 18°N on 26 May. The appearance of north-easterlies also coincided with the first reports of both immature and mature swarms in western Darfur, and of swarms in central Chad (Fig. C11.3 a). The two reports in Chad on 29 May were among four from this area at the end of May and in early June, of which two swarms were reported to be *immature* (the maturity of the other two was not reported), and they, like the immature swarms in western Darfur, had almost certainly moved south-westward on the north-easterlies from Egypt and Libya.

The source of the *mature* swarms appearing in Darfur on 29 May is less obvious but can probably be related to the mature population in central Sudan during the second half of May. These swarms may well have moved north into the very poorly reported areas of north-western Sudan during the period of southerlies, thus providing a source from which mature swarms could move south-westward into western Darfur along with the immature swarms on the north-easterly winds of 29 May.

Easterlies and north-easterlies persisted across north-eastern Africa during early June (Fig. C11.3 d), and the appearance of *immature* swarms in western Niger by 4 June (Fig. C11.3 c) can be related to movement on these winds of swarms earlier in Egypt. The maturity of the swarms in eastern Niger was not reported (Fig. C11.3 c), but they were almost certainly *immature*. During the second half of May and in early June, then, swarms spread westward and south-westward from Sudan and Egypt, reaching western Niger by the first week of June. This movement was under the influence of dominant easterly and north-easterly winds, characteristic at this time of year to the north of the ITCZ.

CASE STUDY 11.4

SPRING GENERATION SWARMS IN NIGER, MALI AND ALGERIA, JUNE 1968 (D.P., Z.W.)

During the second half of June 1968, swarms appeared in north-west Niger, north-east Mali and adjacent Algeria (Fig. C11.4 a) after an absence of confirmed reports since late 1967. The nearest known source was the Algerian Sahara, where *scattered* mature adults (but no hoppers) had been reported in February and March in Tidikelt. The only *dense* breeding had been in Wadi Tahihoust in Tassili N'Ajjer, where control was carried out against 58 bands, and fledging started in early May. Some 2,000 km to the west, there was widespread and uncontrolled spring breeding in Mauritania, where it was repeatedly reported as low-density, and where fledging took place in May. Further north, in Morocco, there was control against hoppers over a limited area in Wadi Draa, and against apparently more important infestations in Maader Khemlia, and this was followed by fledging in May and June. These sources seem to have been too small to account for the number of swarm reports in late June, but a more positive indicator of the source comes from an examination of winds at the time of arrival.

The first swarm was reported on 17 June in north-west Niger, on the same day that east winds set in there following the southward movement of the ITCZ (Fig. C11.4 b). East winds had reached north-east Niger on the 16th and had been blowing across northern Chad for many days before then, suggesting that the swarm reported on the 17th had come from Sudan, where a single swarm (which could have come from Saudi Arabia or Ethiopia) was reported in the Kassala Province on 21 May, and which was invaded by numbers of immature, mature and mixed maturity swarms in the first week of June from the Somali Peninsula (via Ethiopia), and in the second week from Saudi Arabia (via Egypt). Swarms had been spreading westward across Sudan to reach 24°E by the 13th (Fig. C11.4 a), and may well have been crossing the empty areas of north-west Sudan during the second week of June, having come from southern Egypt (where they had been reported in the first week). Such a movement would have taken place on the north-east winds of that region, and the 2,500 km between southern Egypt and north-west Niger would have been crossed in 10–14 days, i.e. about 200 km a day — consistent with daytime wind speeds.

The east winds spread westward after the 17th, reaching north-east Mali on the 19th (and possibly 18th), after which the ITCZ became difficult to recognise and south winds blew across southern Algeria from 20 to 23 June (and possibly 24th). Hence, flying swarms would have been taken as far as north-east Mali by about the 19th (consistent with reports there from the 20th) and into southern Algeria by the 20th (consistent with reports there from the 21st). By the 23rd, north to north-west winds had set in over north-east Mali and could have temporarily prevented further westward spread of swarms until the return of east winds across the area of reports by the 28th (and possibly by the 25th). Some swarms laid eggs, for hopper bands were seen later in Niger and Mali, with inferred laying during the last week of June.

The return of east winds gave a chance for swarms to move further west and reach Mauritania by the first week of July (Fig. C11.4 a), when there were reports of invading swarms, some of which had already laid, as judged by the state of their ovaries. These July swarms, however, may have come partly or wholly (along with large *scattered* populations) from sources in Mauritania, Morocco and Algeria (Fig. C11.4 a), although the absence of reports in July from Niger and Mali does suggest movement out of those countries and is consistent with some of the Mauritanian swarms having already laid.

The evidence thus strongly suggests that the swarms reported in the second half of June had come on east and north-east winds across Egypt and Sudan from distant sources in Saudi Arabia and the Somali Peninsula. This suggestion is further supported by morphometrics: a sample of locusts taken in southern Algeria in early July was very similar to a sample taken in south-east Egypt on 9 June. Thus, some of the 1968 spring generation swarms from Saudi Arabia, and possibly the Somali Peninsula, almost certainly moved 4,000 km from their sources to north-east Mali, and possibly 6,000 km to western Mauritania.

CASE STUDY 11.5

INVASION OF WESTERN SAHARA, MAURITANIA AND CENTRAL ALGERIA, JUNE 1954 (E.P.)

Spring breeding in North-West Africa in 1954 extended from Western Sahara through southern Morocco to north-western Algeria (Fig. C11.5 a). This study looks at the first swarm escapes from the breeding area and is therefore concerned with areas of early fledging, from mid May to the end of the middle ten days of June, and the associated reports of *immature* swarms outside the breeding area from 1 to 22 June (Fig. C11.5 a).

The first swarm recorded outside the breeding area was in the extreme south of Western Sahara at 21°N on 5 June. This swarm was of *mixed maturity* and almost certainly contained immature adults of the spring generation. In western Mauritania (which, like Western Sahara, had been reported free of immature swarms for four months), a locust survey party set out northward from Atar (20°N 13°W) on 3 June. Locusts were first encountered at 24°N on 7 June, and from 9 to 14 June *newly-fledged* locusts flying in open formation were observed near Bir Moghrein (25°N 12°W) approximately 110 and 200 km, respectively, to the south-east and south of the nearest known parts of the breeding area. As the survey party returned southward on 19 and 20 June, *immature* swarms were observed at latitudes 22 and 23°N, and on arrival at Atar on 22 June a further swarm was reported. There was thus clear evidence of a general southward movement of fledglings from the spring breeding area.

Further east, two swarms of *mixed maturity*, again almost certainly containing spring generation adults, were reported on 8 June in Touat (27°N 0°W; 28°N 0°W) in Algeria, approximately 300 km to the south-east of the Algerian part of the breeding area.

Throughout June, the wind pattern was dominated by cells of high pressure over the Atlantic and low pressure over the Algerian Sahara. Winds over the western part of the breeding area were thus mainly from the north, veering to north-east over western Mauritania and Western Sahara (Figs. C11.3 d and b; Fig. C11.6 b). Thus the appearance of swarms to the south and south-west of the spring breeding area can be related to movement from the western part of that area.

Contrasting with this clear-cut movement, swarms may have reached Touat in several ways. They may have moved directly south-eastward from the Algerian part of the spring breeding area on 3 and 4 June on north-westerlies and westerlies, blowing behind the cold front associated with a cyclonic circulation which was centred over southern Tunisia on the 3rd (Fig. C11.5 b) but had moved by the 4th to the central Mediterranean. On that day a new cyclonic circulation had started to form over west-central Algeria so that by 5 June there were easterlies blowing across the Algerian part of the breeding area (Fig. C11.6 b). These easterlies prevented further south-eastward movement from the Algerian part of the breeding area before the 8th, but swarms which may have moved from there on the 3rd and 4th could have circulated round the cyclonic centre until being reported on Touat on the 8th. Alternatively, swarms which had moved southward from more western parts of the breeding area may have been carried on north-west winds across western Algeria (Fig. C11.6 b), later to come under the influence of south-westerlies that took them to Touat by the 8th. A further possibility is that the swarms in Touat had moved westward from Egypt, where immature swarms were reported from 18 May (Case Study 11.2), on the dominant easterlies (Fig. C11.6 b), but there was only a single report in the intervening area and this was at Cufra, in Libya, about 2,500 km east of Touat. The nearer source of the North-West African spring breeding area thus seems the most likely.

CASE STUDY 11.6

INVASION OF MALI, JUNE 1954 (E.P.)

During early June 1954, swarms began to move southward from the North-West African spring breeding area (Case Study 11.5) while further east, swarms were spreading westward from north-east Africa into Niger (Case Study 11.3). By 5 June, swarms in west Africa were reported as far south as 21°N in Western Sahara, while swarms in Niger had reached as far west as 6°E (Fig. C11.6 a). On 9 June, swarms appeared in eastern Mali (Fig. C11.6 a), and this study examines the probability that Mali was the meeting place of swarms from two different sources.

The swarms appearing in eastern Mali were both *mature* and *immature* (Fig. C11.6 a), but those in Niger in early June were either *immature* or of *unknown maturity*. The westernmost report of a *mature* swarm before the 9th had been on the Chad-Sudan border at 13°N 22°E on 2 June. Swarms moving out of the North-West African spring breeding area, however, included both immature and mature adults.

Fig. C11.6 a shows that the swarms reported in eastern Mali were only about 500 km from those in western Niger, whereas distances of over 1,000 km separated the swarms reported in Mali from those moving out of the North-West African spring breeding area. There is, however, a large under-reported area in eastern Mauritania and western Mali across which swarms may pass with little chance of being seen.

North-westerly winds blew towards eastern Mali on 6 June, to the west of a low over west-central Algeria (Fig. C11.6 b), and swarms may have been carried on these winds from the spring breeding areas of North-West Africa. Alternatively, those swarms may first have moved south, further to the west, and then been carried into eastern Mali on the westerly winds that blew from 7 to 9 June.

Up to 5 June, easterlies blew into eastern Mali (e.g., Fig. C11.3 d) and swarms moving westward may have arrived on those winds, remaining undetected until 9 June. However, the absence of reports of *mature* swarms between the Chad-Sudan border and eastern Mali during the first nine days of June suggests that at least the *mature* swarms came from the North-West African source area. The *immature* swarms could have come into eastern Mali from either North-West Africa or the east.

SUMMARY 12

MOVEMENT OF 1955 SPRING AND 1954–55 SHORT RAINS GENERATIONS SWARMS INTO THE NORTH-CENTRAL AND WESTERN REGIONS

This Summary deals with the late spring–early summer invasions of north-eastern Africa by

spring generation swarms flying in across the Red Sea from Arabia

the old Short Rains generation swarms moving in through north-eastern Ethiopia from Arabia.

It also deals with the westward spread of the immigrant swarms into the Western Region as far as Niger.

Not all Arabian swarms moved to Africa; many of them flew southward and invaded south-western Arabia.

The described events provide examples of invasions of the summer breeding belt in the North-Central Region from its own spring breeding belt and from the South-Central Region, and of the spread of spring swarms from the North-Central to the Western Region.

Sources

South-Central Region

Following the 1954–55 Short Rains breeding, numerous swarms appeared on the southern Somali Peninsula and in East Africa; their migrations in the South-Central Region are described in Summary 15. A few became involved in very localised early Long Rains breeding in the extreme north-west of the Somali Republic and adjoining part of Ethiopia, where a few young swarms appeared in April (Fig. S12 a). The bulk of the Short Rains generation swarms remained to the south of 10°N until May, when they moved north. They bred extensively in April–May in East Africa and the Somali Peninsula, where numerous young swarms of their progeny (the Long Rains generation) appeared in June.

North-Central Region

Hoppers were last reported in the coastal areas of north-eastern Ethiopia and Sudan in February 1955, and there was a single report in March of a swarm in western Eritrea Province of Ethiopia. In April, some hoppers appeared in the coastal areas of north-western Egypt, but were all controlled; the whole of north-eastern Africa north of 12°N was free of swarms during that month (Fig. S12 a).

There were no reports of swarms from the Yemen Arab Republic or the P.D.R. Yemen from February to April, and no records of breeding. But widespread spring breeding occurred in Saudi Arabia and Iraq. Western, central and northern Arabia were invaded by swarms at the end of 1954, and laying began in January and continued until March. Movement into Iraq began in March and laying occurred over a wide area (Fig. S12 c). In western Arabia, the early spring generation began fledging in March, and some of its swarms matured and laid in April. Fledging by this generation continued during April and merged with the fledging of the main spring generation, which did not come to an end until early June. In central and eastern Arabia, swarms of the main spring generation appeared between mid April and early June (Fig. S12 c).

In Iraq, fledging is unlikely to have started before the end of May, and therefore it was improbable that any young swarms produced there would have been involved in the movements which occurred during May.

Movements southward within Arabia

The Yemen Arab Republic and the P.D.R. Yemen were both invaded by swarms during May (Figs. S12 b and c). They were reported first in the P.D.R. Yemen from 10 to 15 and from 24 to 30 May, and in the Yemen Arab Republic on 16 and 24 May. Most of these swarms were said to be mature or maturing, but later, during June, there were many more reports of immature swarms, suggesting that the movement into southern Arabia continued during that month. The June immigrants may have included swarms from Iraq.

Movements south-westward across the Red Sea from Arabia to Africa

Young swarms began to leave the breeding areas in central Arabia during the second half of April; fledging had begun there during the early part of the month. By the middle of May, both mature and immature swarms were reported on the Red Sea Coast of Arabia between 19° and 27°N. Swarm invasion of Africa began during this period: the first swarm was sighted at Port Sudan on 6 May, in Egypt on the 10th and in northern Ethiopia on the 18th. This movement continued throughout May and possibly during early June (Figs. S12 b, c and d). The swarms invading Sudan across Egypt were all immature, whereas those reaching Sudan directly included some mature swarms of the early spring generation.

Movement northward from the Somali Peninsula

During May, old mature swarms of the Short Rains generation spread over the northern part of the Somali Peninsula, and some of them moved northward together with young swarms of the early Long Rains generation over north-eastern Ethiopia into the Province of Eritrea and probably Sudan, where they became indistinguishable from the swarms immigrating from Arabia (Figs. S12 b and c).

A comparable northward movement of mature swarms from the Somali Peninsula occurred in May 1954 and is described in Summary 11. In June 1955, following the widespread appearance of young swarms of the Long Rains generation over the South-Central Region, some immature swarms moved north through north-eastern Ethiopia and augmented the swarming populations in Eritrea (Fig. S12 d).

Movements westward into the Western Region

The westward movement continued in Sudan, and led to the appearance of mature and immature swarms in Kordofan and Darfur. Further west, immature swarms appeared in eastern Chad on 20 May, in western Chad on 25 May, and at 14°N 9°E in southern Niger on 31 May. Before then, Chad had been free of swarms from February 1955, and Niger from December 1954. Elsewhere in the Western Region there was widespread infestation in May 1955 by laying swarms and hoppers throughout north-western Africa, from Western Sahara to Libya, and the first young swarms were reaching Mauritania, Senegal and Mali; the latter was also invaded by swarms that had over-wintered in West Africa. But all these swarms were reported either to the north of 26°N or to west of 8°W, and there seems little doubt that the immature swarms reaching Chad and Niger in the last ten days of May were derived from Arabia (compare the events in May 1954, Summary 11). Their first appearance in Chad was before the reports of immature swarms in central, northern and western Sudan, suggesting that they may have moved in from Egypt across the unsurveyed north-western corner of Sudan, from which there were no reports. During the first ten days of June, swarms were reported in southern Algerian Sahara and western Niger (Fig. S12 d) but the source of these swarms is uncertain, and they could have started in north-western Africa.

SUMMARY 13

MOVEMENTS OF 1954 LONG RAINS AND SUMMER GENERATIONS SWARMS IN THE SOUTH-CENTRAL REGION FROM OCTOBER 1954 TO JANUARY 1955

This Summary deals with typical southward and south-westward movements of maturing and breeding swarms of the Long Rains generation, which usually take place over the Somali Peninsula and East Africa at the season of the Short Rains. In 1954, this movement included some summer generation swarms from north-eastern Ethiopia. The Summary also discusses movements of Long Rains and summer generations swarms south-westward from central Kenya to northern Tanzania and Burundi, and westward from western Kenya to Uganda, Zaire and southern Sudan.

Sources

There were two areas where 1954 Long Rains swarms had remained immature during July and August.

Northern Somali Peninsula. Immature swarms were reported on the northern Somali Peninsula in July, August and September (Summary 16). By the first week of October, many of them were maturing.

Kenya Highlands. In September and October there were immature, maturing and mature swarms both east and west of the Rift Valley in central Kenya.

Summer breeding occurred in the Danakil and Railway areas of Ethiopia as part of a more extensive summer breeding belt extending through northern Ethiopia to Sudan (Summary 17). Summer breeding by Long Rains swarms also took place in the Samburu and Turkana areas of north-western Kenya. In both cases laying began in July and continued through August, with fledging from 15 September until the end of October. The first fledgling swarms were reported in both areas on 21 September. These breeding areas are shown on Fig. S13 c.

Movements south-westward and westward from Kenya in October and November 1954

In early October, immature swarms moved south-westward through western Kenya to invade the Lake Province of Tanzania (Figs. S13 b and c). These swarms were first reported in Tanzania on the western edge of the Serengeti Plain on 7 October, on the Mwanza–Tabora road at 3°S 33°E on 9 October, and at Geita (3°S 32°E) on 12 October. By 16 October, these swarms had reached Burundi, where they remained during the last week of October and the first week of November. This movement across northern Tanzania is described in Case Study 13.1.

There were no swarms reported in western Tanzania from 18 October until 9 November. Swarms moving south from Burundi appeared on the north-east shores of Lake Tanganyika on 9 November, and reached Uvinza (5°S 31°E) by 18 November (Fig. S13 f). There were no further reports of these swarms.

A few swarms from western Kenya spread to Uganda in October, and one was reported to the north-west of Lake Sessekou Mobutu (formerly Lake Albert) on 13 October. This would suggest a westward movement at the time (9–16 October) when other swarms were moving west across north Tanzania, to the south of Lake Victoria (Figs. S13 b and c).

Movements southward from the Somali Republic (North) and north-eastern Ethiopia to Kenya and Tanzania in October, November and December 1954

During the last two weeks of September and the first week of October, swarms on the Somali Peninsula and adjoining parts of Ethiopia were mainly north of 8°N and consisted of swarms of the 1954 Long Rains and the young 1954 summer generations (Fig. S13 c).

In the second week of October, the usual southward movement (Section 7.6) set in with swarms reaching 7°N 45°E on 10 October, with a fledging swarm being reported at Bugdar Cosar (4°N 45°E), south-west of Belet Uen on 10 October (Fig. S13 c). This southward movement in the first half of October probably involved swarms of both Long Rains and summer generations, and was associated with the change in predominant wind direction over the Somali Peninsula from south-westerlies to north-easterlies as the ITCZ moved south. These changes in wind direction are discussed in Case Study 13.3. There were no reports north of 8°N and east of 45°E after 9 October, and it is likely that the movement of the Long Rains generation swarms took place rapidly during the first few days of north-easterly winds.

Between 15 and 26 October, swarms continued to move south towards the Kenya border. Maturation of the Long Rains generation swarms occurred during this movement, with laying taking place from 24 October in the southern Ogaden and from 26 October in Somali Republic (South). There was no laying by swarms north of 6°N in 1954.

Between 26 and 31 October, some swarms moved south-west from the Somali Peninsula and crossed Kenya to reach the Elgeyo Valley (1°N 36°E) in western Kenya; others moved south across eastern Kenya and as far as the slopes of Kilimanjaro (3°S 35°E) just inside north-east Tanzania (Case Study 13.4). When swarms from the Somali Peninsula reached central and western Kenya, swarms from different sources could no longer be distinguished.

During the last five days of October, immature swarms appeared in the Ogaden Province of Ethiopia. These were probably moving south from the Danakil, where fledging of the summer generation continued throughout October (Fig. S13 c).

Short Rains breeding began in eastern Kenya on 4 November and continued during the rest of November and December.

At the beginning of November, swarms from Kenya moved south on to the Pare and Usumbara Mountains in north-eastern Tanzania, and in the second and third weeks of November further swarms entered Tanzania from Kenya, to west of Kilimanjaro, and moved south-west to reach Tabora (5°S 33°E) on 23 November, and Dodoma (5°S 36°E) on 24 November (Figs. S13 a and f, and Case Study 13.5).

In the second week of December, swarms in Tanzania moved to 8°S (Figs. S13 e and f). This was the only time in the 37-year period between 1939 and 1975 when swarms were reported so far south (see swarm frequency map for December).

Breeding began in Tanzania in early December and continued throughout January. There was laying as far south as 1°S in late December.

Movements westward from western Kenya in November and December 1954

In early November, swarms from western Kenya moved westward across Uganda to reach Lira (2°N 33°E) on 5 and 6 November, southern Sudan on 14 November, and northern Zaire on 17 November (Case Study 13.2). These were mainly summer generation swarms from the Samburu and Turkana areas of Kenya (Section 2 of this Summary) although they could have included others from the Somali Peninsula that had reached western Kenya in late October (Section 3 of this Summary).

In December, there was further movement west to 28°E in Zaire, but a few swarms persisted in central Uganda. There were no further records of these swarms after mid December, and it seems that none of them bred.

Movements in January 1955

In January, swarms were still laying in Tanzania, while in Kenya, Somali Republic (South) and the southern Ogaden they had largely died out after breeding (Fig. S13 g). In southern Ethiopia and western Somali Republic (South) only a few swarms survived into the first ten days of the month. In the Rift Valley of Ethiopia and the Addis Ababa area (9°N 39°E) there were also a few mature swarms reported in January (Fig. S13 h), and a few swarms remained on the Harar Plateau. Spring breeding by the latter is discussed in Summary 14.

CASE STUDY 13.1

WESTWARD SPREAD ACROSS TANZANIA, OCTOBER 1954 (J.P.)

On 7 October, an immature swarm was reported on the western edge of the Serengeti Plain in Tanzania, south-west of the Kenya Highlands. Immature swarms were next reported on 9 October south of Mwanza (2°S 33°E) and on the Mwanza–Tabora road at about 3°S 33°E. On 12 October, swarms of unknown maturity were reported further west in Tanzania; and on 16 October, Burundi was first invaded by an immature swarm (Fig. C13.1 a).

Most of these swarms were of *immature* locusts, the most likely source of which was the summer breeding in the Samburu–Turkana area of Kenya, where the first fledgling swarm was reported on 21 September. The shaded area in Fig. C13.1 a shows degree squares where fledging occurred before the end of September. On the other hand, if the swarms reported as being of *unknown maturity* contained *mature* locusts, their source could have been the Kenya Highlands, for mature swarms had been recorded there at the end of September.

At the end of September, winds from between south-east and south-west blew over Kenya, but from 1 to 3 October north-easterly winds blew from the source areas towards Tanzania. The initial movement from the source areas could have taken place at this time. From 4 to 6 October, however, winds were variable or south-easterly, so swarms could not have travelled directly to Tanzania on these days; but from 7 to 16 October, easterly winds blew across northern Tanzania (Fig. C13.1 b) taking swarms as far west as Burundi.

CASE STUDY 13.2

SWARMS IN UGANDA, ZAIRE AND SOUTHERN SUDAN, NOVEMBER 1954 (J.P.)

Although swarms had invaded Uganda in late September (Case Study 16.1), there were no reports after the 29th, so it is likely the swarms had either died or returned eastward. From 25 October, however, there were further reports from eastern Uganda, followed by a spread westward to reach 33°E by 5 November (Fig. C13.2 a), southern Sudan by the 14th, and Zaire by the 17th (Fig. C13.2 b). Until the 13th, these swarms were reported as *immature* or of *unknown maturity*, but after that date there were some of mixed maturity. The *immature* swarms could have come from two sources:

> Samburu–Turkana area of western Kenya, where the first fledgling swarm was seen on 21 September;
>
> Danakil area of Ethiopia.

Immature swarms from the second area joined *mature* swarms invading north-east Kenya on 26 October (Case Study 13.4), and they moved to Tanzania and western Kenya (Fig. C13.2 a), mixing on their way towards Uganda with swarms already present in western Kenya. Thus, the Uganda swarms of early November most likely came from both sources.

Westward movement across Uganda was made possible by east and north-east winds between the 1st and 6th (Fig. C13.5 b), blowing from the Turkana source, where fledging is estimated to have taken place during the second half of October. East winds then continued to blow across most of Uganda, turning as south-easterlies into southern Sudan on the 14th, the date of the first report from Equatoria Province (Fig. C13.2 c). By the 17th, swarms had reached north-eastern Zaire — possibly on north-east winds from either Uganda or Sudan.

CASE STUDY 13.3

SOUTHWARD SPREAD ACROSS ETHIOPIA AND SOMALIA, OCTOBER 1954 (J.P.)

A well-defined southward movement of swarms took place across the Somali Peninsula during the second week of October 1954. By the 12th an immature swarm was reported as far south as Bugdar Cosar (4°N 45°E) (Fig. C13.3 a).

During the first week of October there had been many swarms of the 1954 Long Rains generation reported north of 8°N on the Somali Peninsula, and there were some immature summer generation swarms present from Diredawa (9°N 42°E) eastward to the Somali border. At this time the ITCZ, separating north-easterly from southerly winds, was slow-moving and lying east-west across the northern Peninsula, but by 12 October it seems to have moved southward to close to where the swarm was seen on that day at Bugdar Cosar.

During the remainder of October, north-east winds spread across the Somali Peninsula and led to a dramatic movement of swarms towards and into Kenya (Case Study 13.4).

CASE STUDY 13.4

INVASION OF KENYA, LATE OCTOBER 1954 (J.P.)

On 26th and 27 October, mature and immature swarms were reported in north-east Kenya for the first time that season (Fig. C13.4 a). Previously there had been reports from western Kenya of both immature swarms (originating in the Samburu–Turkana areas) and others of mixed or unknown maturity (remaining Long Rains generation). On the Somali Peninsula, there had been many reports before 25 October of mature and maturing Long Rains generation swarms and immature summer generation swarms.

Winds over several days up to and including 27 October had been blowing over the southern Somali Peninsula from between north-east and south-east (Fig. C13.4 b), and they could have taken swarms from the Somali Peninsula as far as Wajir (2°N 40°E), where they were reported on 26 October. The ITCZ seems to have reached the Tanzania border about the 28th, and swarms were seen near there from the 29th to the 31st (Case Study 13.5).

By the end of the month there were many swarms in Kenya. As they moved south-west, swarms from the Somali Peninsula became mixed with others already in Kenya, and the origins of particular swarms could no longer be distinguished.

CASE STUDY 13.5

INVASION OF TANZANIA, EARLY NOVEMBER 1954 (J.P.)

The first swarm to be reported in eastern Tanzania before the Short Rains breeding in 1954 was a mature one on the north-west slopes of Kilimanjaro on 29 October. By 5 November, swarms had appeared to the south-east, on the Pare and Usumbara Mountains (Fig. C13.5 a). The main source was the Somali Peninsula, swarms having crossed eastern Kenya in late October. Included among these swarms could have been others that were already present in the Kenya Highlands earlier in October.

Swarms near Kilimanjaro could have come on north-easterly winds from just across the border in Kenya, but those on the Pare and Usumbara Mountains could have entered Tanzania either on north-easterly winds from previously unreported swarms near the coast of south east Kenya (Fig. C13.5 b) or, at least in part, from near Kilimanjaro during a day of north-west winds on 3 November.

The subsequent spread of swarms west-south-westward took place when, for about two weeks in mid month, there were east or east-north-easterly winds over northern Tanzania similar to those of Fig. C13.5 b.

SUMMARY 14

MOVEMENTS OF 1954–55 SHORT RAINS GENERATION SWARMS IN THE SOUTH-CENTRAL REGION

Short Rains breeding in 1954 did not occur north of 6°N in Somali Republic (South), nor in Ethiopia, but it extended through Kenya and Tanzania, south to 8°S. Movements of the resultant swarms took place in three waves:

> northward to Harar Province of Ethiopia in January,
> southward through Kenya and Tanzania in January and February,
> northward to Long Rains and summer breeding areas in April and May.

This Summary discusses these movements.

Sources

Two source areas existed in December 1954: the Short Rains breeding area, and an area harbouring some late summer generation swarms in Ethiopia.

Short Rains breeding.

Laying on the Short Rains began in the third week of October in Somali Republic (South), with estimated fledging beginning there in early December and continuing into January. Laying took place progressively later as the invading swarms moved southward through Kenya and Tanzania (compare Summary 13). Most of the fledging occurred during January in Kenya and during February in Tanzania, where the last reported hatchings took place on 18 January.

Swarms on the Harar Plateau of Ethiopia in December.

Between 5 and 8 December, immature swarms were reported on the Harar Plateau of Ethiopia, together with a population of maturing swarms of a late 1954 summer generation (compare Fig. S13 h).

Movements in January and February 1955

In December, the only Short Rains swarms in the South-Central Region were in the Juba Province of Somali Republic (South) (Fig. S14 a).

Fig. S14 c shows the source area, where fledging was estimated to have occurred during December and the first half of January. On 12 January, a swarm was reported in southern Ethiopia, south of Alghe (6°N 38°E), indicating a westward movement on a spell of easterly winds over southern Somalia and northern Kenya. There was evidence of movements both to north and to south in the middle of the month, with one immature swarm reported on the Harar Plateau on 17 January and another near the Kenya–Tanzania border on 19 January. These northward and southward movements were repeated at the end of the month with fresh swarms in both areas (compare Figs. S14 b and c). Movements north and south in the last ten days of January are discussed in Case Study 14.1.

Fig. S14 e shows the areas where later fledging occurred during the second half of January and during February. In central and north-western Tanzania, control was effective against young hoppers and some areas were believed to have been cleared before fledging; these areas are not shown on Fig. S14 e.

In February, there was further movement north in east-central Ethiopia, with one swarm reported moving north to southern Eritrea, beyond the limit of the considered area. In the same month, there were swarms in most areas of Kenya (Fig. S14 d), with a continued southward movement into Tanzania. Rainey (1963) quotes 14 examples of swarms flying south between 27 January and 17 February 1955, with north-easterly winds. A westward movement of swarms from western Kenya into Uganda was indicated by a swarm report at Magoro (2°N 34°E) on 25 February.

1955 early spring and early Long Rains breeding

Early spring breeding.

This took place on the coastal plain and foothills of north-western Somali Republic (North) during February (Fig. S14 h). Laying was by late summer (1954) swarms from the Danakil and Railway areas of Ethiopia, and possibly by Short Rains swarms that had moved north in January (Fig. S14 c). Hatching occurred at the end of February, and immature swarms appeared in April (Fig. S14 h), when they were reported in the Railway area and near Addis Ababa (9°N 39°E).

Early Long Rains breeding.

Laying by Short Rains swarms took place in some areas of Tanzania in February, with hatching from early March. Some of these hatchings were controlled but there were three immature swarms present in May, after which they disappeared. These swarms are shown on Fig. S14 i.

Movements from March to May 1955

During March (Figs. S14 f and h), swarms were mainly concentrated in two distinct areas: north-western Ogaden and the Harar Plateau of Ethiopia; and southern and western Kenya and northern Tanzania (where they had spread westward into the Western and Lake Provinces). In the second half of March there was only one Short Rains swarm reported in Ethiopia (at 6°N 42°E).

Movements to the north and north-east

In the first fortnight of April there was a northward movement of mature and maturing Short Rains swarms across Kenya into southern Ethiopia with southerly winds over north-east Kenya (Fig. S14 h). In the second half of the month there was a broadening of the invaded area, with swarms moving north through southern Ethiopia, Somali Republic (South) and Ogaden, and reaching western Somali Republic (North) by the end of the month (Fig. S14 h). These swarms bred on the Long Rains as they moved north. The northward movements in April and the associated southerly winds are dealt with in Case Study 14.2.

During the first eight days of May, Short Rains generation swarms spread *eastward* to 50°E on the Somali Peninsula, north of 3°N. This eastward movement probably took place before 6 May, while south-west winds similar to those described in Case Study 14.2 were blowing. After 11 May, swarms spread over the remainder of the Somali Peninsula (Figs. S14 i and j). During May there was also a movement northward to the Railway area of Ethiopia and into Eritrea (Fig. S14 j), beyond the limit of the considered area. Further movements north of 12°N are considered in Summary 12. In May, most swarms in Kenya were reported north of the equator, and subsequent breeding on the Long Rains extended from the equator northward through northern Kenya, Somali Republic (South), the Ogaden of Ethiopia and Somali Republic (North).

In June there were only a few swarms of this generation remaining: in Somali Republic (North) and in southern Danakil (Fig. S14 k). The other swarms of the Short Rains generation in Kenya, Ethiopia and the Somali Republic had died out after breeding on the Long Rains.

Movements to the north-west

At the beginning of April there was a north-westward movement of swarms west of Lake Victoria in Tanzania. These swarms subsequently invaded Rwanda and southern Uganda, and by the end of the month they had reached north-western Uganda and north-eastern Zaire (Figs. S14 g and h). Details of this movement are discussed in Case Study 14.3. Between 1 and 5 May there were several swarm reports in northern Uganda, probably representing a further extension of this movement.

There was evidence of northward movement in north-western Kenya at the end of April and beginning of May. A mature swarm was reported in the south-eastern corner of Equatoria Province of Sudan on 27 April, and this was followed by several other reports in the first half of May. At the beginning of May there were also swarms reported both east and west of Lake Rudolf, and in south-western Ethiopia (Figs. S14 i and j).

There were reports of swarms between 7° and 9°N in the Bahr-el-Ghazal Province of Sudan from 17 May. These swarms could have moved north-west on south-easterly winds from Zaire and northern Uganda, or from south-eastern Equatoria Province of Sudan and south-western Ethiopia (Fig. S14 j and Case Study 14.4). There were no further reports in Bahr-el-Ghazal, but with the ITCZ situated between 10° and 12°N between longitudes 25° and 30°E during the final ten days of the month, it is possible that these swarms moved north on the mainly southerly winds to join spring generation swarms from Arabia that were invading the interior of Sudan at this time (compare Summary 12).

CASE STUDY 14.1

SHORT RAINS GENERATION SWARMS IN SOUTH–CENTRAL REGION, LATE JANUARY 1955 (J.P.)

During the last six days of January 1955, immature swarms of the Short Rains generation appeared in two widely separated areas: the Harar Plateau of Ethiopia, and south-east Kenya (Fig. C14.1 a). Before then there had been only single reports from these two areas (on 17 and 19 January), and during the previous six days (20 to 25 January) reports of immature swarms were confined mainly to an area between 1°S and 2°N in eastern Kenya, although there were two reports from Ethiopia: one at Ghimir (7°N 40°E) on the 21st, and the other (of unknown maturity) at 7°N 47°E on the 25th. The source of the immature swarms was Short Rains breeding in the South–Central Region — in this season from 6°N in Somali Republic (South), through eastern Kenya to 8°S in Tanzania. In the first two countries, fledgling swarms appeared at the end of December, but in north-eastern Kenya not until the second week of January. Fledgling swarms could also have appeared in south-eastern Kenya by the end of January, but swarms seen there in late January may have come from near Garissa (0°N 40°E).

The widely separated reports of the last six days of January suggest movements in opposite directions at about the same time from the extensive source region. Fig. C14.1 b is a weather map for 26 January, a day when movements both north-westward and south-westward could have taken place. Similar winds blew from 18 to 20 January, and on the 27th and the 28th. There were east winds over the whole area from 21 to 25 January.

CASE STUDY 14.2

SHORT RAINS GENERATION SWARMS IN ETHIOPIA AND SOMALIA, APRIL 1955 (J.P.)

During the period 16 to 25 April 1955, swarms from Kenya invaded south and south-eastern Ethiopia and southern Somali Republic (South), and they started to breed on the Long Rains. By 15 April, there were swarms on the north-eastern border of Kenya (Fig. C14.2 a) at 4 to 5°N, and by 17 April one at least had reached 7°N. Between 22 and 25 April, more swarms moved north-east into the Ogaden and southern Somalia (Fig. C14.2 a). All these swarms were *mature*, but there were also *immature* swarms present throughout April in the Railway and northern Rift Valley areas of Ethiopia — the progeny of early spring breeding in the Harar area.

Wind patterns over eastern Ethiopia are difficult to see because there are so few observations, but southerly winds seem to have spread northwards with the ITCZ after the 15th, although probably erratically. Fig. C14.2 b shows a weather map for 20 April, the day on which the main swarm movement from Kenya into Ethiopia and Somalia started. The northward movement of the ITCZ across the Somali Peninsula was probably related to the slow movements of a cold front across Arabia between 19 and 22 April.

CASE STUDY 14.3

SWARMS WEST OF LAKE VICTORIA, APRIL 1955 (J.P.)

During April 1955, swarms west of Lake Victoria moved northward from Tanzania to Uganda (Fig. C14.3 a). By 5 April, swarms had reached 2°S, and on 9 April there was a report in south-west Uganda. During the following seven days there were reports from the north-western corner of Tanzania and also one from Rwanda on the 15th, and on 18 April an immature swarm was reported between Fort Portal (1°N 30°E) and Lake Albert; on 23 April swarms had reached Kurukwala (4°N 30°E) in Zaire. Swarms were also reported east of Lake Albert from 24 to 28 April. These swarms were the product of Short Rains breeding in northern and north-eastern Tanzania.

The first movement north-westward took place when south-east to south winds were blowing over north-west Tanzania from 2 to 7 April. Fig. C14.3 b shows south-east winds extending as far as south-western Uganda on 4 April. For three days previously, winds in this area had been blowing from the north-east or they had been variable, and after 10 April there was a return to east and north-east winds. North-westward movement then stopped and was replaced by movement west, reaching Rwanda on the 15th. On 16 April, southerly winds returned over south-west Uganda, followed by swarms at Fort Portal on 18 April. This spell of southerly winds continued until 20 April (although more variable on some days) and during this period some Uganda swarms may have come from western Kenya. Although there were variable winds south of Fort Portal after 20 April, north of Fort Portal southerly and south-westerly winds continued to blow, enabling swarms to move into Zaire.

CASE STUDY 14.4

INVASION OF SOUTHERN SUDAN, MAY 1955 (J.P.)

There were four reports of swarms, three mature and one immature, in Bahr-el-Ghazal Province of southern Sudan between 17 and 20 May 1955 (Fig. C14.4 a). Swarms in south-eastern Sudan and in neighbouring Zaire, Uganda, Kenya and Ethiopia between 26 April and 15 May were the most likely sources.

Between 8 and 20 May, on all days but two (9 and 13 May), there were south or south-east winds blowing over southern Sudan from the likely sources. Fig. C14.4 b illustrates this pattern of winds.

SUMMARY 15

MOVEMENTS OF 1961 SHORT RAINS GENERATION SWARMS IN THE SOUTH-CENTRAL REGION

This Summary deals with the movement of swarms from the 1961 Short Rains breeding in the South-Central Region. Breeding occurred in two separate areas:

Somalia between 9°N and 1°N, and neighbouring eastern Ogaden in Ethiopia;

along the northern coast of Somalia between 43° and 49°E.

Sources

Laying on the Short Rains began in mid October in the Las Anod (8°N 47°E) area of Somali Republic (North), in the adjacent area of north-eastern Ogaden of Ethiopia, and in the Mudugh Province of Somali Republic (South). In the second half of October, it spread southward to 2°N in Somali Republic (South), and in the first half of November to Upper Juba Province and to 1°N in Benadir Province. (It did not extend to Kenya and Tanzania in the way that it did in 1954 — compare Summary 14.) Laying also took place along the coast of Somali Republic (North) in November and December (Fig. S15 d).

Hatching over most of the Somali Peninsula began in October, and it continued in November. Along the northern Somali Coast, hatching took place from mid November 1961 until early January 1962.

The first fledgings were reported in Mudugh Province of Somali Republic (South) at the end of November, but in December there was fledging over most of the Somali and Ethiopian breeding areas (Fig. S15 d). In some parts of Benadir and southern Mudugh it continued in the first half of January. Along the northern Somali Coast, fledging began in early January and continued until mid February.

Movements to the south-west and west

In December 1961, most swarms were reported within the breeding area (Figs. S15 a and d). At the end of the month, some of them appeared near the border of north-eastern Kenya, indicating the start of a movement to the south-west (Fig. S15 d). Swarms were also reported in north-east Kenya in early January.

By mid January, most of the swarms from the Ogaden and Mudugh areas had moved away south-westward, although there was one report in the Webbe Shibele valley, at 6°N 42°E in Ethiopia, on 17 January, indicating a westward movement (Fig. S15 d). Between 20 January and the end of the month, swarms had spread over eastern Kenya.

In February, apart from two reports of swarms in the source areas of Ogaden and Upper Juba, most of Ogaden and Somali Republic (South) were clear of swarms. In the first ten days of the month, swarms moved west across Kenya into the Kenya Highlands north of 1°S, and one swarm was reported west of Lake Rudolf in north-west Kenya on 9 February. Other swarms moved south-westward to reach the Arusha and Moshi (3°S 37°E) areas of north-east Tanzania by 12 and 13 February. (There was a similar movement south-westward through Kenya in late January 1955, discussed in Case Study 14.1.) During the remainder of February, swarms were reported in the Kenya Highlands and north-east Tanzania.

In March, only two swarms were reported in Tanzania, whereas in Kenya some more were reported in the Kenya Highlands throughout the month (Fig. S15 e). There were also several reports of scattered locusts in northern and eastern Uganda throughout March (Fig. S15 e). Because several of these were reported as immature, it is likely that they represented remnants of swarms that had entered Uganda from Kenya (there was a similar westward movement at the end of February 1955 — see Summary 14).

By April, most of the swarms had disappeared from East Africa: only two were reported from Kenya, together with scattered locusts in northern and eastern Uganda. There was no Long Rains breeding in 1962 in Kenya and Tanzania, in contrast to the events in 1954 (discussed in Summary 16).

Movements to the west and north

Swarms resulting from breeding along the northern Somali Coast moved westward in January, reaching the Harar Plateau of Ethiopia on the 27th and 29th. During February there were swarm reports in the Somali Republic (North) (Fig. S15 c), reflecting the later fledging in the northern breeding area, while in eastern Ethiopia swarms spread further west on the Harar Plateau and in the Railway area, and northward into the Danakil (Fig. S15 d). Scattered locusts were reported in the Lake Zwai (8°N 39°E) area of the Ethiopian Rift Valley on 28 February, probably representing a limited south-west movement from the Awash (9°N 40°E) area. It is unlikely that these scattered locusts came from the south because on no days between 15 and 27 February did southerly winds blow.

In March, swarms were still present in the Railway area and in the northern Harar Plateau, and more swarms moved north from this area in the middle of the month to be reported in the Danakil (Fig. S15 e), and as far north as 13°N in Ethiopia, and the Republic of Djibouti. Swarms were reported as far south as 8°N in the Ethiopian Rift Valley (Fig. S15 f), and it is probable that they had moved north from Kenya early in March, as there were several days when southerly winds blew over southern Ethiopia and Kenya. (There was a similar move northward in April 1955 — see Case Study 14.2.) Such a movement northward from Kenya would also explain the reduction of swarm reports in East Africa in March and April (Fig. S15 e).

Swarms were maturing in the second half of March, and Long Rains breeding began at the end of the month in the northern Rift Valley and the Railway area in Ethiopia, and in adjacent areas of Somali Republic (North). This breeding continued in April, mostly in the extreme west of Somali Republic (North) and the adjacent Railway area of Ethiopia.

SUMMARY 16

MOVEMENTS OF LONG RAINS SWARMS IN THE SOUTH-CENTRAL REGION, MAY TO SEPTEMBER 1954

This Summary discusses breeding on the 1954 Long Rains in East Africa and describes the movements of the resultant swarms. Some of these swarms matured to take part in summer breeding in the Danakil and Railway areas of Ethiopia, and the Samburu and Turkana areas of Kenya. Most of the Long Rains generation swarms, however, became concentrated on the northern Somali Peninsula where they remained immature until September. A few also stayed in the Kenya Highlands.

Sources

Long Rains breeding in 1954 extended from the Somali Republic (North), through the Ogaden and adjacent areas of Ethiopia, the west of Somali Republic (South), to northern and central Kenya and north-eastern Tanzania (Fig. S16 d). Laying began during March in the Borama (10°N 43°E) area of northern Somali Republic, the Dire Dawa (10°N 42°E) area of Ethiopia, and in southern Kenya. In April, laying was widespread over the breeding area but in May there was laying only in Ethiopia and central and western Kenya. The first fledgling swarms appeared in late May (Fig. S16 a), in the areas of early laying. Fledging continued in June over the whole breeding area, and possibly until mid July in central and north-eastern Kenya, and a few places in the northern Ogaden (Fig. S16 g).

Movements

The distribution of Long Rains generation swarms in May is shown in Fig. S16 a. Swarms were reported at Dire Dawa (10°N 42°E), in the Somali Republic (North), and in the adjoining part of northern Ogaden. There was also one report in northern Tanzania and another west of Lake Rudolf in Kenya. All these reports were after 24 May.

In June there were reports of immature swarms over most of the breeding area (Figs. S16 b and d). A few were also reported west of the breeding area, in Uganda, and one on 21 June in the Repubilc of Djibouti, north of the breeding area. Fig. S16 d also shows those parts of the source area where there was fledging in the first half of July.

Winds across the Somali Peninsula, north of 2°N and east of 38°E in June, July and August were from the south or south-west on most days, as is usual at this time of year (Section 7.3), and swarms could have moved north and north-east on almost any day during the whole of those three months.

In July, most of the Long Rains swarms were found either in central and western Kenya and adjoining parts of Uganda and south-east Sudan, or in the north of the Somali Peninsula and in east-central Ethiopia, to where they would have moved downwind. There were also reports of isolated locusts in southern Ethiopia and north-eastern Kenya, probably representing the later fledging in those areas; it is most likely that these too moved to northern Somalia, and that the northward movement of late fledglings continued in August, when it would have accounted for isolated swarm reports between 5° and 8°N throughout the month (Fig. S16 e). Over the northern Somali Peninsula, most of the Long Rains swarms remained immature during August and September, where their distribution became restricted to a narrow band across Somali Republic (North) (Figs. S16 f and g), in the vicinity of the local wind convergence zone (see Sections 7.3 and 7.13). The subsequent movements of these swarms are dealt with in Summary 13.

Those of the Long Rains swarms that reached the Railway and Danakil areas of Ethiopia matured and bred there in July and August, with a few of them surviving into early September (Fig. S16 f). This breeding population was continuous with the maturing population in Eritrea and Sudan, which is considered in Summary 11.

In Kenya in August, there were swarms of all maturities. In the Kenya Highlands, swarms were reported as mainly immature or of unknown maturity; but further north, in the Samburu and Turkana areas, maturation had taken place and there was summer breeding in July and August, with most of the breeding swarms dying off by September. Long Rains swarms were still present in the Kenya Highlands in September, however, and some of them moved to Uganda at the end of the month on easterly winds. This movement is discussed in Case Study 16.1, and subsequent movements in Summary 13.

CASE STUDY 16.1

INVASION OF UGANDA, SEPTEMBER 1954 (J.P.)

There were eight reports of swarms of mixed or unknown maturity over eastern Uganda from 24 to 29 September 1954 (Fig. C16.1 a). There had been no reports in Uganda in the previous month, although there had been some in eastern Uganda in July. These latter swarms had either died or moved east to breed in the Turkana summer breeding area.

Breeding in the Samburu and Turkana districts of western Kenya started with laying at the end of July, and the first fledgling swarm was reported on 21 September. In the Kenya Highlands there had been swarms of all maturities present during the first three weeks of September.

Some of the Uganda swarms were of *mixed maturity* so it is unlikely that they came from a Turkana source because there would have been insufficient time for even partial maturation. The source of these mixed swarms was most likely to have been the Kenya Highlands. If the swarms of unknown maturity were in fact *immature* they could have come from either source.

Fig. C16.1 b is a weather map for 23 September and illustrates easterly winds blowing from the Kenya Highlands and Samburu–Turkana area into Uganda. These winds blew from 21 to 25 September, and the movement into

Uganda could have taken place during this period, though some swarms stayed in the previously infested areas of the Kenya Highlands – perhaps within local convergence zones among the mountains. Before 21 September, winds were variable in direction over Uganda and south-westerly over the Kenya Highlands. There is no evidence that any movement occurred at that time.

SUMMARY 17

MOVEMENTS OF 1954 SUMMER GENERATION SWARMS IN THE WESTERN REGION

This Summary deals with movements of the 1954 summer generation swarms through the Western Region, some of which reached Egypt after passing over Algeria and Libya. Longitude 37°E is taken as the easternmost limit of spread. Movements described include the north-westward spread into the North-West African spring breeding areas, the spread into Egypt (and possibly Jordan), and the Southern Circuit (Section 8.9). The area covered by this Summary is bounded by latitudes 38°N and 7°N and longitudes 20°W and 37°E. Although there were no *swarm* reports to the west of 20°W or to the north of 38°N, reports of *scattered* locusts beyond these limits suggest more widespread movement over the Atlantic than is studied here. There were no swarms reported south of 9°N in the Western Region. Movements *directly eastward* in the North-Central Region on to the Red Sea Coast (and possibly across the Red Sea into Saudi Arabia) are not considered.

Sources

The 1954 summer breeding, from which swarms spread into countries of the Western Region, extended from Mauritania in the west to Sudan in the east (Fig. S17 d). Fledging dates, based on both reports and estimates from hopper and laying records, are divided into two periods: one where fledging had commenced between late August and the first week of October, and the other where it began later. This division helps understanding of swarm movement.

The earliest fledging was estimated to have begun in the last ten days of August in north-western Niger (based on unconfirmed hopper reports) and in eastern Sudan. Fledging was more widespread in September and by the second half of the month many young swarms were reported in the areas where fledging is shown on Fig. S17 d to have commenced by the first week of October.

In Mauritania, fledging began later, during the second week of October (Fig. S17 d), and continued there into early November. In northernmost Chad, fledging was at least a month later, and the young swarms appearing there during the last ten days of November and in early December were almost certainly the progeny of mature swarms which had moved into northern Chad at the end of September (Summary 11). In central Chad, areas where fledging had commenced by the first week of October were not sufficiently far away from areas of later fledging for movements of resultant swarms to be separated.

Movements from September to November 1954

The first evidence of movements of the 1954 summer swarms away from the breeding areas came during the last ten days of September. On 25 September, a young swarm appeared in southern Algerian Sahara at 19°N 3°E (Fig. S17 a) to the north of nearby breeding areas (Fig. S17 d) where it had probably originated (Case Study 17.1). On the same day, a young swarm appeared in southern Western Sahara and there were several further reports of immature swarms during the last week of September in nearby western Mauritania (Fig. S17 a), where swarms from local breeding were estimated not to have emerged until the second week of October (Fig. S17 d). It seems that swarms had moved west-north-westward from breeding areas in Mali (Fig. S17 d, Case Study 17.2).

Westward and north-westward spread of summer swarms from the breeding areas in the Western Region continued in October. Young swarms moved westward and then northward during the first half of October into the Hoggar region of Algerian Sahara and into south-western Libya (Fig. S17 b, Case Study 17.4). Further west, summer swarms appeared in Western Sahara to the north of previous limits and of the breeding belt (Fig. S17 b). By 13 October, a swarm was reported as far north as 26°N along the coast of northern Western Sahara, and by 16 October a swarm had reached 31°N on the western coast of Morocco. There had been opportunities for swarms to move into northern Western Sahara both northward from western Mauritania and also northward and westward from the breeding areas further east, after crossing Algerian Sahara (Case Study 17.5). Swarms moving into Morocco from the 16th almost certainly also spread northward and westward through Algerian Sahara (Case Study 17.5). Meanwhile, strong east-south-easterly winds had developed over the coast of northern Western Sahara, carrying swarms out over the Atlantic to the Canary Islands from the 14th (Fig. S17 b, Case Study 17.5). The winds veered to southerlies over the Atlantic, and by 17 October scattered locusts were reported as far north as the Scilly Isles (50°N 6°W) in southern England (Rainey 1963).

The appearance of a swarm on 20 October at Gibraltar (36°N 5°W), a long way to the north of swarms spreading across Algerian Sahara into southern Morocco (Fig. S17 b), was almost certainly related to the northward movement off the coast of North-West Africa. A return to the more usual north-easterly winds over the Atlantic during the second half of October was accompanied by sightings of flying locusts landing on board ship as far to the south and west as 15°N 22°W.

In West Africa during November, swarms which had been reported in Western Sahara and Mauritania to the north of 20°N during the first few days of the month appeared to move northward into southern Morocco, probably under the influence of warm southerlies associated with depressions over the Atlantic (Fig. S17 d). Not all swarms disappeared from Mauritania, however, for there were several reports from north-western and central Mauritania during the second half of the month (Fig. S17 c).

To the south of the summer breeding areas there were south-westward swarm movements into north-eastern Nigeria and southern Chad (Fig. S17 d). These probably commenced at the end of September (there were two reports of swarms in Chad just to the south of the breeding area there on 30 September) and continued during the first ten days of October, when there were many swarm reports to the south of the breeding areas (Fig. S17 b, Case Study 17.3). There were no swarms reported to the south of the breeding area in Chad after 9 October, however, and in Nigeria there were only two reports in November (Figs. S17 c and d) to follow those in the first ten days of October. It seems that the majority of swarms which had moved to the south of the summer breeding area either perished or moved northward again (with a temporary northward surge of the ITCZ) to come under the influence of winds carrying swarms to the north-west and north-east.

In the east, there were not many reports of young swarms produced in the summer breeding areas of Sudan in September or October (Figs. S17 a and b), but those in western Sudan almost certainly took part in movements to the north-west and south-west as described above. Swarms produced further east may have moved eastward to the Red Sea Coasts of Ethiopia and Sudan, where there were many swarm reports during October; by early November, swarms had spread northward along the Red Sea (Fig. S17 d), reaching as far as 22°N (Fig. S17 c) by the 1st. Other swarms may have crossed the Red Sea, but they are outside the concern of this Summary. Further north, immature swarms moved north-eastward into northern Egypt, having crossed Libya during the middle of November. These swarms had previously moved north, north-east and possibly north-west into Libya from the summer breeding areas in Mali, Niger, Chad and possibly Sudan, some crossing the Hoggar of Algerian Sahara (Fig. S17 d and Case Study 17.6).

Movements in December 1954 and January 1955

Swarms had spread north-westward across Algerian Sahara into Morocco during October, and there were again reports of swarms in western Algerian Sahara during December (Fig. S17 e). Their appearance in western Algerian Sahara was probably due partly to further northward and westward movements from southern Algerian Sahara (where there had been a swarm reported at the end of November) but mainly to an eastward and north-eastward movement from the population in Morocco and northern Mauritania under the influence of a spell of westerly and south-westerly winds in the second week of December (Fig. S17 e). During January, the east-north-eastward spread across northern Algerian Sahara continued, with swarms reaching western Tunisia by the end of the month, although this invasion may have been supplemented by swarms coming north from Libya (Fig. S17 g, Case Study 17.8), while swarms in Morocco spread further north (Fig. S17 g). There were a few reports of swarms on the Canaries and nearby islands until January (Fig. S17 f) but there is no evidence to suggest that these were related to a fresh invasion; they were probably survivors from the October invasion.

Immature swarms appeared in Senegal from 15 December onwards (Fig. S17 e). These swarms almost certainly moved south-westward (Fig. S17 g) from the population in northern Mauritania, where locusts were reported during November and December (Figs. S17 c and e), and this movement was the first in the Southern Circuit of 1954–55.

The persisting population in northern Mauritania matured during January, and the appearance of mature swarms in the second half of the month on the northern part of the Mauritanian coast was almost certainly related to westward movement from that population (Fig. S17 f).

In North-East Africa, following the November invasion of Egypt from the south-west (Fig. S17 d), a population of immature swarms persisted during December (Fig. S17 e), although by the end of the month it was concentrated along the Gulf of Suez. There were no reports of swarms in Egypt during early January, but on the 17th mature swarms appeared in north-western Egypt. These could have come from north-eastern Egypt, for rain there may have stimulated maturation of the swarms reported in December, and there were opportunities for movement from north-east Egypt to the north-western coast of Egypt (Fig. S17 g, Case Study 17.7).

Movements in February and March 1955

In North-West Africa, there was a further northward and eastward spread of swarms during February and March (Fig. S17 j). By 17 February, swarms had spread eastward into north-western Libya and northward to the northern coast of Tunisia (Fig. S17 h). During March, these movements continued and swarms reached as far east as 15°E in northern Libya by the 12th; while to the west, swarms spread to the coastal plains of north-eastern Morocco and northern Algeria during the last ten days of the month (Fig. S17 i).

Further east, mature swarms continued to be reported in northern Egypt during February (Fig. S17 h), but there were no further reports after the 27th. Some of the swarms may have moved eastward towards western Jordan, where there were unconfirmed reports of swarms on 9 and 28 February (Fig. S17 h), although swarms may equally have moved there from the population in central Saudi Arabia because both west and south-east winds blew during February (Fig. S17 j). After February, there were no further reports of swarms in Jordan.

In West Africa, immature swarms spread further south in Senegal during February (Fig. S17 h) than had been reported in January (Fig. S17 f), and from 22 February swarms appeared in central Guinea (Fig. S17 h). There had been opportunities for swarms to move southward and then north-eastward into central Guinea from *western* Senegal and also more directly southward from *eastern* Senegal (Fig. S17 j, Case Study 17.9). During March the Southern Circuit swarms in Guinea spread only slightly further eastward (Fig. S17 j). Further north, in Mauritania, *immature* swarms were reported 'to the north of 19°N' in March, and because previous reports in this area had been of *mature* breeding swarms in January it is almost certain that the immature swarms were their progeny, resulting from fledging which was reported in western Mauritania from 8 March onwards. The movements of these young swarms are discussed elsewhere (Summary 19).

Movements from April to June 1955

During April and May in North-West Africa, the main change in swarm distribution from that in March was a split into two populations, one in Morocco and the other in northern Algeria, Tunisia and north-western Libya (Fig. S17 n). There was a gradual reduction in the number of reports of 1954 summer swarms during these months, the numbers in Morocco declining first (Figs. S17 k and l), and by June there were only a few swarms remaining in North-West Africa which could be attributed to the 1954 summer breeding (Fig. S17 m). These were the last of that generation to be reported anywhere in the Western and North-Central Regions.

The appearance of two mature swarms in April in northern Mauritania (Fig. S17 n), to the south of the main populations in North-West Africa, may have been related to a southward movement from the population in Morocco on warm northerly winds blowing at the end of March. These were the only swarms reported outside the March swarm limits in North-West Africa, except for swarms in north-west Libya (Figs. S17 n and m).

The Southern Circuit continued in April and May, with swarms spreading north-eastward from Guinea into southern Mali during April (Fig. S17 k, Case Study 17.10) and further north-eastward in southern Mali by early May (Fig. S17 l). The appearance of immature swarms, to the north-west of the Southern Circuit swarms, in southern Mali in the last ten days of May, can be related to a southward movement of spring swarms from the breeding areas in North-West Africa (Summary 19) and there were no swarm reports after 9 May which could be related certainly to the Southern Circuit.

Breeding by the 1954 summer swarms

Spread of the 1954 summer generation swarms through the countries of the Western Region resulted in widespread spring breeding in North-West Africa (Summary 19). There was an *unconfirmed* report of laying in western Algerian Sahara on 30 December 1954, but the earliest *confirmed* reports were in January 1955 in Mauritania, parts of southern Morocco, and also in north-western Egypt. No swarms resulted from the breeding in Egypt.

By February, laying was reported from Morocco, across northern Algerian Sahara and Tunisia to north-western Libya, and during March spread further north in Morocco, Algeria and Tunisia. Swarms fledging in March from the early breeding in Mauritania moved eastward (Summary 19) and may have matured to become indistinguishable from the 1954 summer swarms. The last laying which can be related to either the 1954 summer swarms or the matured spring swarms was in north-western Libya in June 1955.

CASE STUDY 17.1

INVASION OF SOUTHERN ALGERIA, LATE SEPTEMBER 1954 (E.P.)

Even when a new generation has fledged, old parent swarms can still take part in an invasion. This happened in late September 1954 when both old, *mature* and young, *immature* swarms invaded parts of southern Algeria where swarms had not been reported for nine months (Fig. C17.1 a).

Fledging from the summer breeding was widespread by mid September in Mali, Niger and Chad (Fig. C17.1 a), and, whereas there were no reports of mature swarms of the parent generation in Mali or Niger after August, *mature* swarms were present in north-western Chad during the second half of September (Fig. C17.1 a).

From 19 to 25 September, when *mature* swarms first appeared in the Hoggar, easterly winds to the north of the ITCZ swept across northern Chad and Niger day after day, turning to south-easterlies as they approached the Hoggar. Fig. C17.1 b illustrates this flow for 23 September, the day when the southerly component over the Hoggar was greatest, and when the ITCZ reached as far as about 22°N over the southern Hoggar.

Thus, the invasion of the Hoggar region of Algeria by *mature* swarms can almost certainly be related to west-north-westward movement from north-western Chad. *Immature* swarms from summer breeding in Chad may also have moved westward with the mature swarms, and on 21, 22, 24 and 25 September easterlies and north-easterlies blew into southernmost Algeria, where young swarms were reported on 25 and 26 September (Fig. C17.1 a). These were, however, much nearer sources of *immature* swarms in September: the breeding areas of Mali and Niger, the latter just extending into southern Algeria (Fig. C17.1 a). The south-westerlies extending into Algeria on 23 September (Fig. C17.1 b) could have brought swarms directly from the breeding area in Mali. Alternatively, swarms could have moved first north-eastward from the Niger breeding area and then into the Adrar region on the easterlies and north-easterlies of the next two days.

During late September, then, there were opportunities for invasion of Algeria by *immature* swarms from several parts of the summer breeding area, although there was only one known source for the invasion by *mature* swarms.

CASE STUDY 17.2

INVASION OF SOUTHERN WESTERN SAHARA AND WESTERN MAURITANIA, LATE SEPTEMBER 1954 (E.P.)

Immature swarms were reported in southern Western Sahara on 25 and 26 September 1954 and in western Mauritania from 27 September (Fig. C17.2 a), in areas where only *mature* swarms had been recorded since the middle ten days of July 1954.

Summer breeding had taken place in western Mauritania, but estimated fledging would not have begun until October. Western Mauritania was kept under careful surveillance throughout the summer of 1954 so it is unlikely there had been any undetected local breeding that could have produced swarms as early as the last week of September. The nearest known breeding area where fledging was estimated to have started by mid September was in Mali (Fig. C17.2 a): a report of a swarm of *unknown maturity* in the western part of the Mali breeding area on the 16th may well have been one of the first fledgling swarms.

Daily weather maps show that, since 20 September, winds with a strong easterly component had been blowing across southern Western Sahara and western Mauritania, where swarms were reported from 25 September onwards. These winds, replacing the north-north-easterlies as the 'trade front' was pushed further west to a position over the coast itself, came from a large region with no weather reports but, by interpolation from surrounding areas where the wind pattern could be recognised with some confidence, they could be traced back to the north-easterlies blowing across Algeria and eastern Mauritania (Figs. C17.1 b and C17.2 b show winds on 23 and 25 September 1954). The ITCZ generally lay to the north of the breeding area in Mali, and south-westerlies (Fig. C17.1 b) may have taken swarms north-eastward so that they came into the path of the north-easterlies and easterlies on occasions when the ITCZ moved temporarily southward.

There appear, then, to have been opportunities for swarms to have moved north-eastward and then westward towards Mauritania from the nearest known breeding areas in Mali (or maybe eastern Mauritania), where fledging is likely to have taken place by mid September.

CASE STUDY 17.3

IMMATURE SWARMS IN CHAD AND NIGERIA, SOUTH OF THE SUMMER BREEDING AREAS, LATE SEPTEMBER TO EARLY OCTOBER 1954 (E.P.)

Until 30 September, no *immature* swarms were reported to the south of the summer breeding areas in Africa. Between 30 September and 9 October 1954, however, immature swarms appeared in Nigeria and Chad to the south of the breeding areas in Niger, north-eastern Nigeria and Chad (Fig. C17.3 a).

This spread of swarms was related to the seasonal onset of north-easterly winds with the southward displacement of the ITCZ. In 1954 the ITCZ moved south from around 14°N at the end of September and well-defined north-easterlies reached about as far south as 10°N by 2 October (Fig. C17.3 b), although winds to the south of the ITCZ were variable. North-easterlies were blowing to similar latitudes in north-eastern Nigeria and southern Chad on 3, 4 and 6 October and thus provided opportunities for swarms to move south-westward from the summer breeding areas in south-eastern Niger, north-eastern Nigeria, Chad and probably also Sudan.

CASE STUDY 17.4

NORTHWARD SPREAD OF IMMATURE SWARMS IN ALGERIA AND INTO LIBYA, MID OCTOBER 1954 (E.P.)

Following the appearance of *mature* swarms in the Hoggar region of Algeria during the last ten days of September 1954 (Case Study 17.1), *immature* swarms appeared there from 10 October (Fig. C17.4 a). On 11 October a swarm of mixed maturity was reported in south-eastern Algeria, near the Libyan border, and on 14 October an immature swarm was reported at Gatrun (24°N 14°E) in south-western Libya (Fig. C17.4 a). This was the first time that *immature* swarms had been reported in Libya since May 1954. In Algeria, there had been no reports of immature swarms since July 1954, except for one just inside the southern border with Mali at the end of September, and a swarm of unknown maturity, which may have been part of the 1954 summer generation, at 22°N 1°E. Apart from these in south-western Algeria at the end of September, *immature* swarms were reported at the end of September and in early October in the breeding areas of Mali, Niger and Chad, where fledging is estimated to have begun by the first ten days of October (Fig. C17.4 a). An immature swarm at Zouar (20°N 16°E) in north-western Chad on 20 September may be an indication of the presence of other swarms, unreported in the largely uninhabited areas of northern Chad and north-eastern Niger.

Daily weather maps show a general easterly and north-easterly flow across southern parts of Libya and Algeria, and across northern Chad, Niger and Mali during early October, but from 8 to 12 October this easterly flow over the Hoggar was interrupted by southerlies associated with a depression moving north-eastward across central Algeria. These southerlies were continuations of the easterlies blowing over northern Chad and Niger, although on 10 and 11 October they grew stronger and more widespread (from about 16°N over central Chad to western Libya; Fig. C17.4 b shows the winds on 10 October). Thus flying swarms were probably carried first westward from Chad and Niger and then northward into the Hoggar as they came under the influence of the southerlies. The swarms appearing in the Hoggar on 10 October had probably followed this route, but those appearing in the Hoggar after that date may have moved north from more southerly latitudes, in the southerlies that were blowing from about 16°N on 10 and 11 October.

A return to a more easterly flow on 13 and 14 October suggests that the Gatrun swarm first came into Libya on the spell of southerlies, which had extended furthest east on 11 October, and then moved westward, to be seen on the 14th for the first time in this very sparsely inhabited part of Libya.

The northward spread of swarms during the first half of October into Algeria and Libya thus seems to have been related to a spell of southerly winds interrupting the prevailing easterly airflow and caused by the presence of a depression moving north-eastward over North-West Africa.

CASE STUDY 17.5

INVASION OF THE CANARY ISLANDS AND MOROCCO, MID OCTOBER 1954 (E.P.)

The appearance of young swarms on the Canary Islands on 14 October 1954 (Fig. C17.5a) heralded the first large-scale invasion of these islands since 1932. Until 12 October, young summer swarms had been reported at more southerly latitudes in southern Algerian Sahara, Mali, western Mauritania and Western Sahara (Fig. C17.5a), but on 13 October a swarm was reported on the coast of Western Sahara to the north of these earlier reports, and by 16 October a swarm had appeared on the western coast of Morocco (Fig. C17.5a). Locusts during this period were also reported widely out to sea between 23° and 35°N.

On 13 and 14 October, when swarms were first reported in Western Sahara, there were east-south-east winds blowing from northern Mauritania. For the previous two days east-north-east winds had been blowing over northern Mauritania and Western Sahara from Algerian Sahara, and it therefore seems probable that the swarms appearing on the coast of Western Sahara on 13 and 14 October had moved westward from an undetected location in northern Mauritania or western Algerian Sahara. The absence of reports in these sparsely populated areas is not unusual, but it makes analysis of probable swarm movements up to 11 October very uncertain. There was a brief spell of south-westerlies over Western Sahara and western Mauritania on 9 October, and swarms which were reported there during October may have moved north-eastward into northern Mauritania, to be affected by the east-north-east winds from 11 October. Further east, there was a more persistent south-westerly airflow into central Algerian Sahara, ahead of a cold front, lasting from 8 to 12 October (for the wind pattern on 10 October see Fig. C17.4b). Thus swarms may have first moved north-eastward from Mali, or possibly Niger, into central Algerian Sahara (Case Study 17.4), and later westward on the easterly winds.

Swarm movements from 13 October onwards are easier to understand as both locust swarms and weather were better documented over the north-eastern Atlantic and its coastline. The onset of east-south-east winds over Western Sahara on 13 October was related to a deepening centre of low pressure over the Azores which caused a breakdown of the characteristic 'trade front' along the Atlantic coast of North-West Africa by 14 October. On that day east-south-easterly winds reached the Canary Islands, coinciding with the first appearance of swarms there, and by 15 October the offshore winds veered to southerly and strengthened as the low pressure centre deepened further (Fig. C17.5b). The appearance of thin swarms at sea at 35°N on 15 and 16 October may be related to these strong south winds.

Along the coast of Morocco, westerly onshore sea breezes were recorded but their effect would have been only local and the appearance of the swarms as Essaouira (31°N 9°W) on 16 October (Fig. C17.5a) is much more likely to have been associated with continuing south-easterlies blowing into Morocco from the Algerian Sahara (Fig. C17.5b).

CASE STUDY 17.6

INVASION OF EGYPT, NOVEMBER 1954 (E.P.)

Immature swarms appeared in the North-Western Desert and along the Mediterranean Coast of Egypt from 17 November 1954 (Fig. C17.6a). This was the first time since June 1954 that swarms had been reported anywhere in Egypt.

During early November, *immature* swarms had been reported in the Hoggar region of Algeria, in northern Chad, and along the Red Sea Coast of Sudan (Fig. C17.6a). Swarms were subsequently reported in Libya from the 16th and in Egypt from the 17th (Fig. C17.6a).

The appearance of swarms along the Mediterranean Coast by 17 November was almost certainly due to movement on that day on south-westerly winds ahead of a secondary cold front (Fig. C17.6b). The absence of swarm reports to the south-west on the previous few days can be related to the fact that this is a poorly populated and under-reported area. Had swarms moved on to the Mediterranean Coast of north-west Egypt on the previous one or two days, then their arrival would have been associated with westerly winds; but there were no reports of swarms from the coastal regions of north-east Libya during mid November, and it would be expected that swarms moving across that area would have been reported. Thus, it seems that swarms moved on to the coastal areas of Egypt on 17 November from the south-west. Westerly winds blowing across northern Libya and Egypt on the previous two days almost certainly brought swarms eastward from north-central Libya. Although these westerlies were cool (21 – 26°C), there would have been some flight; however, movement would have been greatest with the slightly higher temperatures (27°C) of the 17th.

It may be assumed, then, that the swarms appearing on the Mediterranean Coast of Egypt by 17 November came from Libya. However, their movements before 15 November can only be guessed at. There were very few reports from central and northern Libya before 19 November (Fig. C17.6a), but that may have been because these areas are almost uninhabited, and anyway there would have been little flight from 11 to 14 November because temperatures were low, reaching a maximum of only 23°C in northern Libya by 14 November, following the passage of the main cold front on 11 November. However, on 11 and 12 November, while most of Libya was covered by a cool airstream, southerly winds were still blowing ahead of the cold front into eastern Libya from Chad and may have brought some swarms northward from the summer breeding areas there, or even from the Sudanese Red Sea Coast. On the previous two days there had been south-westerly winds ahead of the cold front (the weather pattern was similar to that of 8 January; see Fig. C17.7b), and temperatures were about 30°C, providing further opportunities for swarm movement north-eastward from the summer breeding areas of Chad, and also Niger and Mali, crossing the Hoggar region of Algeria and northern Chad, where swarms were reported from 1 to 10 November (Fig. C17.6a).

Thus, there were opportunities for swarms to move from Mali, Niger, Chad and possibly Sudan, across Algeria and Libya into northern Egypt by 17 November, the main northward surges being related to south winds ahead of a series of cold fronts.

CASE STUDY 17.7

INVASION OF NORTH-WESTERN EGYPT, MID JANUARY 1955 (E.P.)

Mature swarms were reported from 17 January 1955 on the western part of the Mediterranean Coast of Egypt (Fig. C17.7a, which shows *mature* swarms only, 17 – 29 January), where the last report had been of *immature* swarms on 23 November 1954. A continued presence of swarms from November to January in this well-reported area is very unlikely, so the January swarms probably came from an outside source. Several sources are possible (Fig. C17.7a): the nearest was north-east Egypt, but others were the Red Sea coasts of Sudan and south-west Saudi Arabia, and also northern Saudi Arabia, Algeria and Chad.

In north-eastern Egypt, swarms had been reported during the second half of December and control was continued until 3 January, but some may have escaped. These swarms were *immature*, but maturation may have been stimulated by rainfall (totals from 14 to 23mm fell at four stations in north-eastern Egypt from 20 December to 4 January). Opportunities for movement to north-west Egypt were provided from 4 to 9 January, when north-east winds over north-eastern Egypt turned to south-east across the Mediterranean Coast of Egypt under the influence of a centre of low pressure to the north of Libya (illustrated by Fig. C17.7b). This flow was interrupted from 10 to 16 January by cool west and south-west winds behind the cold front shown in Fig. C17.7b, but south-easterlies returned on the 17th, the day when swarms were first reported on the north-western coast. Even with an average of only 5h flying a day, and winds of 20km h^{-1}, there would have been enough time for swarms to reach north-western Egypt.

Along the Red Sea coast of Sudan, *mature* swarms were reported in early January, but movement inland would have been on north-east winds, and it was not until 9 January that southerly winds from northern Sudan could have taken swarms along a curved 3,000km track to Egypt around an anticyclone slow-moving over eastern Libya. Even assuming an average 7h flying a day (in temperatures of 23 – 28°C) and 30km h^{-1} winds, there would not have been enough time to reach north-western Egypt. The same would apply to the mature swarms reported in early January from northern Saudi Arabia.

To the west and south-west, there were reports of *immature* swarms in Algeria (the easternmost at 29°N 0°E — Fig. C17.7a), and of a single swarm in north-western Chad. The west and south-west winds over north-western Egypt from 10 to 16 January may have brought swarms from these sources, but they would need to have matured in the meantime. Rain in northern Algeria and Libya during January may have stimulated maturation of swarms crossing those countries, but there seem to have been no suitable rains for swarms coming from Chad. Because temperatures would have been seldom above 20°C on a flight from Algeria, even with winds of 30km h^{-1} there would not have been enough time to reach Egypt.

It therefore seems most likely that the swarms in north-western Egypt from 17 January had come from the nearest source, north-eastern Egypt, even though they had not been seen crossing the Nile valley.

CASE STUDY 17.8

INVASION OF TUNISIA AND CENTRAL ALGERIA, LATE JANUARY – EARLY FEBRUARY 1955 (E.P.)

Immature swarms appeared in western Tunisia from 30 January 1955 (Fig. C17.8a) – the first record of swarms in that country for nearly four years. This study examines the alternative sources of these swarms, and also of *mature* swarms on 31 January and 1 February in the Gourara area of central Algeria (Fig. C17.8a), where the last swarm report had been on 13 January.

From 20 to 29 January 1955 there had been numerous reports of swarms of all maturities in Morocco and across north-central Algeria, reaching as far east as 5°E (Fig. C17.8a). At the same time, mature and maturing swarms had been reported in Western Sahara and western Mauritania while, further east, in south-western Libya an immature swarm was reported at the 'end of January' (Fig. C17.8a).

The report of an immature swarm in western Tunisia on 30 January coincided with a burst of south to south-east winds blowing into Tunisia from Libya. Since early January there had been only one other period (24 – 26 January) when winds had blown from a similar direction, but the report of an immature swarm in Libya at the end of January suggests swarms may have invaded Tunisia from the south-east. To the west of Tunisia, however, there were many reports of swarms during the last ten days of January in north-central Algeria, and these may have been carried north-eastward into Tunisia on south-westerlies from 27 to 29 January. Although 1200 GMT temperatures were low, only occasionally reaching 20°C, winds were up to 35km h^{-1}, so even if flight were possible during only a few hours of each day, locusts would perhaps have been able to travel 50 – 100km a day. Swarms may thus have reached Tunisia on 29 January from Algeria but not have been reported until the next day.

By 31 January, swarms were reported near the Algeria-Tunisia border, near the centre of a depression which had developed to the south of the Atlas the previous day and had moved north-eastward (Fig. C17.8b). On this day, swarms may have moved into Tunisia either on the warmer southerlies ahead of the cold front or on the cooler westerlies behind. From 1 February, however, because the depression had moved further north-eastward to lie over the central Mediterranean, only winds with westerly components blew across Tunisia. Again, swarm movement was probably restricted to a few hours each day, since temperatures reached only 20°C, but by 4 February an immature swarm had reached the south-eastern coast of Tunisia (Fig. C17.8a).

The *mature* swarms in and near the Gourara region of central Algeria on 31 January and 1 February 1955 (Fig. C17.8a) were almost certainly ones that had gone unseen from the time they were last reported on 13 January, for there does not seem to have been much chance of movement from known sources. North and north-easterly winds blowing over Mauritania and Western Sahara (Fig. C17.8b) prevented north-eastward swarm movement from the populations reported there during January (Fig. C17.8a), while north-westerly winds blowing into central Algeria from Morocco (Fig. C17.8b) were cool (up to 18°C) so that it is unlikely that swarms flew south-eastward from Morocco.

Thus, while the appearance of *mature* swarms in and near the Gourara region of central Algeria on 31 January and 1 February can almost certainly be related to swarms reported there a couple of weeks earlier, the appearance of *immature* swarms in Tunisia can be more certainly related to invasion from outside source areas. Two sources may have been involved; both locust and wind data heavily point to invasion from Algeria, but this may have been supplemented by invasion from the less well reported areas of Libya.

CASE STUDY 17.9

INVASION OF GUINEA, LATE FEBRUARY 1955 (E.P.)

On 22 February 1955, swarms were reported for the first time in four years in Guinea, some 400 – 700km to the south-east of swarms reported earlier in the month in Senegal (Fig. C17.9a). Throughout this period there were no other swarms reported anywhere in western Africa to the south of 20°N,

During much of February, the ITCZ over western Africa (west of 0°W) lay between 9 and 12°N, separating very dry easterly winds to the north from moist south-westerly winds to the south (Fig. C17.9b). Along the west coast, winds were more variable, partly due to sea breezes, but there were also spells of northerly winds to the west of about 10°W associated with intermittent quasi-stationary cyclones which developed along the ITCZ. One spell was 16 to 18 February and another started on 22 February (Fig. C17.9b), and these were both associated with cyclones centred near 10°N 10°W over Guinea.

These spells of northerlies could have enabled swarms to move southward from Senegal. Swarms moving from *north-eastern* Senegal (Fig. C17.9a) would have been carried directly southward into central Guinea, but the fate of the swarms in *western* Senegal is less certain. A combination of the northerly flow and onshore sea breezes may have moved swarms south-eastward along the coast and into the vicinity of the ITCZ. On 22 February, as on other days, the ITCZ lay across the coast at about 9°N (Fig. C17.9b) so that swarms could have been carried along the coast to the southern border of Guinea. A slight northward shift of the ITCZ would bring swarms into south-westerlies and so they could have moved north-eastward into central Guinea. Alternatively, the swarms in western Senegal may have been lost at sea during periods of offshore winds. This may have been the fate of the mature swarms in western Senegal as there was no further record of them after 19 February, or they may just have died.

Thus, the invasion of Guinea in late February 1955 was almost certainly by swarms moving southwards from Senegal under the influence of northerlies associated with quasi-stationary cyclones along the ITCZ. It is not possible to tell whether movement was just from the population in *north-eastern* Senegal or whether it was supplemented by movement from that in *western* Senegal.

CASE STUDY 17.10

INVASION OF SOUTHERN MALI, EARLY APRIL 1955 (E.P.)

Swarms were reported for the first time in four years in southern Mali on 6 and 7 April 1955 to the east-north-east of swarms which had been in Guinea since late February 1955 (Case Study 17.9). These were the only swarms reported throughout western Africa south of 20°N during this period (Fig. C17.10a).

During the first half of March, the Inter-Tropical Convergence Zone (ITCZ) lay at about 10 to 11°N over Guinea, but from mid March onwards the ITCZ made a series of northward moves, reaching at times as far north as 15°N.

Thus, the swarms in Guinea which had been close to the ITCZ in early March came at times under the influence of south-westerlies as the ITCZ moved northward (Fig. C17.10b). Although some swarms remained in Guinea, others appear to have moved north-eastward into southern Mali (Fig. C17.10a), demonstrating general eastward movement in winds to the south of the ITCZ, contrasting with well-documented *westward* movements in winds to the north (e.g. Case Studies 11.2, 11.3 and 17.3).

SUMMARY 18

MOVEMENTS OF 1958 SUMMER GENERATION SWARMS IN THE WESTERN REGION

This Summary deals with the typical migrations of swarms, produced in the summer breeding zone of the Western Region, to the spring breeding areas in North-West Africa, and with their distribution in the spring. It also describes the movements of summer swarms that have remained south of the Sahara and become involved in the Southern Circuit (Section 8.9). Migrations of the swarms produced in summer 1958 in the extension of the summer belt to east of 24°E are described in Summary 9.

Sources

The first hatching from summer 1958 breeding was in late July in southern Mauritania and central Mali; in August and September, widespread hopper infestations were reported from these countries, as well as from northern Senegal, Niger and Chad. In all the affected territories, fledging and swarm formation began in September and, except in Chad, continued into the first half of October. The formation of new swarms resulting from later layings and hatchings continued locally in the second half of October in south-western Mauritania, northern Senegal, and northern Mali and Niger (Fig. S18e).

Northward movements

Northward movement from the source areas began in the last days of September 1958 when some swarms, flying with a spell of southerly and south-easterly winds (Gerbier 1965), reached Tamanrasset (22°N 5°E) in the Hoggar, and Reggan (26°N 0°E). In Chad, some swarms reached southern Tibesti (Figs. S18a and e).

By 4 October, some swarms had penetrated into southern Morocco in the upper Wadi Draa area (30°N 5°W), while from eastern Algerian Sahara swarms spread northward to Ghat (25°N 10°E) in south-western Libya. During the next ten days, further waves of swarms moved north and north-west through Algerian Sahara with warm southerly and south-easterly air streams associated with a succession of eastward-moving lows (Gerbier 1965), and swarms reaching Morocco spread west through that part of the country lying south of the High Atlas range. By 14 October, a swarm reached Madeira (Fig. S18b) on south-easterly and easterly winds blowing from southern Morocco (Gerbier 1965). In the meantime, some swarms moving northward in eastern Algeria reached Touggourt (33°N 5°E) on the 12th (Figs. S18b and e).

Between 15 and 20 October, a south-easterly to southerly air current became established over the whole area from Senegal to Morocco, in association with a depression over the Canaries (Gerbier 1965), and swarms moved north-west from Senegal and Mauritania, reaching the Canaries on 16–17 October. During the last ten days of the month, swarms were reported at a number of points throughout the length of Western Sahara (Figs. S18b and e).

During November (in particular between the 9th and 14th), further swarms moved over Algerian Sahara towards Morocco, where the infestation spread to the north of the Atlas ranges in November and December. Other swarms moved north in November, through eastern Algerian Sahara and western Libya, where they reached as far north as the Nalut area (31°N 10°E). About the middle of November, some swarms flew over the Jalo oasis (28°N 21°E) in eastern Libya (Fig. S18c). In December, the movement to north and north-east continued in northern Algerian Sahara and spread over the southern half of Tunisia and into north-western Libya as far as Misurata (32°N 15°E). Further south, swarms were reported in the Fezzan and in northern Tibesti (Figs. S18d and e). Not all the swarms produced in summer 1958 in West Africa moved out in a general northward direction. While by the end of 1958 the main mass of the regional population had reached a belt lying to the north of the Sahara and extending from Morocco to western Libya, a proportion of swarms had remained in the West African countries to south of the desert zone (see Figs. S18d, f and i, and the account of the Southern Circuit below).

Movements in North-West Africa in the first half of 1959

Between January and March, swarms gradually spread northward as far as coastal areas in north-eastern Morocco and Oran Province of Algeria (Figs. S18f, g, h, i), with the infestation extending into northern Alger and Constantine Provinces of Algeria in April (Fig. S18j) and northern Tunisia in May (Fig. S18k). There was some eastward extension of the infested area in January—February in north-western Libya (Figs. S18f, g, i), where layings began in January and laying swarms persisted till April. Layings began in Morocco, Algeria and Tunisia in March, continued in Tunisia into April, and in Morocco and Algeria till June.

It will be seen that after the initial long-range migrations, resulting in the invasion of North-West African countries in the last quarter of 1958 (mainly from late September to November), swarm displacements there became more restricted, and the infested areas underwent comparatively little change throughout the first five months of 1959 (compare Figs. S18i and l).

The Southern Circuit

To the south of the Sahara, swarms continued to be recorded in November 1958 in Mali, southern Mauritania and Senegal, where their distribution extended southward beyond their October limit (compare Figs. S18b and c). Southward and westward tendencies are suggested by the distribution of swarms in December (Figs. S18d and e); such tendencies would be associated with the southward retreat of the ITCZ and the establishment of north-easterly and easterly winds. By January (Fig. S18f), except for a single report on the 1st in south-western Mali, all the swarms became confined to south-west Mauritania, western Senegal, Gambia and northern Guinea; in February their distribution in western Guinea extended south (Figs. S18f, g). An eastward tendency appeared in March, with swarms reported in northern Sierra Leone on the 10th, and in northern Ghana and Upper Volta in the second half of the month (Figs. S18h, i). The eastward tendency persisted in April, when swarms appeared to the east of the March distribution in northern Benin and northern Nigeria (Fig. S18j). In May, the movement became more to the north-east (presumably with northward advance of the south-westerly winds blowing towards the northward-moving ITCZ), and in the first half of that month swarms appeared in southern Mali, and south-west and south Niger (Figs. S18k and l).

All these swarms staying south of the Sahara remained immature throughout winter and spring. In the second week of May 1959, fledging began in the spring breeding areas to north of the Sahara, but the first young swarms were not reported there till 15 May. Further east, other young swarms originating in the spring breeding areas in Arabia and the Middle East invaded north-east Africa from mid May, with the first swarms appearing in Egypt on the 15th, in northern Sudan on 16th – 17th, and in eastern Chad on the 20th.

It is likely, therefore, that all the swarms reported south of the Sahara and west of 24°E up to 15 May belonged to the populations that had overwintered in West Africa and had performed the Southern Circuit (Section 8.9); later, these swarms became indistinguishable in the reports from young swarms invading West Africa from the north and east.

SUMMARY 19

MOVEMENTS OF 1955 SPRING GENERATION SWARMS IN THE WESTERN REGION

Spring breeding in the Western Region in 1955 was protracted, starting in northern Mauritania in early January and ending in the first week of June in western Libya. Between these two dates, breeding took place over most of North-West Africa. This Summary discusses the movements of resulting swarms between April and August, and those of other swarms that had been present in or had invaded the considered area will be referred to.

Sources

Spring breeding in North-West Africa

Laying by summer generation swarms began in the Adrar area of Mauritania in early January, and in south-west Morocco at the end of January. In February, laying took place in southern and western Morocco, in northern Algeria (north-eastern Ain Sefra, southern Oran, Alger and Constantine Provinces), in central Tunisia and in north-western Libya. Laying spread further north in March — to northern Morocco, northern Algeria (central Oran, Alger and Constantine Provinces) and to northern Tunisia, and it continued in north-western Libya. There was further laying throughout April and May in these areas, and until the first week of June in north-western Libya. Swarms laying in May and June probably included some resulting from early spring breeding in Mauritania that had moved north-east in April to mature and mix with the mature summer generation swarms still remaining in Algeria, Tunisia and Libya. Hatching began in late January in Mauritania, spreading to Morocco in February, north-western Algeria in March, and to the rest of the breeding area (northern Algeria, central and northern Tunisia, and north-western Libya) in April. The first fledging, in mid March, was similarly in Mauritania (Fig. S19a), where it continued throughout April (Figs. S19b and d). In April there was also fledging in south-west Morocco and near Bou Arfa (33°N 2°W). By the end of May there was fledging throughout Morocco, northern Algeria, Tunisia and north-western Libya, and it continued over most of the breeding area in June and July (Figs. S19d, g and i).

Swarms south of the Sahara

These swarms are discussed in Summary 17; they had remained in Guinea from the end of February until April, when they moved north-east into southern Mali. They were present in south-east Mali in May (Figs. S19a – c).

Movements

The first fledglings appeared in Mauritania from 8 March (Fig. S19a), but in this month they remained within the breeding area. In April there was movement from north-western Mauritania northward to western Algeria, around Tindouf (28°N 8°W), and to southern Morocco between 16 and 20 April. This was followed by an eastward movement, south of the Atlas Mountains, to the Beni Abbés area (30°N 2°W), Ghardaia (32°N 4°E), Touggourt (33°N 6°E) and south of Ghadames (30°N 9°E)(compare Fig. S19d and Case Study 19.1). Some of these swarms may have moved further north to northern Ain Sefra, southern Oran, Alger and Constantine Provinces of Algeria, to Tunisia, and also further east to north-western Libya (where they would have mixed with mature swarms of the parent generation already present and breeding there), and they explain the prolonged spring breeding in these areas. There was also limited fledging, leading to a few swarms, in the second half of April in southern and south-western Morocco (Fig. S19d).

During May, fledging occurred over a wider area in North-West Africa, extending from Morocco across northern Algeria into Tunisia and north-western Libya. Immature swarms were more widespread in Morocco than in April, and there were also several in Algeria and Libya. From 20 May, swarms were also reported in southern Mauritania, northern Senegal and western Mali (Fig. S19d), and it is likely that they came from Morocco and northern Mauritania on northerly winds which blew on most days in the second half of May. A similar movement that took place in early June 1954 is discussed in Case Study 11.5. Swarms could also have moved southward across the Algerian Sahara, where one of unknown maturity was reported at In Salah (27°N 2°E) on 4 May.

In May there were swarms from two other sources in the summer breeding belt to the south of the Sahara: mixed maturity swarms in southern Mali at the beginning of May, which probably belonged to the population that had over-wintered south of the Sahara (compare Summary 17); and immature swarms in Niger, from spring breeding areas in the North-Central Region (compare Summary 12). After the end of May, swarms from the different sources in the summer breeding zone could not be distinguished from each other. In June and July, more immature swarms were forming over North-West Africa (Figs. S19g and i), with fresh waves moving southward through Mauritania and possibly over the Algerian Sahara. Swarms in southern Mauritania and northern Senegal were beginning to lay at the end of June.

The pattern of movement in July and the first half of August (Figs. S19g and i) was similar to that of June, with swarms moving south-westward across the Sahara from the spring breeding area to supplement those already present in the summer breeding belt, where breeding was continuing. After mid August there were no spring generation swarms left in North-West Africa.

CASE STUDY 19.1

IMMATURE SWARMS IN THE ALGERIAN SAHARA, APRIL 1955 (J.P.)

Before 20 April 1955, most swarm reports in North-West Africa had been of the *mature* breeding population in the valleys of the Atlas Mountains. There were also a few reports in western Algeria of swarms of *unknown* maturity on 16 and 18 April (Fig. C19.1a). On 20 and 21 April, swarms were reported further east, near Beni Abbés (30°N 2°W). These reports were followed on 24 April by others: a *mixed maturity* swarm south of Adrar (28°N 0°W), and an *immature* swarm (date uncertain) at Adrar. At about this time, *immature* swarms were reported further east at Biskra (35°N 6°E), Touggourt (33°N 06°E), Ghardaia (32°N 4°E) and Lagouat (34°N 3°E). *Immature* swarms were also seen on 25 and 26 April at Temassinine (28°N 07°E) and Ohanet (29°N 09°E).

It is unlikely that these largely *immature* Saharan swarms were the progeny of the *mature* swarms among the Atlas Mountains, because the first fledglings from spring breeding by the latter did not appear until May. Fledging was reported in the Draa Valley in Morocco on 20 April, and in the Bou Arfa (33°N 2°W) area from 23 April (Fig. C19.1a). The latter fledging was too late to account for the Sahara swarms, and in any case swarms were further east than the Draa Valley on 20 April. Although fledging in Morocco could have subsequently added to the Algerian population, the earliest immature swarms are likely to have come from elsewhere.

In north-west Mauritania, early spring breeding led to fledging from 8 March, and young swarms were present in the breeding area in the first half of April (Fig. C19.1a). It is therefore possible that this area was the source of the mainly immature swarms in the Algerian Sahara.

The weather map for 17 April (Fig. c19.1b) illustrates the south winds that blew from 16 to 18 April over northern Mauritania that could have taken swarms from source areas there northward to southern Morocco, where there were reports between 15 and 20 April (Fig. C19.1a), although those seen on the 15th may have come on an earlier spell of south-west winds. By 20 and 21 April, winds over this area had become westerly, leading to an eastward movement of swarms. The westerlies backed to south-west by 23 April, as a depression developed south of the Atlas Mountains, but on the next day they veered to north-west as the depression moved eastward (Fig. C19.1c), thereby enabling swarms to be brought further south in the Algerian Sahara by 26 April.

PART 3

PRINCIPLES OF LOCUST FORECASTING

This part of the Manual deals with the thought processes involved in producing a forecast from field reports. The steps are treated in numbered Sections for ease of reference operationally.

Chapter 9 describes the nature of field reports, how they reach the forecaster, and how they are best presented for operational use. Chapter 10 discusses the ways in which the reports are used to assess the distribution of locusts at the time the forecast is made (size of population, stage in life cycle, breeding, movement) in the light of known locust biology and ecology (Part 1 of this Manual) and of our understanding of past locust events (Part 2). Chapter 11 extends the techniques discussed in Chapter 10 into the forecast period, and includes an account of methods of presentation of the forecast and its distribution to users. Chapter 12 draws attention to problems peculiar to recessions, when the greatest need is to be able to forecast upsurges.

A brief outline of Desert Locust forecasting has been published as a symposium paper (Betts 1976). This part of the Manual seeks to amplify that short account into a reference document for the working forecaster, but it is not intended to be a definitive treatise on locust forecasting. The locust situation is continually changing, as has been made clear in Parts 1 and 2. Also, our understanding of the locust situation is continually changing as new results of research in locust biology and ecology are added to the increasing archive of documented locust events in the field. Each forecaster will build up his own stock of experience of locust events, will seek to understand particular events, and will add to general understanding of the Desert Locust; as a result, forecasting methods will change. Moreover, new developments in communications will offer opportunities for revising the organisation of work. The forecaster will therefore need to seek actively for better ways of preparing his forecasts.

9 LOCUST REPORTS

The locust forecaster uses all available reports to help assess a locust situation that has been continually changing, and to help prepare a forecast of likely future changes. Reports must be reliable and up-to-date. Each report should be as detailed as possible — who saw what, where and when, and what the reporter's views on the sighting were — and each report has to be related to all others. The nature of locust reports is considered in this Chapter, together with their storage, retrieval and mapping. Assessing the current situation is considered in Chapter 10, and preparing the forecast in Chapter 11.

9.1 SOURCES OF REPORTS

By far the majority of locust reports are based on sightings over land; a few come from ships at sea; fewer still come from aircraft.

9.1.1 SOURCES OVER LAND

Locust reports reach the forecaster from trained staff of locust control and plant protection organisations, as well as from untrained people such as farmers and nomads, police and government officials, military units, truck drivers and travellers, many of whom have seen locusts before and know what they are. At times when there are great numbers of locusts, when swarms and bands are widespread, most reports may well come from untrained observers. Many such reports from the past have been used in compiling the frequency maps used in this Manual, as well as the maps in the Summaries and Case Studies of Part 2. Attempts are often made to confirm this kind of report, by questioning the observer or by seeking further field evidence, and the results of such attempts may have been added to the report. The observer may be asked to compare what he saw with specimens or pictures, or his description of behaviour may be compared with that typical of the Desert Locust, the aim being for the interrogator to find out whether or not there has been confusion with another species (see Section 2.1) or confusion between swarms and, say, clouds of dust or smoke.

9.1.2 SOURCES AT SEA

In 1960, the Commission for Maritime Meteorology of the World Meteorological Organization agreed to encourage the sending of locust reports by radio from ships on the seas around Africa, Arabia, India and Pakistan. Such reports have been used in forecasting, in research, and in the preparation of this Manual. They give the following information:

- date, time and position where locusts were first and last seen
- whether there were swarms or individual fliers, or locusts floating dead in the sea (few or many)
- colour (yellow, pink, grey)
- wind direction and speed.

9.2 TRANSMISSION OF REPORTS

A locust report passes between several people before reaching the forecaster. Fig. 9.1 outlines the most usual stages. Both detailed written reports and brief cabled reports are valuable. Fig. 9.2 shows the reporting forms recommended by the Food and Agriculture Organization of the United Nations. Speed and completeness are essential, otherwise much of the value of a report to the forecaster can be lost and the cost of getting and sending the report may be largely wasted. Delays may be due to poor or broken communications, political upheavals, or individual human failings. Whereas many reports reach the forecaster within days or a week or two, some are months late. The latter still have value for the assessment of the current situation (Sections 10.1 and 10.2). Late reports may indeed be critical in the reinterpretation of earlier events. Good forecasting, however, relies on prompt reporting.

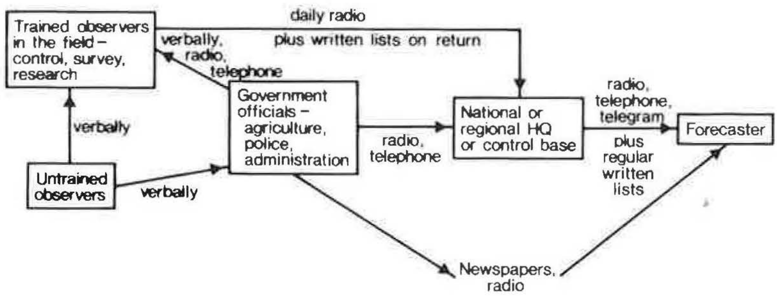


Fig. 9.1 Usual stages in the transmission of locust reports.

9.3 CONTENTS OF REPORTS

An ideal report contains as much information as possible that is useful to the forecaster. Sections 9.3.1 to 9.3.5 discuss the various kinds of information that can be included, with an indication of how each part is used by the forecaster. Section 9.3.6 discusses errors in reports.

9.3.1 LOCUSTS

Information about locusts in reports usually comes under the following headings:

- evidence that the report refers to Desert Locust
- stage of life cycle
- gregarious behaviour
- flight behaviour
- scale of infestation
- sexual maturity
- control measures undertaken.

Table 9.1 lists the commonest kinds of locust information and their usefulness to the forecaster, together with references to the Sections in Chapters 2 to 4 where relevant discussions can be found. Many of the terms used in locust reports are defined in the *Trilingual glossary of terms used in acridology* (FAO 1980).

Completed form to be returned to:
FAO through UNDP/FAO Pouch Service
or by mail to: FAO
Via delle Terme di Caracalla
00100 ROME, ITALY

LOCUSTS, OTHER MIGRATORY PESTS AND EMERGENCY OPERATIONS GROUP
AGP Division

FAO/1

Country ____________________

DESERT LOCUST SWARM REPORTS received at ____________________ during period ____________________

Locusts, even in large numbers, should not be reported as a swarm if they have not shown concerted movement, but should be recorded on form FAO/3

No.	Date and Time	Locality	Co-ordinates		Maturity	Density	Height of flight	Estimated size	Estimated direction of displacement, (State "from" and/or "to".), or settled	Remarks	Origin of report
			Lat.	Long.							

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For notes on reporting, see reverse side

Fig. 9.2 Locust reporting forms recommended by FAO.

NOTES ON THE REPORTING OF DESERT LOCUST SWARMS

MATURITY: Colour - pink, yellow or mixed.
State of ovaries - eggs undeveloped, partly developed or fully developed; evidence of previous laying.
Egg-laying or copulation - whether seen. Details of egg-fields should also be entered on this form even when the laying swarm itself was not seen.

DENSITY: i.e. thin (swarm visible only when near enough for separate locusts to be distinguished), medium, dense (swarm obscuring parts of nearby features, e.g. trees).

HEIGHT OF FLIGHT: i.e. low (topmost locusts below 10 metres, i.e. below "tree-top" height), medium, high (locusts as high as naked eye can see, i.e. several thousand feet).

ESTIMATED SIZE: i.e. small (estimated size less than 1 sq. kilometre), medium, or large (estimated size more than 100 sq. km.), together with any facts providing evidence of size - e.g. lengths of traverses, or time taken by swarm to pass with weather conditions including wind-speed. The estimation of swarm size is always difficult and often impossible for a single observer on the ground.

ESTIMATED DIRECTION OF DISPLACEMENT: The direction of movement, both of individual locusts and even of whole groups, provides no indication of the direction of displacement of the whole swarm. The best approximation to the direction of displacement of the swarm as a whole which is obtainable from the ground is by taking a compass bearing on the swarm when it has passed over and is retreating. Even this direction will apply only to the time of observation, and can change and even be reversed from hour to hour. Direction from which wind is blowing, and approximate wind strength, should also be included (under "Remarks") in reports of flying swarms whenever possible. The following terms are recommended for non-instrumental records of wind-strength:
Calm - smoke arises vertically (less than 0.3 metres per second)
Light air - wind direction shown by smoke drift (0.4 - 1.5 metres per second)
Slight breeze - wind felt on face (1.6 - 3.0 metres per second)
Gentle - wind extends light flag (3.1 - 5.4 metres per second)
Moderate - raises dust and loose paper (5.5 - 8.0 metres per second)
Fresh - small trees in leaf begin to sway (8.1 - 11.0 metres per second)
Strong - large branches or whole trees in motion; whistling in telegraph wires (11.1 - 17.0 metres per second)
Gale - generally impedes progress; trees damaged (above 17.1 metres per second).

REMARKS: Air temperature, cloudiness, etc.; notable recent weather (rain, dust-storms, high winds); for settled swarms any available information on date and time of first arrival; feeding; damage; whether specimens obtained.

ORIGIN OF REPORT: In cases of "unconfirmed swarm reports" - state whether, and how soon after the report, locality was visited; if so, whether any grass or crop cover (in which stragglers might be expected); if excreta present; and evidence of any available local witnesses.

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Via delle Terme di Caracalla
00100 ROME, ITALY

FAO/2

LOCUSTS, OTHER MIGRATORY PESTS AND EMERGENCY OPERATIONS GROUP
AGP Division

Country ____________________

DESERT LOCUST HOPPER BAND AND FLEDGLING REPORTS received at ____________________ during period ____________________

Sparse hopper populations, not marching, and associated fledglings should not be reported here, but recorded on form FAO/3.

No.	Date	Locality	Co-ordinates		Size of infested area	No. of bands	Size of bands	Density	Instars present	Dates of hatching or fledging if known	Remarks	Origin of report
			Lat.	Long.								

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For notes on reporting, see reverse side.

NOTES ON THE REPORTING OF DESERT LOCUST HOPPER BANDS AND FLEDGLINGS

INFESTED AREA:	Area within which hopper bands or groups of fledglings occur at intervals of less than 10 kilometres.
NO. OF BANDS OR GROUPS:	Total, if known; when infested area extensive, give number of bands or groups seen in stated distance traversed.
SIZE OF BANDS OR GROUPS:	State whether small, medium, large or very large, from following scale: small: 5 x 5 to 50 x 50 metres medium: 50 x 50 to 200 x 400 metres large: 200 x 400 to 400 x 800 metres very large: above 400 x 800 metres. Whenever possible, give actual sizes of largest bands.
DENSITY:	Thin, medium or dense, or numbers per sq. metre, if available.
INSTARS PRESENT:	For fledgling reports insert the letter "F".
REMARKS:	e.g. feeding; damage; control in progress.

Completed forms to be returned to:
FAO through UNDP/FAO Pouch Service
or by mail to: FAO
Via delle Terme di Caracalla
00100 ROME, ITALY

FAO/3

LOCUSTS, OTHER MIGRATORY PESTS AND EMERGENCY OPERATIONS GROUP
AGP Division

REPORTS OF DESERT LOCUST POPULATIONS
(other than obvious swarms/bands)

Name of Observer ______________________ Country ______________________

Route ______________________ Maps used ______________________ Period ______________________

No. A	Date and Time B	Locusts seen at or between: (place names, lat. and long.) C	Stage D	Colour E	Type of population (isolated or groups) F	Extent of infested area G	Density and extent of main concentrations or groups seen H	Vegetation in which main concentrations or groups seen I	Remarks (behaviour; weather; samples; etc.) J

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For notes on reporting, see reverse side.

NOTES:

D. Hopper instars, or adults

F. Isolated = locusts seen singly

Groups = several or many locusts seen at once

EXAMPLES

A	B	C	D	E	F	G	H	I	J
1	7 March 1979 10.00 - 10.30	20.12N 40.36E to 20.08N 40.50E	Adult	?	Isolated	23 km. x ?	7 in 3 km. by vehicle	Dry Panicum plain	Cloudless
2	10 March 1979 12.00	20.00N 40.39E	V	Green	Isolated	60 x 20 m.	5 in 10 x 15 m.	Stand of green Dipterygium	Intermittent sun
3	12 March 1979 08.30	19.40N 40.52E	I,II,III	Dark green	Groups	250 x 150 m.	9 in a Heliotropium patch 1 m. in diameter	Dense low Helitropium	Overcast
4	13 March 1979 12.00 - 12.15	19.18N 41.08E	III,IV,V	Black and yellow with a few green	Groups	50 x 50 m.	Groups of 15-20 in areas of 0.1 -0.2 sq.m.	Pennisetum up to 2 m. high and free from weeds	Groups on patches of bare ground in sunshine
5	20 March 1979 14.00 - 15.00	17.40N 42.07E	Adult	Greyish brown	Groups	300 x 30 m.	10-15 flushed in 2's and 3's for 150 m. of foot traverse	30-60 cm. Aerva along drainage channel	Slight NW breeze after several days moderate SE
6	22 March 1979 10.00 - 12.30	17.10N 42.30E	Maturing adults (eggs half developed)	Yellowish	Groups	4 x 5 km.	Up to 100 per Pennisetum plant in stretches of 50-100 m.	Edges of ripe Pennisetum cultivations	Rain overnight; soil moist to 2.5-5.0 cm.; sample of 50 males and 50 females

9.3.2 PLACE

The place where locusts were seen should have been reported as precisely as possible by means of latitude and longitude (or a map grid reference, if the reporter and forecaster have agreed on the kinds of map and grid reference systems to be used). In the absence of such a precise reference, the name of a settlement, water hole, hill or other topographic feature on the map is often used. The names of rivers, plains, administrative districts, provinces and such like are vague and should not be used if they can be avoided. Precise numerical references have several advantages: they avoid the difficulties that can arise where there is more than one place with a given name or closely similar name, or where names cannot be found in the forecaster's gazeteers and maps, or where sightings are in remote and un-named places. They also avoid ambiguities where reference is made to a sighting some stated distance along a twisting road or track from a known place, rather than in a straight line from that place. Precision in reports helps the forecaster compare reports and relate them to vegetation and weather.

9.3.3 TIME

Knowing the *date* of a sighting adds precision to any comparison with weather observations and to calculations needed during the preparation of a forecast — for example, dates of hatching, fledging and onset of migration. Moreover, the speed and timing of, say, a progressive invasion are made much clearer than if reports referred to, for example, 'beginning of the month'. Sometimes, however, it is not clear whether a date refers to the *sighting* or the *reporting*, for a report may be passed on by several people (Fig. 9.1), so there is a risk that the date of passing on the report becomes substituted accidentally for the date of sighting. If there is doubt, the forecaster should try to check the true date by asking the reporter.

A casual observer may be unable to give an exact date when questioned many days after a sighting, but an approximate date may be given if the sighting can be referred to some other known event, such as a festival, the visit of a notable person, or a severe storm or flood. Otherwise, it may be possible to state the time only to the nearest week, part of a month (early, middle, late, first half or last half), or even whole month. Such reports are still valuable, and their precision may be improved by comparison with locust reports from other parts of the country or from nearby countries.

The forecaster should be aware that errors can come from converting one calendar to another.

Time of day can be useful in a report, for it can help the forecaster assess the report in the light of known or likely changes during the day of locust behaviour or ease of visibility, both of which need to be taken into account when estimating scale of infestation.

9.3.4 ENVIRONMENT

A locust report may well contain useful information about the environment, even in the absence of locusts, notably:

- depth of soil moisture (in relation to egg laying)
- vegetation — species, both wild and cultivated
  state of growth (e.g., sprouting, full growth, drying out — in relation to feeding)
  density (e.g., sparse, dense — in relation to sheltering and development of gregarious behaviour)
  extent of damage (in relation to numbers present)
- weather.

Weather information from remote places can very usefully supplement that available routinely from other sources. Of particular value are reports of:

- heavy or widespread rain (preferably with amounts recorded by gauges at named places), and possibly resulting floods
- air temperature and humidity, wind speed and direction, and clouds (type, and amount of sky covered) at stated times, preferably corresponding to times of synoptic weather maps (Section 3.3), but sudden changes as well.

Survey parties of some control organisations keep weather diaries whilst in the field, and they record the weather at one or more times each day using simple instruments — whirling (sling) psychrometer for air temperature and humidity, hand anemometer for wind speed (or a simple subjective estimate using the Beaufort scale), and compass for wind direction (*from* which the wind blows).

All these reports should have clearly stated dates and places where the observations were made.

9.3.5 REPORTER'S COMMENTS

In addition to facts about what was seen, where and when, the forecaster will want to know any comments made by the reporter. These might include:

- a judgment on the reliability of a report being passed on from an untrained observer

Table 9.1 Information in locust reports and its usefulness to the forecaster.

	Information in the report	Usefulness of information to the forecaster	Reference (Section)
Evidence for correct species identification	Specimens seen (or sent) — including parts and droppings Results of questioning untrained observer — comparison with pictures or specimens — description of appearance or behaviour — past acquaintance with locusts Origin — name(s) of trained observer(s) and organisation — occupation of untrained observer	Help decide reliability of report	
Egg fields	Laying date, size, density of pods	Calculate hatching and fledging dates; probability that more than one egg field exists	4.4, 4.5
Hatching	Date	Calculate fledging date	
Hoppers			
A. Bands			
Area infested	Dimensions or size of area infested	Gregarious phase (most damaging)	2.2
Number of bands	Estimate of total; numbers of bands seen on a traverse		
Size	Range, average, maximum		
Density	Estimate, measurement, mean, maximum		
Behaviour	Roosting, basking, grouping, marching	Enables estimate to be made of scale of infestation	2.3.1.1 4.8
B. Low Density			
Area infested	Dimensions or size		
Density	Numbers per hectare or per kilometre of traverse or per plant, especially maximum		
Behaviour	Groups forming, marching starting		
Colour	Ground colour; black markings appearing Proportion with each ground colour in each instar	Gregarisation taking place	2.2
Instars	Range, predominant, two separated instars (mixed populations)	Calculate fledging date	4.7 4.8 4.9
Fledging	Fledglings not in swarms	Likely recent breeding nearby	3.1.1
	Fledglings in swarms	Source likely to be as much as 100 km away	3.1.1
Adults			
A. Swarms		Gregarious phase	
Number	Estimated total number of swarms*		
Size	Dimensions — foot, vehicle, aircraft, radar Forming	Enables estimate to be made of scale of infestation	
Density	Estimate, measurement, mean, maximum		
Maturity	Mature, immature, mixed, maturing; colour change	Maturing, may lead to egg laying soon	4.2
Height of flight	Cumuliform or stratiform; height of topmost — estimate or measurement		
Direction of displacement	(Swarm as a whole) Radar, aircraft, bearing of departing swarm; breaking up		2.3.1.1
B. Low Density			
Area infested	Dimensions or size		
Density	Numbers per hectare, or per kilometre of traverse, or per plant, especially maximum	Estimate total numbers of locusts	
Flight	Starting by day after being only at night; appearance at lights	Gregarisation taking place	2.2, 3.2.1
Colour	Ground colour, tibia of hind leg, tip of male abdomen		
	Pink	Gregarisation taking place	
	Brown	Vegetation drying, likely to be followed by emigration	
	White	Bred at high temperatures	
Shape	Pronotum, eye stripes Morphometrics — sample size, timing specimens kept	Phase, gregarisation	4.7.2
Ovarian development	Stage	Maturity, ability to breed, already bred	4.2.4
Copulation		Laying expected there and then; calculate fledging date	4.3
Egg laying	Normal, or on ground	Possibly unsuccessful breeding	4.4
Control	Methods, types and amounts of insecticide	Enables estimate to be made of scale of infestation	

*The number of swarms present is not necessarily the same as the number of sightings, because some swarms may be seen more than once, and many not at all.

- the results of field searches to try to confirm a report, and their significance
- an assessment of the local locust situation
- ideas on likely coming events — e.g., hatching, fledging, migration, vegetation drying — and reasons for those ideas.

Informed comments of this kind from trained staff can greatly help the forecaster when making his own assessment and forecast, but it must be remembered that the reporter may have come to his conclusions using fewer reports and from a smaller area than those available to the forecaster.

9.3.6 ERRORS

In practice, many reports are less than ideal because there are gaps and errors, or parts are vague. *Gaps* arise because the observer failed to record, for example, the instars present in hopper bands or the colour of locusts in a swarm, but such gaps are less likely if the reporting forms approved by FAO are used. Other gaps are introduced during the transmission of reports to the forecaster and may be due to simple error or conscious omission on the part of someone who wished to shorten a long report, such as when a series of reports is being condensed into a summary. Nevertheless, the assessor (Chapter 10) and the forecaster (Chapter 11) must remember that every report has value.

Errors can come about by faulty observation, or by accidental alteration of words or numbers during transmission (place names can be mis-spelt, and grid reference or latitude and longitude can have figures transposed). Perhaps the most serious error of observation is faulty identification of species. Table 9.2 lists some species that have been confused in the past with *Schistocerca gregaria*, together with an indication of the extent to which their distribution overlaps with that of the Desert Locust. In the absence of specimens sent to him, the forecaster must judge each report and decide whether or not it refers to Desert Locusts. This is possibly the forecaster's most difficult task. Reports from trained staff can be accepted without question, but others must be judged in the light of any information there may be on the observer's account and his earlier experience, on the results of questioning by trained staff and of further field searches, and on the relation between the reports in time and space to other reports known to be of Desert Locusts or of other species. The forecaster should look through such information as is available on the recent distribution of other species (e.g. the FAO Regional Pest Bulletin) so that he knows which species that could be confused are currently numerous. A map of the distribution and dates of any records of large populations of the other main species of locusts and swarming grasshoppers during the past six months or year, depending on the number of records available, can be very helpful as a quick form of reference. The forecaster may like to consider maintaining such a map. Furthermore, the forecaster should also look at the literature on the distribution of other species, so that he is aware of the areas and times where and when these species might be confused with *Schistocerca gregaria.* Studies of seasonal redistributions of locusts and grasshoppers include: *Locusta migratoria migratorioides* (Betts 1961, Batten 1966, 1967, Farrow 1974, Davey 1959, Popov 1972); *Nomadacris septemfasciata* (Morant 1947, Symmons 1978); *Anacridium melanorhodon* (Popov & Ratcliffe 1968); *Oedaleus senegalensis* (Batten 1969); *Aiolopus simulatrix* (=*savigny*) and other grasshoppers in eastern Sudan (Joyce 1952). There is a map of the distribution of *Locusta migratoria* sub-species in Tsyplenkov (1978), *Anacridium* spp. in Dirsh & Uvarov (1953), *Hieroglyphus* spp. in Mason (1973) and notes on the general distribution of grasshoppers in Africa in Johnston 1956 and 1968). The distribution of swarming *Phymateus aegrotus* in eastern Africa is described in Roffey 1964. Key maps from much of the literature on locusts and grasshopper distribution are included in Uvarov 1977.

Sometimes there will be insufficient evidence to decide if a report refers to Desert Locusts or some other species; it is not forgotten, but reassessed later in the light of further information. Even so, some reports will remain uncertain indefinitely. Judgement is more difficult during recessions, when trained observers usually survey areas known for the common occurrence of *scattered* locusts, and when reports of *swarms and bands* come mostly from untrained observers. Errors can also occur in any of the kinds of information listed in Table 9.1, and others are mentioned in Sections 9.3.2–9.3.5.

Lack of precision reduces the value of a report. For example, there may be reference to a month rather than a date, to an area rather than a place, or simply to locusts rather than hoppers or adults.

9.4 REGISTRATION OF REPORTS

As each report reaches the forecaster it should be registered by:

- marking with the date of arrival
- giving it a file reference number
- entering the date of receipt in a register.

Dating of reports is useful in any review of the working of the forecasting service, and shows up any need there may be to hasten the transmission of reports. Reference numbers are needed for ease of finding a given report from the files. The simplest filing system is probably a geographical one, using a two-part numbering system: the first part identifying the country or organisation of origin, and the second part a serial number for each report. Particular care should be taken to ensure that late reports are entered into the filing system and fully used.

Table 9.2 Locusts, swarming grasshoppers and other grasshoppers liable to be confused with the Desert Locust.

The whole invasion area of the Desert Locust

Cyrtacanthacris tartarica
Eyprepocnemis plorans
Oedaleus senegalensis (especially Sahelian zone of Africa)
Aiolopus simulatrix (formerly *A. savigny)*
Sphingonotus spp.
Catantops spp.

Mainly in north Africa and the Middle East, eastward to north-western India

Anacridium aegyptium
Dociostaurus maroccanus
Calliptamus barbarus
Calliptamus wattenwylianus (north Africa only)
Calliptamus italicus (Middle East)

Mainly in Africa south of the Sahara and south-western Arabian peninsula.

Anacridium melanorhodon melanorhodon (mainly African. Sahel zone)
Anacridium melanorhodon arabafrum (mainly south-western Arabian peninsula; a few records from Saudi Arabia, Libya and Algeria)
Anacridium wernerellum
Cyrtacanthacris aeruginosa
Homocoryphus nitidulus
Locusta migratoria migratorioides
Nomadacris septemfasciata (particularly south-central Region)
Phymateus viridipes
Phymateus aegrotus

Eastern Region only

Patanga succincta

There will be occasions when a report is not filed under the appropriate country or in the correct time sequence. For example, locusts seen in one country may be reported along with locusts seen in another (as in reports from regional and international organisations), and late reports will be filed further on in the sequence of a file. To avoid difficulties with retrieval, it is helpful to have a classified *index of reports*, preferably on cards filed by country and year. Each entry on a card should have the period concerned, a brief note of the contents of the report, and the report file number. If there are many reports, monthly or 3-monthly cards can be used instead of yearly. Like kinds of information should be put on like parts of the cards, for ease of reference. Separate cards for hoppers and adults are useful. Indexing is best done immediately after plotting of the large-scale map has been checked (Section 9.5.1).

9.5 MAPPING OF REPORTS

Mapping has been found to be effective as a first step in visualising both the geographical relationships of near contemporary reports, and their changes with time. Symbols are used as a convenient shorthand in place of the written report. Map scale varies with map use:

- *large-scale* — to show details of locust reports on a topographic map
- *medium-scale* — to show relationships between populations over the whole invasion area
- *small-scale* — to show the distribution on a map of handy size.

9.5.1 LARGE-SCALE MAPS

These maps show the distribution, stage in life cycle, scale of infestation, and behaviour in as much detail as possible, together with dates of sighting. The maps are used as a main source of reference when compiling the assessment and forecast. They are also used to construct the medium- and small-scale maps.

Base map

This should be topographical (showing coastlines, rivers, mountains, roads, settlements, etc.) for ease of locating places of sighting, and for relating locusts to their physical environment. The scale should be large enough to allow plotting of all available reports but small enough to show changes in the locust distribution. Maps at *scales* between about 1:500,000 and 1:2,000,000 have been found suitable: the former show most place names in all but the most densely populated parts, give comfortable plotting space, and show local locust movements; whereas the latter might be short of place names and lead to crowded plotting, although they would clearly reveal long-distance migrations. Such maps are produced by many national survey departments, most of which also publish updated map catalogues. A world catalogue, *International maps and atlases in print* (Winch 1976), is updated periodically.

Time period

Each map should cover the same length of time: one month has been found to be appropriate. Longer periods can lead to overcrowding, but they are nevertheless useful for showing long-distance movements of, for example, a single generation. Shorter periods (for example, 5 days) can be useful when reports are plentiful (Section 9.5.5).

Data to be plotted

Every report referring to the Desert Locust should be plotted. Every other report of uncertain species that might be Desert Locust, should also be plotted, so that they are not overlooked when the assessment is being made and their significance can be considered in relation to other reports, known to refer to Desert Locust, including late reports.

Symbols

The forecaster is interested particularly in stage of the life cycle, numbers and behaviour. These can be represented by symbol shapes and colours. Fig. 9.3 shows a system of symbols that has long been in use at the Centre for Overseas Pest Research, in which symbol *shape* distinguishes eggs, 'breeding', hoppers and adults (separating gregarious from others — groups, isolated and 'scattered'), and symbol *colour* distinguishes sexual maturity. Dates of observation are shown by numbers plotted against the symbols. These symbols have evolved from those first recommended internationally in 1931.

Plotting technique

Whatever system of symbols is used, no data should go unused, but there should be minimum inference where a report is vague or ambiguous. All inferences from, and corrections to, reported facts should be made quite clear in case they turn out to be incorrect.

Symbols can be plotted on the base map or on a transparent overlay. Choice will depend mainly on the availability of enough maps, and the comparative costs of maps and transparent drawing materials. An advantage of overlays is that they can be easily superimposed for comparison. If an overlay is used it should be marked and headed to fit a stated map.

It is convenient to use two maps for each month: one for hoppers, the other for adults. Fledglings and egg fields are plotted on both maps, to give more complete pictures of breeding and migration. Each map should be headed with species name, stage (hoppers or adults), map scale, sheet name and time period — all preferably at the same position on each map for easy reference when searching through a pile.

Every record should be plotted, and the most appropriate symbol is chosen from the set in use (e.g. Fig. 9.3). The exact place of sighting is indicated by a conventional part of the symbol: the tip of an arrow, the junction of upright and cross in a 'T', the centre of a triangle, diamond or whirl. Where two colours are needed, it is preferable to use the darker one first — for example, blue before red. Where a sighting is not related to a particular grid reference or latitude and longitude, it will be necessary to find a named place. Using gazeteers or atlas indexes is quick; otherwise, large-scale topographic maps will need to be searched (of kinds not used to prepare the gazeteers — check their introductions for sources used). The search should be methodical, using the maps' grid systems, and taking care to use each type style and colour, but it is likely to be time consuming. Ways of narrowing the area of search might be got from answers to questions such as:

where else have reports come from (in same country and nearby countries)?

where else has reporter been recently (is there an itinerary)?

Where the precise position is uncertain, a large, broken symbol can be plotted in the middle of the area concerned and annotated accordingly (for example, 'pos?'), and a boundary drawn around the area if it is known (for example, if it is an administrative district).

If there are many reports from the same locality, plotting them all can lead to overcrowding, but this can be avoided by:

- adding barbs (of appropriate colours) to a symbol to show there was more than one report from the same place, or a '+' if 5 or more
- using larger-scale maps or overlays for crowded areas (properly headed and marked with reference points) and then fixed to the main map, on which the area involved is outlined and annotated
- displacing some of the symbols and using arrows to point to their true positions.

Against each symbol is plotted the *date of sighting*. This is the day of the month, but if that is unknown the fact should be stated (for example, by plotting 'date?'). Sometimes a report refers to 'early', 'mid' or 'late' month (which can be plotted as 'a', 'b', 'c'), or 'first half' or 'second half' (which can be plotted 'A', 'B'). Use the same colour as that of the plotted symbol.

Maps of ground survey routes are useful in differentiating areas seen to be probably free of locusts from those not seen and where locusts may have gone unreported. Such maps can be drawn on separate overlays, and should show dates and direction of travel. Air survey routes can be mapped similarly, and should show times.

After plotting, each original report should be marked in some way to show that it has been plotted — for example, by means of an ink tick. Such marking can be of use later when a check is made that all available reports have been plotted.

Population type			Stage of life cycle: Egg	Hoppers (instars)	Adults: Immature	Adults: Mixed maturity	Adults: Mature	Adults: Unknown maturity
Locusts in swarms or bands		Egg field	○					
		'Breeding'	◆	◆				
		Hopper bands		● I,II,III,IV,V				
	Flying swarms	Direction known			↗	↗	↗	↗
		Direction unknown			T	T	T	T
		Circling			9	9	9	9
	Settled swarms	Roosting			▲	▲	▲	▲
		Copulating					⚠	
		Egg-laying					△	
	Unknown activity				⊥	⊥	⊥	⊥
Locusts not in swarms or bands	Groups (two or more locusts seen together)	Hoppers		V I,II,III,IV,V				
		Adults			V	V	V	V
		Copulating					V cop	
		Egg-laying					V lay	
	Isolated (locusts seen singly)	Hopper		○ I,II,III,IV,V				
		Adult			●	●	●	●
		Egg-laying					● lay	
	Unidentified low-density populations	Hoppers		⅄ I,II,III,IV,V				
		Adults			⅄	⅄	⅄	⅄
		'Breeding'	◇	◇				

Species uncertain 'sp?'

Fig. 9.3 Principal symbols for locust plotting on large-scale maps.

Checking

Because large-scale maps are used both for assessing the locust situation (Chapter 10) and for preparing other maps, they need to be checked carefully for any errors of plotting. Checking is best done by someone other than the original plotter. If this is impossible, the maps should be left overnight and checked the next day. In this way, there is less chance of the plotter repeating the same mistakes. Start by checking the map (or overlay) heading and reference marks. *Each report* should be taken in turn and checked that:

- it has been plotted
- symbols and colours have been chosen correctly, particularly for stage in life cycle, numbers and behaviour
- symbols have been positioned correctly (the checker may know or be able to find some place names that the plotter has been unable to find) — common errors are 10′ or 1° in latitude or longitude, and confusion between east and west of the Greenwich meridian, and between north and south of the equator.

Before altering a plot, the checker should ensure that he is not in error. Differences in interpretation between plotter and checker should be reconsidered by them jointly in the light of other reports and local knowledge of other staff members.

After checking, each original report should be marked in some way to show that plotting has been checked. Each report is then indexed (Section 9.4) and placed in its correct file for easy retrieval.

9.5.2 MEDIUM-SCALE MAPS

Because locusts of the same generation can migrate from one Region to another (for many examples, see Chapters 5 – 8), the forecaster must have maps showing the locust distribution over the whole invasion area. Even though the forecaster may have responsibility for only a part of the area, he needs to take account of events elsewhere. Hence, such maps are used in preparing the assessment of the current situation (Chapter 10), and a sequence of them provides a convenient reference to past events. The maps therefore need to contain as much detail as possible that is plotted on the large-scale maps, but they must not be too large for handling and storage.

Base map

This should cover the whole area from which reports are likely to come. In the past, reports have come from the longitude range 41°30′ W to 96°30′ E and the latitude range 55°N to 35°S, but the smaller area from 20°W to 95°E and from 45°N to 15°S excludes very few past reports and is an appropriate one to use. Maps of such an area are not available commercially and must therefore be drawn specially for the forecaster. A map with *scale* 1:11,000,000, and with dimensions 1.23m by 0.74m (including a 30mm margin all round), has been used satisfactorily at the Centre for Overseas Pest Research for some 30 years, but this scale and size could be modified to suit available materials and storage plan presses. The most suitable *projection* is Mercator; it has the advantages that bearings are true, scale does not change excessively with latitude over the invasion area, and it is used in the maps of many national meteorological services. Such a base map can be prepared from:

1:10,000,000 *Carte générale du monde*, sheet 5 and parts of sheets 6, 8 and 9, published 1967, Institut Géographique Nationale, 136 bis rue de Grenelle, Paris VII;

1:11,000,000 *The world*, AMS series 1142, sheets 6 and 9, published 1972, U.S. Army Topographic Command and U.S. Naval Oceanographic Office.

The map should have:

- margin
- 1° graticule all over, with every fifth line heavy and numbered in the margin
- coast lines
- country boundaries
- larger lakes (as guides to the eye when plotting)
- scales in kilometres at the equator and 45°N, and one or two intervening parallels
- space for heading and key.

The map should be printed:

- on durable transparent material to enable comparisons to be made by overlaying, and to withstand handling many times in later years
- in reverse on the back to allow prominence to plottings
- in ink with a colour distinct from those used in plotting (for example, brown).

Time period

Each map should cover the same length of time: one month is most appropriate.

Symbols

These are the same as those used on the large-scale maps.

Plotting technique

As with large-scale maps, it is convenient to use two maps for each month: one for adults and one for hoppers. Each map should be properly headed with species name, stage (adults or hoppers) and time period.

Adults

Arrange the large-scale maps in geographical order and work systematically across each map by 'degree — squares', transferring every report wherever space is available. Ensure that the exact place of sighting is retained, even though a symbol may extend into an adjacent square. Near a country boundary, ensure that the symbol is on the correct side. In the more crowded parts of the map, it will be necessary to combine symbols and some suggestions for such combinations are shown in Fig. 9.4. When combining records, aim to depict the full range of locust stages present within each degree square: fledging, immature swarms, mature swarms, copulation and oviposition, together with some degree of abundance of swarm reports (indicated by barbs or plus signs — see section 9.5.1), and the range or ranges of dates (e.g., '3 to 30' if reports were occurring intermittently throughout much of the month, or '2 – 4, 24 – 29' if there were two discrete groups of reports. Since it is practicable to get about eight symbols into a degree square at this scale, it is normally possible to include all swarm reports by combining within quarter-degree squares, thus retaining spatial accuracy to within 50km. When working in particularly crowded parts of the map, it is often helpful to try out combinations of symbols in rough on a separate piece of paper. In squares where swarms are numerous, reports of low-density populations may be omitted, except

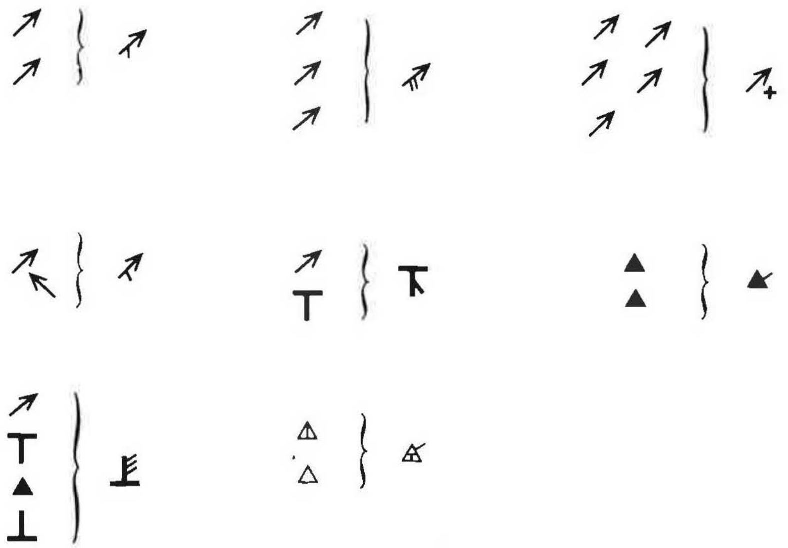

Fig. 9.4 Some combinations of locust plotting symbols in Fig. 9.3.

where they add significantly to the picture of the situation provided by the maps, such as the first appearances of fledglings, an extension of the time period when swarms were known to have been present and which might indicate the presence of larger populations. In areas where locusts are sparse, the low-density populations should of course be shown. Again there can be combinations of several symbols for groups or for isolated locusts, provided these are of the same maturity, and isolated locusts can be omitted in the presence of grouping populations. Add survey routes (using colour to distinguish ground from aircraft), together with dates of start and finish. Inferred dates of egg laying and expected dates of emergence and fledging can also be usefully added to these maps (Section 9.5.4).

Hoppers

Again, work systematically from the large-scale maps by degree 'squares'. Because there is a smaller range of symbols than for adults, and they have simpler shapes, combination presents fewer difficulties. Thus, there is no need to plot *every* report of bands in crowded parts of the map; and *ranges* of instars, hatching dates or dates of sightings can be plotted against a group of band symbols ringed by a fine line. Where hatching date is reported, instars of subsequent hoppers in the same area (and hence their inferred hatching dates) may be omitted.

Checking

As with large-scale maps, this is best done by someone other than the original plotter. The large-scale maps are taken in turn, and *each symbol* is checked to ensure that:

- it has been transferred to the medium-scale map
- similar symbols have been properly combined
- dissimilar symbols have been properly selected, bearing in mind the priorities
- calculated egg-laying dates and fledging dates have been transferred correctly from the breeding maps (Section 9.5.4).

9.5.3 SMALL-SCALE MAPS

These maps are condensed forms of the medium-scale monthly maps for use in:

- briefly reviewing developments over periods of many months or years
- selecting *analogues* — months similar to the one on which the forecaster is working (see Section 11.2).

They therefore cover the whole invasion area, and are small enough that monthly maps for many years can be filed together for easy reference, yet large enough to show the details needed. By having a set of such maps displayed as a *wall array* — by column for year and by row for month — it is possible to see quickly the changes in any one year, and to compare a given calendar month from year to year.

Base map

This can be very similar to the medium-scale map, but with a scale about 1:45,000,000, and size about A4. Like the medium-scale map, it needs to be specially drawn and printed. It should have the same characteristics: 1° graticule all over, coast lines, country boundaries etc (see Section 9.5.2), and should be printed on paper or transparent film in coloured ink (symbols will be plotted in black). One map can be used for both adults and hoppers, and each map should cover the same length of time: one calendar month is most appropriate.

Symbols

A simplified set is needed, one that distinguishes eggs, hoppers and adults, and whether there are swarms (bands), groups or isolated locusts. Several sets have been developed in the past; the one used most recently is shown in Fig. 9.5. Larger populations are emphasised by bold symbols, and it is possible to combine some symbols (see Fig. 10.2 for examples). An earlier set, particularly useful when swarms are widespread, emphasised the distinction between breeding and potentially mobile populations, and also allowed more flexibility in combining symbols.

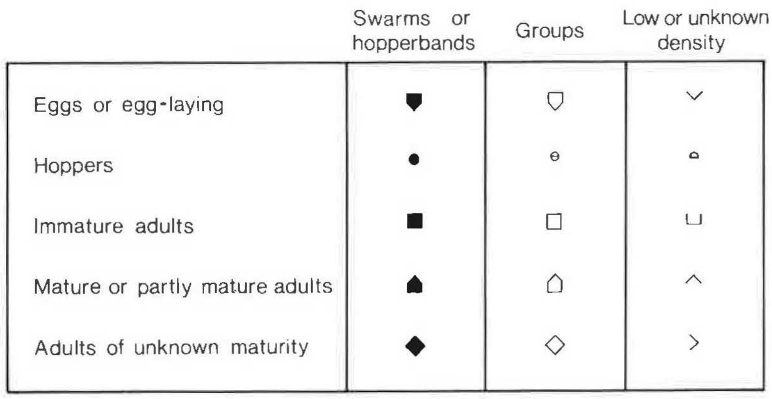

Fig. 9.5 Symbols for locust plotting on small-scale maps.

Plotting technique

One map can be used for both adults and hoppers, and one symbol is used for each degree 'square', the aim being to show the most important population. Where a choice must be made, the following priorities should be used:

- swarms or bands or both, rather than groups, rather than isolated or scattered locusts
- laying, rather than mature non-laying locusts, rather than immature locusts (unless they have recently appeared amongst otherwise mature locusts).

Checking

As with the other maps, this is best done by someone other than the original plotter.

9.5.4 BREEDING MAPS

Reports of breeding (eggs, hoppers, fledglings) imply the presence of adults, both those that led to the breeding (even though they may have gone unreported) and the new generation to come. Estimates of the date when the parents were present, and when the new generation is likely to fledge, can be calculated from development rates for eggs and hoppers. These estimated dates can then be related in time and space to the reports of adults already plotted on the medium-scale maps (Section 9.5.2), and used to help distinguish those populations that have apparently migrated and bred from those yet to breed. A convenient intermediate step is to gather all breeding reports on to transparent overlays, or breeding maps, one sheet for each season, and make the calculations on the sheets. Working by one-degree 'squares' is a compromise that retains geographical variations but avoids unnecessary repetition of calculations. A scale of 1:1,000,000 gives degree squares about 10cm by 10cm. Each square with at least one breeding report is divided into three columns headed 'laying', 'hoppers' and 'fledglings'. All reports are then transferred *in ink* from the medium-scale maps as follows:

- first column: dates of all egg laying and egg fields
- second column: dates and instars of all hoppers
- third column: dates of fledglings and of young swarms appearing a month or more after first hatching.

Subsequent *deductions* are written *in pencil.*

To estimate *egg-laying dates*, development periods are first selected — for eggs see Section 4.5.2, and especially Tables 4.2 to 4.7; for hoppers see Sections 4.7.4 and 4.10.2, and especially Table 4.9. From the date of sighting, the estimated egg-laying date can be got by subtracting the appropriate number of days in the development period(s). Similarly, the estimated dates of fledging and swarm formation can be got by adding the appropriate number of days in the development period(s). For examples of the use of these Tables, see Sections 4.5.2 and 4.7.4.1.

Where there is a series of closely spaced reports, calculations need be made only for the first and last dates. During recessions, the few reports available can be dealt with on single sheets of paper.

Results of the calculations are transferred to the medium-scale maps using ink colours different from those for *reported* locust sightings, for example — green for egg-laying dates, purple for hatching dates, orange for fledging dates. These colours are related to those used for corresponding sightings (blue, black and red, respectively). There is no need to transfer the results of calculations if there are *reports* of egg laying or fledging within a few days of the calculated dates.

9.5.5 PENTAD MAPS

For relating locust movement to weather at the time, it has been found useful to prepare five-day (pentad) maps on which dated reports are plotted to the nearest degree of latitude and longitude, and at a scale the same as that of the weather maps (Rainey 1963). Pentad maps are particularly useful in the preparation of tactical forecasts (Section 11.7); they have also been used in research case studies of past events, notably during 1954 – 55 (Rainey 1963, 1976) and some of the Case Studies in Chapters 5 – 8 of this Manual, as well as operationally, e.g., during the last few months of 1968, when locusts were spreading rapidly across Africa from Sudan to Morocco (Betts 1976).

Base Map

This should be printed on transparent material, for ease in over-laying the weather maps, and have similar characteristics to those of medium-scale locust maps (Section 9.5.2).

Plotting technique

Both *incidence* and *maturity* of locusts should be indicated. *Swarm* incidence is shown by dates plotted as numbers in standard positions within each degree square: the first date of the pentad in the top left corner, the second in the top right, the third in the middle, etc. *Lower-density* populations are shown by dates enclosed within brackets, e.g.:{ } for groups, ( ) for isolated locusts, [ ] for density unspecified. *Maturity* can be shown by a colour code for the plotted dates, distinguishing immature, partly mature, mature, egg-laying, and maturity unknown. Where swarms of more than one stage of maturity are present on the same day and in the same square, the date is plotted in more than one colour. *Estimated* (not reported) *dates of egg laying* and *dates of swarm formation* (Section 9.5.4) can be added in distinctive ways. The latter can be on a transparent under-lay, using a colour code to show various degrees of reliability.

If a report is dated not to a day but to some longer period, then that period should be plotted on each of the pentad maps within or overlapping the period concerned. For example, if a report referred to '1 – 4 October' then those dates would be plotted on the two pentad maps, 28 September-2 October and 3 – 7 October. Or, as another example, if a report is dated simply 'October' then it would be plotted as such on all the pentad maps from 28 September to 1 November.

Pentad maps can show the progressive spread of swarms from more than one source, as well as variations in the rate of maturation from different sources (perhaps leading to prolonged and widespread egg laying).

9.5.6 DISPLAY MAPS

In addition to large- and medium-scale maps, which are prepared as working documents that are easily handled, it can be useful to have a display map on a table or wall showing the latest reports. Such a map can be used for group discussions, and for showing to visitors. The map should be covered with a tough, long-lasting, transparent material on which the symbols can be plotted, either in an easily erasable medium, such as wax pencil or felt-tip pen, or with self-adhesive paper or plastic shapes that can be peeled off easily and used again. Such a map needs to have a scale larger than that of the medium-scale map (if the whole invasion area is to be visible from a distance of, say, 10m), but smaller than that of the large-scale map. A scale of about 1:5,000,000 is appropriate. The whole invasion area can be covered by several sheets from a published series of the whole world.

10 LOCUST ASSESSMENTS

Before a forecast is prepared, the best possible assessment must be made of what the locust situation is *now*. Such an assessment uses all the reports that have become available since the last assessment was made. These reports, it must be emphasised, are seldom complete because not only may known populations be imperfectly reported but also some populations may not be reported at all. Moreover, all reports are more or less delayed on their way to the forecaster, and anyway refer to past events that may well have changed in the meantime. Thus, any assessment of the present locust situation must consider not only the reported locusts and what they are likely to have been doing (Section 10.1), but also any others that may have gone unreported (Section 10.2).

10.1 ASSESSMENT OF REPORTED LOCUSTS

The question to be answered is: what has happened to the locusts between now and the time they were seen? Has distribution changed as a result of movement? Have numbers changed as a result of breeding or death? We discuss ways by which these changes can be assessed.

All countries with at least one report should be considered, and in a systematic order. Every report should be taken in turn and answers sought to the following questions about what might have happened to the locusts *since they were seen*. Written notes should be made of the conclusions reached, and the reasons for them, so that nothing is missed when the final assessment is made (Section 10.3). The documents needed are:

- assessments and forecasts for the previous six months
- all reports since the last assessment and forecast were prepared
- large-, medium-, and small-scale locust maps for the previous six months
- locust frequency maps of this Manual
- daily weather maps since the last assessment was prepared
- monthly rainfall maps for the previous six months
- Parts 1 and 2 of this Manual.

Try to answer each of the following questions. If an answer is 'yes', decide where, when and on what scale the happening took place, noting if it has begun since the last assessment was made, or if it has continued or finished after starting earlier. Find out if the happening is usual for the country and season. Use the aids suggested to help get answers (numbers refer to Sections in the Manual).

1	If adults were reported, have they moved on?	Displacement (3.1, 3.2) Daily weather maps (3.3.2) Swarm frequency maps (Vol. II) Small-scale locust maps (9.5.3)
2	Were the adults mature or could they have matured since being reported?	Maturation (4.2) Rainfall maps (4.11.3)
3	Have eggs been laid?	Egg laying (4.4) Rainfall maps (4.11.3) Outbreaks (2.6)
4	Have eggs hatched (including any laid before the last assessment was made)?	Egg development (4.5) and hatching (4.6) Breeding maps (9.5.4) Daily weather maps (3.3.2) Hopper frequency maps (Vol. II) Small-scale locust maps (9.5.3)
5	Have bands formed?	Bands (2.3.1.1, 2.3.2)
6	Have hoppers fledged?	Hopper development (4.7, 4.10.2) and fledging (4.9) Breeding maps (9.5.4) Daily weather maps (3.3.2)
7	Have new swarms formed?	Swarm formation (2.3.1.2, 2.3.2) Swarm frequency maps (Vol. II) Small-scale locust maps (9.5.3)
8	Have new generation adults flown away, and in what proportions swarming and scattered?	Displacement (3.1, 3.2) Daily weather maps (3.3.2) (Look especially for winds leading to large and rapid displacement)
9	Have locusts died — eggs, hoppers, adults?	Mortality of eggs (4.5.3), hoppers (4.7.5) and adults (3.1.10) Termination of plagues (2.8) Effects of control

10.2 ASSESSMENT OF ANY UNREPORTED LOCUSTS

The question to be answered is: what has happened to any locusts that might be present but have not been reported so far? *Each country* should be considered in turn, whether or not there have been reports from it since the last assessment was prepared. Try to answer the following questions, using the same set of documents as listed in Section 10.1, and writing notes of the conclusions reached and the reasons for them.

1	Were locusts forecast to be present, and would the forecast need amending in the light of the late reports received since the forecast was prepared?	Previous assessment and forecast, notes used in their preparation, latest reports
2	Are locusts likely to be (or have been) present (other than any already reported); if so, how did they come, where, when, and on what scale?	Medium-scale maps, daily wind maps (examine possibilities for immigration)

Then go on to apply the questions listed in Section 10.1 to any locusts inferred to be present as a result of answering the two questions above.

10.3 PRESENTING THE ASSESSMENT

The aim of a written assessment is to give a concise statement of what has happened, or is likely to have happened, to locusts since the last assessment was prepared. It is the background against which the forecast is interpreted, and it should be written in a style easily and quickly understood by the readers, who may be:

- administrators — including heads of government departments and of pest control and plant protection organisations
- technicians — survey and control staff
- farmers
- general public (through newspapers and radio).

It is compiled from the notes written about the fate of reported locusts (Section 10.1) and on the judgements about there having been unreported locusts (Section 10.2). These notes should be arranged systematically, along with the reports and maps on which they were based in case they are needed to check particular points. The assessment consists of heading, abstract, text and map.

Heading

Give a serial reference number, and state the area and period concerned, such as:

'Summary of locust reports for (Region, country, etc.) during (month, quarter, etc.).'

Abstract

State very briefly where the largest populations are, or are likely to be, and what they are doing (breeding, migrating, dying, etc.).

Text

Outline the general situation, then take each country, or group of countries in which similar populations occur, and describe what locusts have been reported and what others may be present, starting with the most heavily infested parts. Describe the scale of infestation. Often this can be done only qualitatively, but it is helpful (a) to state whether infestations are widespread or local, (b) to give some indication of sizes of areas infested and the number, sizes and densities of bands or swarms, and (c) to highlight details of the largest populations. Some swarms may be reported more than once; hence the number present need not be the same as the number reported. The following are some example descriptions.

> 'Medium-sized and large swarms were widespread in areas....., and the largest swarm, measured by aircraft, covered some 150 km^2.'
>
> 'Small swarms, groups and isolated locusts were reported over a total of some 1,000 km^2, the largest of the three reported swarms being 0.5 km^2.'
>
> 'Isolated locusts were widely spread over some 2,000 km^2; there were some groups, one of which was reported to cover 10 m^2 at a density of 15 locusts per m^2.'

When there are many reports, they must be condensed if the text is not to become unduly long. During recessions, however, it is helpful to include all or most of the available information, especially about swarms and bands.

Summarise any information on rainfall and vegetation suitable for breeding, and on wind systems likely to displace locusts. Name each Region and country, even if only to say 'reported clear' or 'no reports received'. It is important to distinguish between these two — the former is a positive statement that no locusts have been seen, whereas the latter implies that it is not possible to say whether locusts were seen because there are no reports on which to base a statement. Maintain consistency on the spelling of place names — decide on a particular source (for example, an atlas or a gazeteer) and keep to it. Ensure that the meaning of original reports is kept; minimise interpretation.

Map

This should be compact but large enough to show the main locust events in each degree square; a map with a scale about 1:30,000,000 on A3 paper is adequate for the whole invasion area. The general style and symbols could well be similar to those described in section 9.5.3. However, the map would show all available reports for the whole of the previous month and the beginning of the current month, rather than for one calendar month only, as recommended for the uses described in section 9.5.3. Furthermore, the need to print many copies imposes some differences in construction. The printer requires an outline map with coastlines, country boundaries, latitude and longitude at 10° or 15° intervals in the margin (but no degree square grid over the map), scale and key to the symbol used. This outline map is used to print a stock of base maps in a coloured ink. A working draft of the assessment map (with symbols for locust data, registration crosses, map serial number and time period covered) is then drawn on a gridded map, traced off in black ink on to a sheet of transparent film and sent to be printed on the base maps. Map and text must be consistent, but because the map may take longer to print; late reports may appear in the text but not on the map (and should be clearly marked in the text).

10.4 EXAMPLE ASSESSMENT

To illustrate the kind of thinking needed for the preparation of an *assessment*, rather than a mere *list of reports received*, an example is given here based on reports received by the former Desert Locust Information Service, sponsored by the Food and Agriculture Organization of the United Nations, and provided by the Anti-Locust Research Centre (now the Centre for Overseas Pest Research). The example is an assessment of the locust situation up to the cut-off date 20 May 1961, a time when there were both plague and recessions situations in different parts of the invasion area at the same time. The reader should assume he is the forecaster making the assessment up to that date, as a preliminary to preparing the forecast for June 1961 (Section 11.5).

The forecaster would have been following the developing locust situation so that previous events were clear in his mind. There would be available: locust distribution maps for the previous few months (with any reports received late included on them), the previous assessments and forecasts mentally updated to take account of any late reports, recent daily weather maps and monthly rainfall maps, reference material on previous locust situations, and other aids to forecasting such as are listed in Section 10.1. In the present example, the preparation of one monthly forecast only is considered, and a brief outline of the locust situation leading up to the selected month is needed for the reader to follow the reasoning in the example.

Fig. 10.1 shows the main features of the developing situation. Unusually severe breeding in inaccessible parts of the northern Ethiopian highlands from July to September 1960 was mostly uncontrolled, and large immature swarms moved mainly northward from there between October and December, and began to lay eggs by November in the lowlands on both sides of the Red Sea and in the interior of Saudi Arabia. Breeding was more rapid in the former areas and, despite control, numerous locusts fledged in February and March, and young swarms moved generally eastward across Saudi Arabia as well as some northward into Egypt. A few swarms from northern Ethiopia appear also to have moved south-east towards the Somali Peninsula during October. Here they joined some 400 km^2 of maturing and mature swarms that were moving south-westward with north-east winds across the Somali Peninsula; swarms later moved northward (at the time of the depression highlighted in Case Study 4.5 for its effects on movement in the Eastern Region). Eggs were laid first in central Somalia and nearby Ogaden in October – November and later along the shore of the Gulf of Aden in November. Young swarms formed in these two areas in, respectively, January and late January to March, and subsequently moved into Ethiopia (see also Betts 1976, Fig. 6.5).

In West Africa, there was heavy breeding in Mauritania and Senegal, and control was undertaken over some 2,300 km^2 during September and October. However, young swarms from areas of uncontrolled breeding moved north towards Morocco, where they were estimated to total 500 km^2 at the beginning of the campaign there, but were reported to have been controlled by mid February. Elsewhere, from Mali to Sudan, and in south-western Arabia, breeding was much more restricted than usual, and in Niger and Sudan it was unusually late.

In the east, some swarms from two generations of extensive breeding in north-western India and Pakistan moved out southward and eastward, and others moved westward (Summary 4 and Case Studies 4.1 and 4.5).

Fig. 10.2 shows the distribution of recent reports (for April and early May) available on the cut-off date, 20 May. They are grouped into two more or less discrete geographical areas, north and south of about 20°N. For brevity, we shall consider in detail only the northern section. Each country is taken in turn, starting with a summary of the reports (the text that would be issued with the forecast), some notes on the original reports, and a discussion of the inferences that can be made about the locust situation up to the cut-off date. Finally, a summary of the general situation is derived from the plotted maps and individual country accounts, although it would be placed before them in the published assessment (Section 10.3). The aim of presenting this example is to illustrate the solving of some kinds of problems commonly met by forecasters. The example is not complete, but the whole would be produced, as is the part given, by applying the principles explained in Sections 10.1 and 10.2.

Individual countries during April and early May 1961

EGYPT

Swarms of immature and mature locusts spread though the south-eastern desert during early April and reached Quseir and the middle-eastern desert. Some 2,700 late instar hopper bands were controlled in the south-eastern desert, scattered over 300 km from Abraq to Sheiq Shazli, and further layings occurred to the east of Aswan and Idfu.

> This text is based on two cables of 15 and 18 May. The first summarised swarm invasions and hopper infestations; the second (in response to a request for details) gave dates of swarm arrivals. The text brings out the sequence of movements by invading swarms, and emphasises the succession of breeding, old hoppers and new laying. Nothing was known at the time about the scale of swarms, but records of individual events (including most of the information requested on standard FAO forms) were available later. These records allow a much fuller interpretation of the events in progress in nearby countries than could be deduced at the time. There were 54 records of individual sightings of swarms, reported mainly as scattered density over areas ranging from 2 km × ½ km to 15 km × 4 km.

The following is an attempt at answering the nine questions listed in Section 10.1.

> 1 Winds in April and May over Egypt are dominantly northerly, but are interrupted by spells of mainly south winds (Section 6.3). Movement on south winds was in progress in early April (Case Studies 10.5 and 10.6) and the reported swarms could therefore have moved further north across eastern Egypt to the Middle East. One of the later reports (for 13 April) was of a swarm substantially further north than any mentioned in the cable. It seems to have moved first northward with south winds ahead of a low that crossed the eastern Mediterranean Sea on 10 and 11 April, and then eastward with lighter west winds as the low moved away north-eastward. This isolated record of a swarm, together with the reduction in number of reports farther south, may have indicated a movement across southern Israel and Jordan, and into north-western Saudi Arabia (*q.v.*), where more swarms appeared in mid April. Winds favourable to a

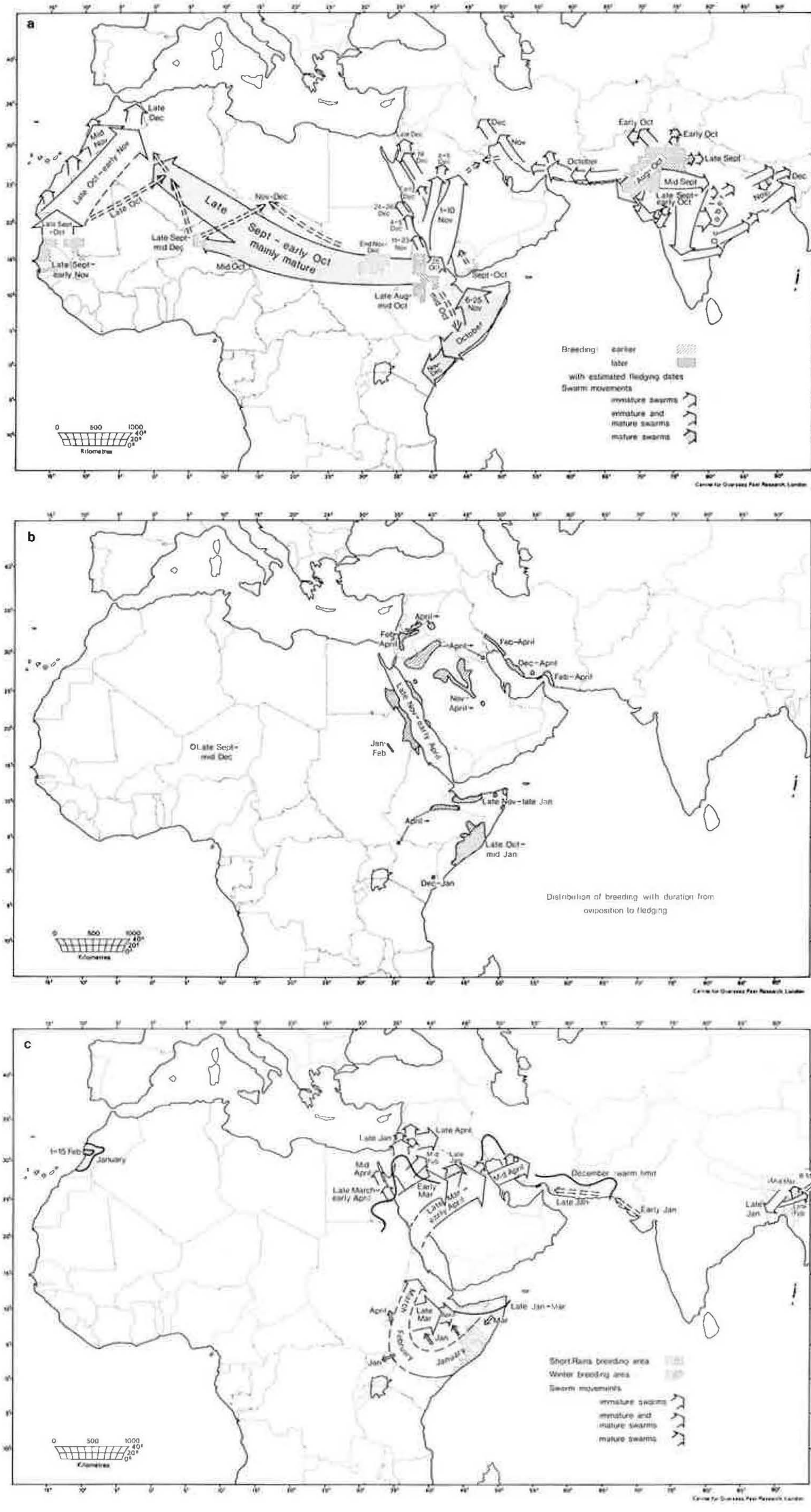

Fig. 10.1 Main locust developments, July 1960 to April 1961:
a monsoon and Short Rains breeding and swarm movements to December 1960;
b Short Rains 1960, winter 1960–61 and spring 1961 breeding to April 1961;
c source areas and main swarm movements to April 1961.

move into Libya are very unlikely at this time of year; and both the swarm frequency maps and the absence of reports in northern Syria show that swarms are very unlikely to have reached Turkey.

2 In the absence of rain and fresh vegetation, the remaining immature swarms are unlikely to have matured at any time in the period considered (April, and May to the 20th) within the south-eastern desert.

3 – 6 The main hopper infestations were in the middle to late instars in early April, and late instar in mid April. Escapes from the control operations could have been fledging and forming swarms throughout the month but particularly in mid to late April. At this time there were further reports of immature swarms in south-eastern Egypt, after the apparent evacuation of 9 – 10 April when swarms moved north; these could have been either locally-produced swarms or others returning southward as north winds were restored. There was hatching on 8 April and (from the early April egg laying) on 20 – 25 April. Any escapes from the resulting bands would fledge in mid May, and late May to early June, respectively.

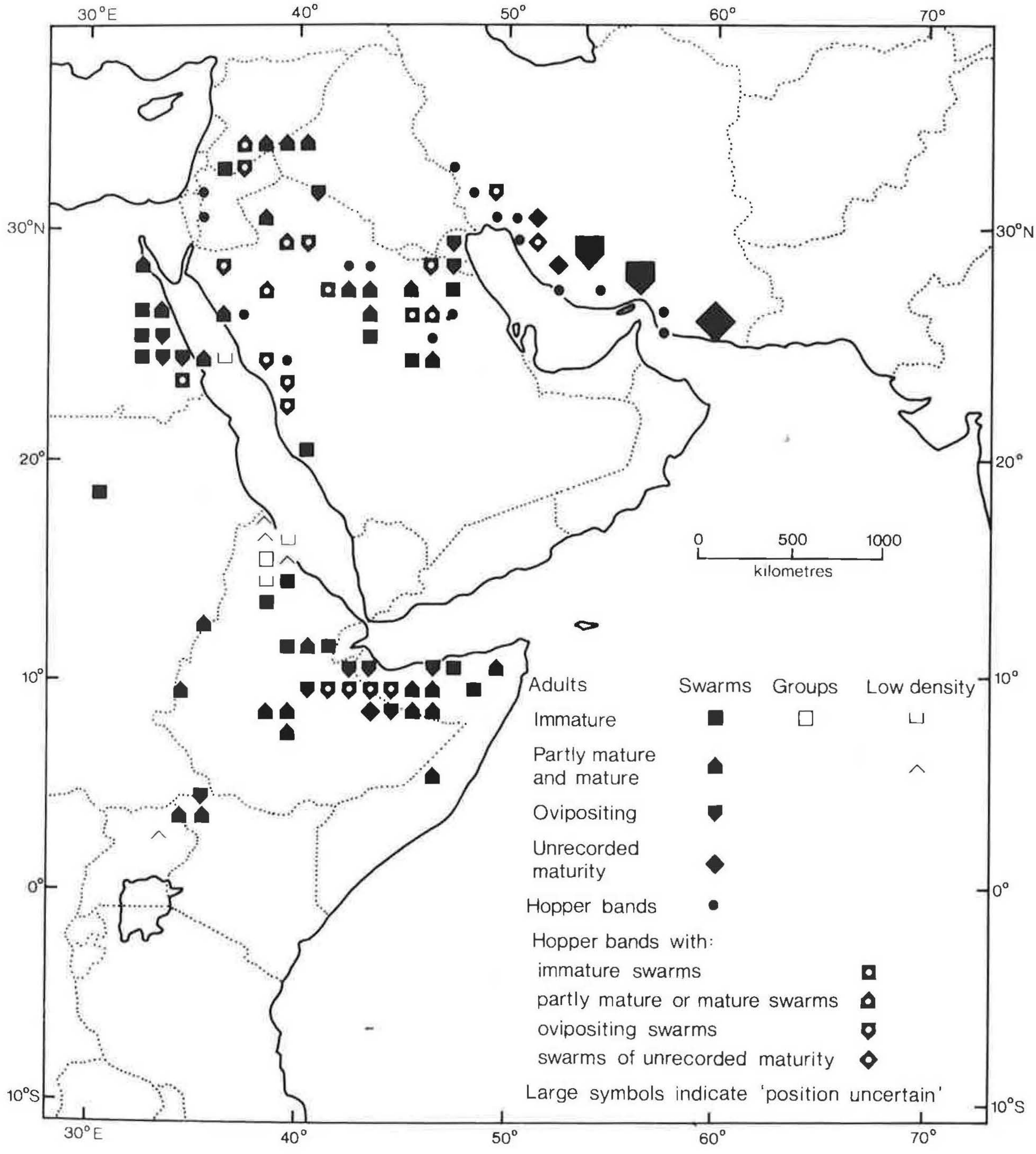

Fig. 10.2 Locust reports for April and early May 1961.

7 – 8 Any new generation swarms from the bands in early to mid April might have moved away as discussed above. Fledglings from later infestations are more likely to have moved south-westward into Sudan, or even further west into Chad, from mid May onwards.

9 Natural mortality is not easy to assess. Breeding in the south-eastern desert is rare (see hopper frequency maps), and by mid May the area is likely to have been drying out rapidly and becoming unsuitable for supporting hoppers. (Timing of the rains on which the season's breeding started is unclear: it was probably January or December, judging by scanty reports.)

We turn now to the two questions in Section 10.2. It is very unlikely there were locusts in Egypt outside the eastern part of the country. They had not been reported for many months, and they are not to be expected there, judged by the frequency maps. It is also very unlikely that there would have been invasions from the Middle East before 20 May: such invasions usually occur after mid May, and although widespread breeding was reported in the Middle East (see texts for other countries), swarms from there are unlikely to have fledged until June.

SUDAN

One immature swarm was reported at El Khandaq, in the Nile valley of Northern Province; the rest of Sudan was free of locusts in April.

The date of this swarm report was not known on 20 May, but a later report gave it as 1 April. Again, we attempt answers to the questions of Sections 10.1 and 10.2. The single immature swarm is likely to have moved south within Sudan on the dominantly north winds, perhaps reaching as far as the ITCZ, and possibly going on south-westward to Chad or south-eastward to northern Ethiopia. It is very unlikely to have matured and bred in the very dry country it was crossing, and it may well have perished for want of food or even from delayed effects of insecticide if it had come (as seems likely) from unusual breeding in the Berber and Atbara areas of the Nile valley, where egg laying had been reported in early and mid January, and hatching in late January (and probably extending into early February), and where escapes might have been expected (and fledging swarms were in fact reported in late March). It is possible that one or more other swarms accompanied this one but went unreported. They, too, are likely to have perished. Some scattered fledglings may still have been moving north into the south-eastern desert of Egypt from the Red Sea coast at the beginning of April, but after that the coast would have been clear. Invasion from Middle East countries during the period considered is very unlikely, for the reasons given above, but it is just possible that some scattered locusts could have moved into north-eastern Sudan from northern Ethiopia (see Fig. 10.1) on south-east winds associated with northward surges of the RSCZ.

ISRAEL

Control was undertaken against some 50 small and medium-sized bands within infested areas totalling some 46 km^2, mainly in the low-lying area to the south-west of the Dead Sea (where hatching had occurred in late March), and also at Dimona, on the Negev hills to the west (where hatching occurred in late April over 8 km^2). No adults were reported.

This text is based on a list of hopper bands giving all the requested information except instars. There was some ambiguity, however, in that hoppers reported on 17 April were stated to have hatched on 23 – 25 April — clearly impossible and presumably a copying error for hatching on 23 – 25 March, contemporary with all other reported hatchings in the area. Because of this obvious error, ambiguity also arises about the hatching date of the Dimona infestations (hatched 23 – 25 April, reported 28 April), which would otherwise be taken as correct. In the text, the later date has been accepted for several reasons: the general principle of limiting amendments to those reports that are obviously wrong; the probability that the duration of incubation from recorded egg laying on 4 March at over 500 m above sea level in the Negev hills might be longer than that from eggs laid at about the same date in the Dead Sea valley some 200 – 300 m below sea level; and the possibility of later egg laying having occurred at Dimona, because there had been a mature swarm in southern Israel as late as 20 March.

Again, we consider the questions listed in Sections 10.1 and 10.2.

1 – 8 No adults were reported, so no new laying by reported locusts was possible. Bands were reported but they were controlled; their age was not given but they were probably a result of hatching seen in late March. If so, a development period of 30 – 35 days (Table 4.10) would lead to fledging from late April to early May, with any resulting swarms moving away from about mid May, particularly on spells of warm south winds.

9 Most of the hopper infestations may well have been found, however, so that control would have reduced the chances of significant escapes. More significant is the chance of invasion by swarms from Egypt and Saudi Arabia (*q.v.*) at any time up to the cut-off date, 20 May, but more especially in mid April, with subsequent egg laying followed by hatching from late April or early May, and fledging into June on a larger scale than if there had been no invasion. It is not known if the swarm seen in March (or any others that may have accompanied it but went unreported) stayed in Israel to breed.

JORDAN

There has been a press report of large swarms in the south of the country, and of a swarm in the Bethlehem district.

The last official report was dated 25 January; since then there had been none because locust staff had been busy with control work. Use was therefore made of a newspaper report of 16 May referring to a report from the Jordan Ministry of Agriculture dated 15 May. Small- and medium-sized immature swarms had invaded the country in December, and swarms of mixed maturity had spread through most of southern, central and north-western parts during the first three weeks of January. One of these had been reported to be 4 km × 10 km in size, but most were much smaller. Because the northward limit of movement had been Israel and southern Syria before late March, it is likely that the January swarms in Jordan had remained there, and also matured in February, as they had done in Israel and Syria. Egg laying is therefore likely to have begun in February and almost certainly in March, so that bands would be expected in April and probably also in May, with widespread fledging in May. Northward movements into Syria in late March would have reduced the number of parent swarms in Jordan, but more may have invaded from the south, particularly from mid April (see Egypt, Israel and Saudi Arabia), leading to further egg laying, and hatching from early May. (It was later reported that there was widespread egg laying from 1 February to 26 March over areas totalling some 1000 km^2, with hatching from 10 March. Further swarms invaded the north-eastern area on 22 April and moved on to Syria.)

SYRIA

Mainly mature swarms continued to infest the south of the country during April; egg laying continued and was reported over some 250 ha in Deraa, Soueida and Zelaf districts; and hatching began in mid April over some 200 ha in the last-named district.

Fortnightly reports were used to prepare this text, each containing a short summary of the situation and combined lists of swarms and bands giving most of the details requested on the FAO forms, and a map of the records. The populations present up to mid April appeared to represent the northern extent of swarms that reached Jordan in December and southern Syria in February. Their movements and the onset of breeding (egg laying from 8 March, hatching from 12 April) appeared to have been restricted by cold weather, but the increasing spells of warmer weather in April enabled the locusts to become more active. In early April, some swarms moved temporarily some 150 km further north during a spell of warm south winds (Case Study 10.6). On 13 April, a swarm of mixed maturity appeared in Deraa district and laid eggs there; it may represent an invasion from Egypt (*q.v.*). Mature swarms appearing in Zelaf district from mid April may represent an invasion from Saudi Arabia across Jordan (*q.v.*) on south winds, and they may subsequently have moved east (as winds turned to west), appearing in Terif district on 29 – 30 April. Further invasions from the south and south-east are possible, and further laying and hatching could have occurred at any time up to the cut-off date, 20 May, and anywhere in Syria but most likely in the east (swarm frequency maps), with fledging from late May.

IRAQ

Mature and copulating swarms, ranging in size from 1 × ½ km to 10 × 3 km, appeared in six localities of Ramadi province on 24 and 25 April. All other provinces were reported clear.

A monthly report, consisting of a brief summary and a swarm list, was available just in time for preparation of the assessment. The list included most items asked for on the FAO forms but omitted latitudes and longitudes. Localities named could not be found on maps or in the gazeteer available but were stated to be in Ramadi province. Because this province extends 600 km from the border with Jordan and Syria eastward to the river Euphrates, the forecaster is faced with the problem of estimating which part might have been invaded. The report stated that swarms were coming from both Syria and Jordan, so some at least are likely to have been in the far west of the province. All other provinces were reported clear, so swarms were not entering the country in the extreme south, even though they were reaching Kuwait (*q.v.*) by 30 April. Daily weather maps showed that light winds during the first few days of the invasion probably prevented swarms moving east of about 42°E, but west winds following a cold front moving eastward on 28 – 29 April could have brought swarms to the Euphrates valley by the end of the month. Thus, the evidence suggests that swarms invaded *western* Ramadi province, and later reports confirmed they were mainly clustered near 33°N 40°E. Further invasions could be expected to have occurred up to 20 May, under the influence of spells of warm southerly winds, and egg-laying swarms are likely to have become widespread. Hatching could be expected from mid May (incubation period about 20 – 25 days — by interpolation from Table 4.6), and fledging from mid June (development period about 35 days — Table 4.10).

KUWAIT

Reported clear until 29 April. Thereafter, several dense, mature swarms moved north-eastward from Saudi Arabia into Kuwait and the southern Neutral Zone. Small, medium and large copulating and egg-laying swarms were reported in 18 localities between 30 April and 5 May. Heavy rains in April favoured breeding. All swarms found were dusted with BHC or sprayed with aldrin or dieldrin.

> The original report was a detailed swarm list, with written summary and notes on the weather. These were the first reported locusts of the season in Kuwait. Laying would have been followed by rapid incubation (about 12 days) and hopper development (about 30–35 days), so that hatching could be expected from mid May and fledging in mid to late June. Further invasions from Saudi Arabia, and possibly southern Iraq, could be expected before the cut-off date, 20 May. Control teams were already being organised in the breeding areas, so that new generation swarms are likely to have been on a smaller scale than they would have been in the absence of control.

SAUDI ARABIA

Swarms in all stages of maturity were widespread in the greater part of western, northern and central Saudi Arabia during April. Layings continued in Qassim and Hail areas, and also occurred in Yanbu, Masturah and Rabigh districts of the Tihamah. There were hopper bands in Riyadh, and heavy hopper infestations in Qassim and Hail areas were beginning to fledge. Heavy hatchings occurred in the Nafud Dahna, north-eastern Hasa, the Linah area and the Great Nafud; and there were somewhat lighter hatchings, particularly in the latter part of April, in the north-west, near Al Jawf, Tabuk, Tayma and Al Ula, and further south near Medina, Badr and Rabigh. In south-western Saudi Arabia, a pink swarm was seen on 24 April flying over Lith (20°N 40°E) from north to south-west, and there were scattered mature locusts at Gizan. By mid May, however, most northern, western and south-western parts were reported clear, except for hopper infestations in the Sakakah and Al Jawf districts, but in central parts further mature swarms were reported in Riyadh, Qassim and Hail areas with extensive breeding.

> This text is based on the following reports: cables summarising the situations in April and early May, a narrative summary of events during April throughout several regions of this very large country, a cable from the Egyptian Anti-Locust Unit summarising events in the region covered by the Egyptian team, and a cable of 18 April from the Syrian Ministry of Agriculture notifying a report of 15 April from the Emir of Sakakah that mature swarms had come from the south to Wadi Sirhan. Swarm and hopper band lists on FAO forms (although received too late for use by 20 May, and not all having the information requested) have been taken into account here. Some swarm reports were grouped to a range of dates (often one week), thus making it difficult to relate them to the weather on individual days. It was also unclear whether swarm areas quoted for a given group were estimates for the same swarm seen repeatedly or for all the swarms grouped together. Cables and summaries contained information not on the detailed lists. By a detailed analysis of the reports (for brevity, not reproduced here), by comparing sequences of events with those in nearby countries, and by using daily weather maps, it can be deduced that: (a) the widespread, mostly mature, swarms in *northern* and *western* Arabia in April had largely come from the Red Sea area, both Egypt (*q.v.*) and Arabia (first northward, then eastward — consistent with the stated eastward movement in early April reports from Hail, Qassim and Hasa), adding to an older population there; and (b) the widespread clearance by mid May corresponded to the observed appearances in *central* Arabia, Jordan, Syria, Iraq, Kuwait and Iran (*q.v.*) from mid April to early May. The invading swarms laid widely in western and northern Arabia, with hatching and band formation from the end of April (incubation period about 17 days — Table 4.6 — a longer period than in Kuwait, which is nearer sea level and therefore warmer), but fledging would not have started until the end of May (development period 30–35 days — Table 4.10). In *central* Arabia, laying continued from March, but was greatly augmented by the mature swarms arriving in early May. Fledging from the earlier layings would have occurred from mid May onwards, but from the later layings not until about mid June. Further movements to between east and south could have taken swarms to countries around the Gulf by 20 May, but new generation swarms would not have been ready until June to undertake seasonal movements eastward to Pakistan and India, southward within Arabia, and south-westward to Egypt, Sudan and beyond. In *south-western* Arabia, the pink swarm seen on 24 April was flying in winds that had turned to north behind a cold front, after having been strong southerly for several days. The origin of this swarm is unclear: it may have come from the south (Somali peninsula) or from the north (around the northern Red Sea). It is likely to have remained on the eastern side of the Red Sea and to have moved south across the Tihamah of Saudi Arabia in dominantly north winds.

IRAN

Extensive layings and hatchings continued in Khuzestan, Fars and Kerman regions. Mature swarms invaded Fars from 13 April, and an immature swarm appeared in Khuzestan on 6 May. Some 200 km^2 of hopper bands were controlled in early April, and 1500 km^2 in early May.

> This text is based on two fortnightly reports (for the first halves of April and May — the one for the second half of April was not received), a swarm list giving most of the information requested on the FAO forms, and a routine end-of-month cabled summary. The reports indicate a mid April invasion from Saudi Arabia (contemporaneous with movements to other countries, discussed above), adding to populations that had come from India, starting in October 1960, and that had bred in Iran during spring. Some extension northward and eastward by these swarms could be expected by the cut-off date, 20 May,

possibly reaching southern Afghanistan and western Pakistan. Further swarms of the spring generation could be expected to develop from the extensive hopper infestations by the end of May, despite control measures undertaken, and further invasion from Middle East countries could also be expected, with egg laying, and the resulting fledging continuing into July.

The whole invasion area can be considered in the same way, including countries that have been reported clear or from which there have been no reports. Having done that, it is possible to summarise the descriptions into a text that will be the introduction to the forecast for June 1961 (Section 11.5). The following is a text that describes the situation, known and inferred, at 20 May 1961.

'Summary of locust reports for the whole invasion area during April and until 20 May 1961.

(*Abstract*)
The heaviest infestations are in the central part of the invasion area — in Iran, Arabia and East Africa — where there are many breeding swarms. West Africa, Pakistan, India and Bangladesh are reported clear.

(*Text of summary*)
Extensive layings and hopper bands were reported in Iran, particularly in Khuzestan and Fars, where more swarms were reported in mid April.

In central Arabia, breeding has been both extensive and prolonged. Laying continued and fledglings were already appearing during April, and further mature swarms were reported in early May. Laying and hatching continued during April in western and north-western Arabia, whilst lighter breeding was in progress in Israel, Syria, and almost certainly Jordan. Spells of warm southerly winds brought swarms into Israel, Jordan, Syria, Iraq and Kuwait from mid April.

Hopper bands and further layings were reported in south-eastern Egypt, where there were immature and mature swarms in early April.'

(The remainder of the text would be concerned with parts of the invasion area that have not been examined in this example.)

11 LOCUST FORECASTS

A locust forecast is a statement of the chances that certain locust events will happen during some stated period of time in the future and for some stated area. It is based on:

- what is judged to be the locust situation at the time the forecast is issued
- what changes are likely to happen to that situation.

The forecast is intended to give guidance to national and regional locust control organisations and plant protection services on the scale, timing and location of likely changes in numbers and distribution of locusts, particularly those that may require survey and control measures. Forecasts are also used in the allocation of funds to undertake such measures, and they make possible the deployment of staff and materials in advance of expected changes. They can also provide guidance to survey and control teams in the field on where best to look for locusts on a daily or even hourly basis.

11.1 NATURE OF FORECASTS

There are three kinds of forecast, according to the period covered.

- *Short-term* — for hours or days ahead. Used by staff already in the field to plan day-to-day activities, or by headquarters staff to start survey and control measures. Usually prepared and issued on request, or as supplements to medium-term forecasts.
- *Medium-term* — for some weeks ahead. Used by headquarters staff for planning deployment of resources. Usually prepared and issued regularly — for example, monthly or fortnightly.
- *Long-term* — for some months or a generation (or more) ahead. Used by headquarters staff for obtaining funds, materials and field staff. Usually prepared and issued on request, but could be regular — for example, every 3, 6 or 12 months.

The forecaster should remember the user's interests. He should try to answer questions that should be in the mind of the user, such as:

- what is the scale of infestation likely to be?
- where and when are the largest and most damaging populations likely to be found?
- how quickly are numbers likely to change?

Answers to these questions will enable the user to judge the damage that might be done if there were no control measures undertaken, and the steps that should be taken to reduce that damage.

11.2 PREPARING THE FORECAST

A forecast is prepared by extrapolating the assessment of the present locust situation (Chapter 10) into the future. The results of known or likely ways by which that situation will change are judged from answers to questions of the same kind as those listed in Section 10.1, but applied to the forecast period rather than the immediate past — will locusts move from where they were reported? will eggs be laid? will eggs hatch? etc. These questions are applied to both reported and possibly unreported locusts, and they need to be answered no matter how long the forecast period is. *Each country* is taken in turn, and written notes are made of the conclusions reached from answering the questions. In practice, it is convenient to write them straight after the assessment of each report, but the two sets of notes can be on separate sheets of paper for ease of use later. Notes are likewise made of the conclusions reached from answering questions like those in Section 10.2. By working systematically, country by country, including countries where nothing has been reported recently, the risk of missing a likely development is lessened.

Where alternative changes seem possible, the chances of each happening should be stated qualitatively by using such phrases as:

will probable almost certain likely expected	high probability
may might	medium probability
possible perhaps unlikely	low probability

Such chances can be judged by the use of ANALOGUES — past years when the locust situation was similar to the present one. The aim is to answer questions of the kind: when the locust situation was like the present one, what developments followed and, by inference, are likely to follow in the present situation? For example, the questions might be:

- when breeding extended to area X, what followed?
- when hatching began as early (or as late) as time Y, what followed?
- when swarms were present in area X at time Y, what followed?

The answer may be that what followed was not the same in each year. For example, after breeding in area X, locally produced swarms moved off in three directions: in 10 out of 12 years to the west, in 6 years to the north, and in one year to the east. Such information would be put into the forecast in the form: 'Swarms produced in. . . . . are *likely* to move towards the west, but some *might* also move north or *possibly* east.' Continuing in this way, it would be possible to answer extended questions of the kind: 'When swarms were present in area X at time Y, in which directions did they move, when, how far did they go, and how often did they reach each country along the route?' For example, it might be found that in the 10 out of 12 years that swarms moved westward from the breeding area X they invaded the nearest country (A) to the west in 10 years, reached the country (B) beyond in 5 years, but extended further west (to country C) only twice. This information would modify the forecast above to: 'Swarms produced in. . . . . are *likely* to move towards the west into (country A), some *might* also invade (country B) and *possibly* (country C); others might also move north into. . . . . etc.'

The following will help the forecaster to find analogues.

- *Locust distribution maps*, including:
  the monthly maps described in Section 9.5.3 (for the period 1942 to 1977; these are available at the Centre for Overseas Pest Research, and there are copies at FAO)

  sequences of monthly maps in the Summaries of Part 2 of this Manual

  sequences of published monthly maps for the period April 1954 to May 1955 (Rainey 1963, Fig. 17), and a selection of months for the period February 1953 to December 1954 (Johnson 1965, Figs. 35a – j)

  published maps for periods of 3 to 6 months (Waloff 1966)

  published maps of hopper bands during successvie 6-monthly periods of the 1949 – 63 plague (Uvarov 1977, Fig. 268).
- *Locust migration maps* for selected periods, including those in Chapters 2 and 5 – 8 of this Manual, and those published for 1954 (Rainey 1963) and 1968 (Betts 1976).
- *Case studies* of movements in relation to the weather, including those in Part 2 of this Manual, and others in a wide range of papers in the locust literature (e.g. those referred to in Part 2, in Rainey (1963, Chapter 3), and in WMO 1965).

All this material forms a reference library of past experience that the forecaster should endeavour to have readily available for frequent reference, and to which he will add from his own experience.

11.3 PRESENTING THE FORECAST

The aim of a written forecast is to give a concise account of what is likely to happen in some stated area for some stated period of time. It should be written in a style easily and quickly understood by the reader. It is compiled from the notes written about likely changes in both reported and possibly unreported locusts, country by country (Section 11.2).

The forecast consists of heading, abstract and text.
Heading. Unless the forecast follows an assessment, the heading should have a serial reference number, and state the area and period concerned, such as:

'Desert Locust forecast for (Region, country, etc.) during (month, quarter, etc.).'

Abstract. State briefly what the most important changes are likely to be, and their consequences as regards damage and control measures needed.

Text. Take each country, or group of countries, and describe what changes are likely to happen to locust numbers and distribution, giving reasons for statements made, referring to analogue years in the past, and bearing in mind the suggestions made in Section 10.3. Start with those parts likely to be most heavily infested, and name each country, even if only to say 'expected to remain clear of locusts'. As with writing the assessment (Section 10.3), maintain consistency in spelling of place names. Be precise; avoid vagueness.

11.4 VERIFYING THE FORECAST

Verification is testing the truth of statements in the light of subsequent events. Its usefulness lies primarily in the ability to show up causes of wrong forecasts so that similar mistakes can be avoided in the future. It also gives some indication of the relative difficulty in getting answers to the questions in Section 10.2, 10.3, 11.2 and 11.3, for different Regions and seasons.

Two main difficulties arise when trying to verify a particular statement in a forecast:

- finding evidence to test the statement,
- deciding whether the statement is right or wrong.

Locust situations are never fully documented; deductions must be made about possible unreported locusts, and these deductions always have some doubt. Hence some forecast statements have to be tested in the light of deductions, not reports. Sometimes these deductions can be made only months after the event, when later reports have been assessed. The absence of reports for a given place where locusts were forecast to be present does not necessarily mean that locusts were absent. Even when there are some reports, a judgement must be made whether the reports are representative of the real situation. This judgement is based on continuity with other reports, in both space and time.

Deciding whether a statement is right or wrong is not as easy as it might seem. For example, is a forecast of 'widespread breeding' right, wrong or partly right when only 'scattered breeding' was subsequently reported? Again, how does one judge a forecast of 'locusts will reach country A' when subsequent reports came from just outside the border after a long and unusual movement towards country A; or 'hopper bands are expected by late May' when subsequent reports were of 'hopper bands in early May'?

Some forecasts are more difficult to make than others — for example, those based on few reports, and those concerned with unusual events.

11.5 EXAMPLE FORECAST

The example chosen here is for June and July 1961; the reader should assume he is the forecaster preparing the forecast on 20 May, using all the materials and aids discussed in Section 10.4. As in that Section, each country is considered in turn, with the aim of showing how the answers to questions listed in Sections 10.1 and 10.2 can be extended into the forecast period.

As with the example assessment, this forecast is not complete, but the whole would be produced by applying the principles explained in Section 11.2 to all countries in the invasion area.

Forecasts for individual countries

EGYPT

Any escapes from fledging in the south-eastern desert are likely to move south (on the dominantly north winds in June and July — Sections 6.3 and 6.14, and Fig. 3.17b), joined by immature swarms moving out of northern, western and central Saudi Arabia and possibly countries to the north (*q.v.*). Maturation and breeding is most unlikely (no rain — Section 6.3, Table 6.2 and hopper frequency maps), and by the end of July the country will be free of swarms (see swarm frequency maps).

SUDAN

Immature swarms will invade the north of the country from early June, coming from the Middle East (on the dominantly north to north-east winds — Sections 6.3 and 6.14, and Fig. 3.17b). On reaching central parts of the country (where adequate monsoon rains south of the ITCZ can be expected in July — Section 6.3 and Table 6.2), these swarms will begin to mature and lay eggs (Section 6.5), with hopper bands becoming widespread by the end of the forecast period (frequency maps). (Some swarms are likely to continue moving either south-eastward into northern Ethiopia, or south-westward into central Chad, and possibly as far as Niger and Mali (Section 8.15; on the east or north-east winds there — Fig. 3.17b), with maturation and egg laying when they reach the monsoon rains south of the ITCZ (Section 8.3 and Table 8.2), but hopper bands are unlikely before the end of July (Section 8.5 and frequency maps).)

ISRAEL, JORDAN and SYRIA

Newly-fledged swarms are likely to move away into northern Saudi Arabia from late May (on the dominant north-west winds — Sections 6.3 and 6.14, and Fig. 3.17b). Further maturation and egg laying is very unlikely (no rain — Section 6.3 and Table 6.3). The countries will be free of swarms by the end of July.

IRAQ

Newly-fledged swarms are likely to move into north-eastern Saudi Arabia, Kuwait and southern Iran from late June (on the often strong north-west winds), and the country will be free of swarms by the end of July.

KUWAIT

Newly-fledged swarms, and others coming from the north-west, are likely to move quickly into north-eastern Saudi Arabia from late June; and the country will be free of swarms by the end of July.

SAUDI ARABIA

Newly-fledged swarms in western, northern and central parts of the country, and others coming from the north-west, will move away southward and south-westward (on the dominant north and north-east winds — Fig. 3.17b). Some will cross the northern Red Sea (Section 6.14) to south-eastern Egypt and northern Sudan (*q.v.*); others may remain to the east of the Red Sea and invade the southern Tihamah of Saudi Arabia, the Yemen Arab Republic and P.D.R. Yemen; and some may possibly cross the Gulf of Aden to reach Somali Republic (North) — Section 7.15. Most will encounter monsoon rains associated with the ITCZ (Sections 6.3 and 7.3, Tables 6.3 and 7.2), and after maturation and egg laying (Sections 6.5 and 7.5) there may be widespread hopper bands in the southern Arabian peninsula by the end of July (frequency maps).

IRAN

Fledging of hoppers resulting from laying by mature swarms invading in mid April should be complete by early July (see assessment), and the resulting immature swarms will spread eastward (on the dominant west winds — Section 5.3, Fig. 3.17b), to reach the summer breeding areas of Pakistan and north-west India (Section 5.15), where maturation and egg laying can be expected if monsoon rains arrive in late June or early July, as they usually do (Section 5.3 and Table 5.2). Widespread hopper bands can be expected there during July (Section 5.5 and frequency maps).

The most significant change expected during the forecast period is the redistribution of newly-fledged swarms from the spring breeding areas of Arabia and the Middle East. These can move to the west, south and east, as has been shown in the discussions on individual countries and in Sections 6.14 and 6.15. However, because, in 1961, a peak in fledging rate was to be expected (in Saudi Arabia, Iran, Iraq and Syria) after mid June, when movements have usually become mostly to the south and east, and especially to the east, the main weight of emigration from the North-Central Region would be expected to be into the Eastern Region, into the deserts of Pakistan and north-west India, where the heaviest monsoon breeding would occur. This is a direct contrast to many other years, when a great part of the fledging occurs in May, and the proportion of swarms going westward is therefore likely to be greater.

It has been emphasised that the prospects for *all* countries in the invasion area need to be considered when preparing an operational forecast. For each country this includes possible developments resulting both from invading locusts and from any locusts already in the country, including any that may have gone unreported. In the example above, locusts were expected to invade the Eastern and Western Regions. Both Regions had been reported clear of swarms during April, but the forecaster has to consider the possibility of unreported locusts being present. This includes, for the Eastern Region, consideration of what might have happened to locusts previously reported at the extreme limits of the invasion area; and, for the Western Region, consideration of problems more characteristic of recession periods (see Chapter 12), but worth illustrating here.

Eastern Region

No swarms had been reported in India, Pakistan and Bangladesh during April, and scattered locusts in the deserts of north-western India were sparse. Because there had been extensive swarm movements southward and eastward across the Indian peninsula and into Assam from September to December 1960 (Summary 4 and Case Studies 4.1 to 4.3), and swarms had continued to be reported in Assam until 23 March, it is necessary to consider whether locusts might still have been present on the day the forecast was prepared, 20 May. Some of the swarms had matured by February, so eggs might have been laid in February or March; if so, and if the young survived, development would have been rapid and fledglings could have been expected in April or May. Migrations into Assam, however, are rare (see swarm frequency maps), and no breeding was recorded during the period of the hopper band frequency maps. Moreover, analogues from nineteenth and early twentieth century records led Rao (1960, p.615) to conclude that such migrations do not contribute to the succeeding year's infestations. Decreasing numbers of swarm reports during early 1961 accord with this conclusion, and the risk of carry-over from this source to the forecast period must be very low indeed.

The main risk to Pakistan and India was that of invasion from the west (see above and Summary 8).

Western Region

No locusts were reported during April in any of the countries of north-western Africa and the Sahara. ('Nil' reports had come from all countries except Morocco, from where the report was, exceptionally, delayed.) Even so, there would have been almost certainly a few locusts at places within the area liable to infestation at this season during recessions (Fig. 2.1). But it is the possibility of the continued presence in remote areas of larger populations, either widespread scattered locusts or small swarms or bands, to which the forecaster needs to give consideration.

The most recent contact with swarms had been those of the 1960 monsoon generation in south-western Morocco, the last of which had been reported as controlled by mid February. Because there had been intensive aerial reconnaissance, the forecaster could have assumed that this area had indeed become largely, if not entirely clear by then. Furthermore, it is unlikely there had been other invasions there during April because there was no evidence of winter breeding in Western Sahara and Mauritania, the most likely source.

Further east, although at least one moderate-sized swarm (3 km × 2 km) had reached north-eastern Morocco by December and was said to have been controlled, it was not clear whether any other swarms had moved at this time into eastern Morocco or northern Algeria. Other immature swarms, possibly also from Mauritania or from breeding in Niger, had reached central Algeria in late October and might have gone further north. Moreover, swarms in the past have often drifted from Morocco eastward across northern Africa, particularly from late February onwards (see Section 8.12; swarm frequency maps for January to March; Summary 17 and Case Study 17.1; and Rainey 1963, Fig. 22 and pp.93–94). The forecaster must therefore look suspiciously upon the coincidence of a disappearance apparently due to control (in this case, in Morocco) at a time when emigration was likely. The scale of any such movement in 1961 would have been small, however, because the populations in south-western Morocco had already been reduced substantially.

Some mature (but not immature) swarms, as well as scattered locusts, had spread across Sudan, Chad and Niger towards southern Algeria in late September and early October, with egg laying in north-western Niger (and therefore fledging expected in late November and December). The possibility of laying in nearby southern Algeria (see hopper band frequency maps, October to December) therefore also needs to be considered. Although there had been 13 mm of rain at Tamanrasset in September, there was little rain elsewhere from September to November so there is likely to have been no, or only very local breeding. There were also reports of scattered locusts in Tibesti (northern Chad) in November, and of an immature swarm in late November (or early December — the report was ambiguous).

The evidence suggests a need to bear in mind the chance of some small swarms being present in eastern Morocco, Algerian Sahara and northern Chad (and possibly in nearby parts of Libya and Niger). Any spring rains might have led to breeding by April, but the months February to April were very dry (after extensive rains in December and January), so that any unreported locusts are likely to have been few and scattered, and they would have contributed little (after seasonal migration — Section 8.14) to the swarms that are forecast to invade Chad, and possibly Niger and Mali, from Sudan in July.

Having considered the whole invasion area, it is possible to summarise the forecasts into a text that will accompany the assessment (Section 10.4). The following is a text that would have been prepared on 20 May 1961.

> Desert Locust forecast for the whole invasion area, June and July 1961.
>
> (*Abstract*)
>
> This is a season of major redistribution of locusts, and the start of breeding in new areas. Many immature swarms will leave their breeding sites in northern Saudi Arabia and countries to the north, moving east, south and south-west, particularly to India and Pakistan, but also to Yemen Arab Republic, P.D.R. Yemen, northern Ethiopia, Sudan and Chad, where widespread breeding will start on monsoon rains.

(Text)

Laying is likely to continue into June in Iran. Young swarms are expected to appear in Iran, Saudi Arabia and countries to the north until July, and movement of young swarms out of Saudi Arabia, the Middle East and Iran is imminent. Most of these swarms are likely to move eastward into Pakistan and India; others are likely to move into the south-western Arabian peninsula and even as far as the Somali peninsula; and yet others will move south-westward into Egypt, Sudan, Chad and northern Ethiopia, and possibly into Niger and Mali. Breeding is very likely from July onwards in Sudan, the south-western Arabian peninsula, Pakistan and north-western India; it may also occur in Chad, Somali Republic (North); and it is possible in Niger and Mali.

11.6 DISTRIBUTING THE FORECAST

A forecast loses value with time; it should therefore reach the user as quickly as possible. One that requires action within hours or a few days needs to be sent by telephone, telegram, telex or radio. Keep a record of the date and time of sending by writing them in a register along with the names of the sender and recipient. Send a confirmatory written copy by mail.

A routine forecast (for example, monthly) needs a carefully planned schedule of registering the reports, assessing them, preparing the forecast, writing, typing (printing) and issuing it. Have a mailing list, and keep a record of the date of mailing.

11.7 SHORT-TERM FORECASTS

So far in this Chapter we have considered the preparation of regular, routine forecasts, usually issued each month. There will be times, however, when rapid changes take place that require a quick response by survey and control authorities. The occurrence of such changes needs to be notified in the quickest possible way to those authorities in the form of *short-term forecasts,* which should include briefly both the relevant report and the forecaster's assessment of likely consequences. Two kinds of short-term forecast are prepared.

Tactical forecasts.

These give day-to-day guidance for survey and control, such as where to search for recently reported swarms that may well be migrating, or where to search when following up an unconfirmed report of locusts, or where to put down insecticide barriers for controlling hopper bands. Such forecasts are prepared at control headquarters, and they depend heavily on the use of the latest synoptic weather maps. They can be used to reduce time wasted in aircraft searches.

Warnings.

These draw attention to recently reported locust or weather events that could quickly lead to a serious development, and they are issued by one country or Region for the benefit of another. A warning may be of a recent locust report that shows or suggests the onset of breeding or movement, whether or not it has been forecast already. Alternatively, a warning may draw attention to an occurrence of rain suitable for breeding, or of winds capable of bringing locusts into areas previously clear, or of taking them away from areas previously infested. Such occurrences can be recognised from synoptic weather maps and satellite pictures, often within only a few hours of their happening. Follow-up warnings are helpful when later reports confirm a suggested onset, or suggest that it has become unlikely. Moreover, there will be occasions when *advance* warning can be given, because the weather systems likely to lead to the rain or winds can be seen developing and moving a day or more before their effects are felt.

Being based on recent reports, these short-term forecasts are more reliable than regular (e.g. monthly) forecasts, which rely heavily on reports that may be weeks old, and which apply to periods some weeks ahead.

The following are some examples of warnings sent by telegram from the FAO Desert Locust Information Service to locust control authorities in the countries named.

- *26 June 1961, to Sudan and Ethiopia*

  Isolated pink locust seen at sea 70 miles west of Jeddah 24 June stop still possibility further young swarms reaching Sudan and Eritrea.
  [In the event immature swarms appeared in the Nile valley in southern Egypt from 25 June and in Sudan from 27 June]

- *10 June 1964, to India*
  Pakistan
  Trucial States
  Desloc at Diredawa, Ethiopia

  Cyclonic depression centred 10 0600GMT near 19N 70E likely to move NNW stop recommend consult meteorological service on future developments possibly affecting locust situation south-eastern Arabia.

- *2 July 1964, to Pakistan*
  India

  Particular vigilance needed possibility localised gregarious breeding following cyclonic storm and associated heavy rains second week June Sind Bahawalpur Punjab Rajasthan.
  [In the event, the cyclone, after starting over the Arabian sea, moved into the Rajasthan desert; locusts were reported and an upsurge of the locust situation develped (Waloff 1966).]

11.8 LONG-TERM FORECASTS

The forecaster may sometimes be called upon to provide summaries of recent events over a period up to a year or more, and forecasts for a similar period ahead. Such summaries and *long-term forecasts* may be needed by, for example, directors of locust control organisations, government ministers, or international bodies such as United Nations specialised agencies or international banks to help them plan available control resources, or to find ways of augmenting them, especially in the event of an emergency. News agencies may request similar forecasts if there is general public concern about the locust situation.

Such a forecast is written in a form suited to the particular reader. If the forecaster expects the reader to know little about the Desert Locust in general, and less still about recent events, it would be appropriate to include a very brief outline of life history, migration and breeding, including the effects of wind and rain. This outline is perhaps best interwoven with the summary of recent events, so as to give the reader enough background for him to understand both the summary and the forecast that follow. Neither summary nor forecast should be as detailed as those prepared regularly, but they should put emphasis on locust populations that are likely to be or become most damaging to crops, their movement within and between countries, and their changes in size, particularly by breeding. Special attention should be put on timing, because that will enable planners to produce a timetable for the preparations needed. Simple sketch maps are a help in describing a complex situation.

The degree of confidence that a forecaster puts in his long-term forecast will vary from one part to another because of, for example, shortcomings in the available reports, the likelihood of rapid changes due to events that have not yet taken place (such as widespread and heavy rains), a lack of analogues from past records, or a lack of understanding of particular kinds of events. It is very helpful if this degree of confidence can be expressed, even only roughly, and it should be explained that confidence decreases as the length of the forecast period increases, because future events will affect locust populations in ways that become more difficult to foresee, or because a choice has to be made between alternative and perhaps equally likely possibilities. After about one generation ahead (which will range from a few months to about 9 months, according to area and season), these largely unknown influences make it almost impossible to give much more than a statement of seasonal movements and breeding, and the chances of their happening, based on past records. Suggestions can be added about the kinds of events that need to be watched for and that might bring about one or other of the possible alternative developments — such as an unusually prolonged rainy season, a drought, the early onset of warm winds, or the occurrence of a rare tropical cyclone. This part of the forecast then becomes conditional; such statements as 'A is likely if B happens, and then C will probably occur if D happens' may have some usefulness for periods up to two and sometimes perhaps three generations ahead, particularly if updated forecasts are subsequently prepared in the light of developments, either at the request of the user or because the forecaster considers they would be helpful. If a plague is already in existence, attention should be drawn to its possible duration (see Section 2.8).

11.9 IMPROVING THE FORECAST

Improvements in the methods of Desert Locust forecasting must come primarily from improvements in methods of monitoring locusts and their environment, and in our understanding of the relation between changes in the numbers and distribution of locusts and changes in their environment.

There is scope for better operational monitoring of soil moisture and temperature (in relation to egg laying and incubation), and of vegetation cover (in relation to food and shelter). Regular surveys for the whole invasion area, or large parts of it, seem feasible only be use of remote sensing techniques from earth-orbiting satellites. Use of such satellites in monitoring rainfall distribution, timing and amount is being expanded, and further developments can be expected. Improvements in the measurement and analysis of wind and temperature fields can also be expected, again with the help of satellite-mounted instruments. And with an increasing understanding of the nature and behaviour of tropical weather systems, the preparation of reliable locust trajectories becomes feasible, both backwards (to assess how past movements took place) and forwards (to forecast invasions). Whether locusts themselves can be tracked by satellite remains to be tested.

Aircraft with radar able to detect flying locusts, and with Doppler wind-finding equipment, have been demonstrated as useful for locating insect concentrations, and, if also equipped with spray gear, might be useful for locust search and strike (Greenbank, Schaefer & Rainey 1980).

One result of improved monitoring of the locust environment will be a clearer demonstration of the distribution of potential breeding sites, especially those in remote areas otherwise seldom visited. The continual gathering of locust reports into a growing archive will enable updating and improvement of the frequency maps for occurrence of swarms and bands, and also the preparation of similar maps for scattered populations, more typical of recessions. Likewise, the growing sequence of small-scale monthly distribution maps will enable more analogues to be found. Greater precision in calculating development periods and trajectories will encourage the making of further case studies to be used as forecasting aids.

12 FORECASTING OUTBREAKS AND PLAGUE UPSURGES

Much of this Manual has been concerned with explaining and illustrating principles of Desert Locust forecasting that have been developed and used in years of plague. The reason is simple: there is a great wealth of field data on the distribution and behaviour of Desert Locusts in such years, and there has been a great incentive to develop a forecasting system that will help reduce the damage done by plague swarms. Even though there is plenty of evidence to show that these principles of forecasting are widely applicable to years of recession, forecasters must accept that there are differences in reporting between plague and recession years. Although the differences make forecasting during recessions more difficult, it is nevertheless true that forecasting of outbreaks and possible plague upsurges can contribute greatly to plague prevention. This final Chapter draws attention to some of the differences in reporting, and it outlines some suggestions for new investigations that could be undertaken to help forecasters become more aware of the possibilities for development of outbreaks and upsurges.

12.1 LOCUST REPORTING DURING PLAGUES AND RECESSIONS

High- and low-density populations of the Desert Locust occur during both plagues and recessions, but during plagues an overwhelming majority occurs in dense and economically important bands and swarms, and the attention of survey and control personnel is concentrated on such formations.

Flying swarms are usually conspicuous. Except in some special circumstances — e.g. when day temperatures are too high for flight (Sections 3.1.2 and 3.1.6), or a swarm happens to be in flight over the sea by nightfall (Section 3.1.6) — swarms roost by night and fly by day, when the larger ones among them often rise to hundreds of metres above the ground (Section 3.1.3). All this increases the probability that during the long traverses between their source and breeding areas (Section 2.4) they will be seen and reported, not only by personnel of locust services and any other local organisations, but also by local inhabitants. In some parts of the Desert Locust area, the efficiency of swarm detection and assessment was greatly increased by regular use of aerial reconnaisance (Rainey 1958, 1963).

Even if some swarms were at times difficult to find because they were grounded for varying periods by low temperatures, clouds and rain (encountered in the highlands or in winter), they resumed their flights and became conspicuous again as weather improved. Moreover, even when swarms became comparatively thin, e.g., on reaching sexual maturity (Sections 2.3.1.2 and 3.1.3), or in strong winds (Section 3.1.3), or when crossing deserts (G. Popov, personal communication), they still attracted attention by continuing to fly by day.

Again, the detection of sites on which plague swarms bred and their progeny appeared was facilitated by the conspicuousness of swarming populations — all the more so because during plagues much of the breeding took place in areas where seasonal rains are adequate to support populations of pastoralists or cultivators denser than those in the central parts of the invasion area (See Fig. 2.1). The positions of breeding sites were manifested by vast numbers of pairing and laying locusts, and the subsequent hopper infestations were known from laying sites or found after the formation of conspicuous hopper bands.

Because swarming populations were so obvious at most stages of their life-cycle, it is probable that the majority of them were seen and reported. Even if a proportion of bands and swarms did sometimes escape notice, reports of the rest were sufficiently numerous and representative of each locust generation to enable forecasters to evaluate the distributions of seasonal hopper infestations and to follow the movements of resultant swarms towards and over the next breeding belt. Running analyses of all this information, and its assessment in context of current weather and analogous developments in earlier plague years, enabled forecasters to arrive at reasoned, and on the whole quite successful, prognoses of swarm movements and breeding during plagues.

It has to be appreciated, however, that the forecasts were concerned primarily with *distributions* and *timing* of future events. The available information on *sizes* of swarming populations was often inadequate and at best qualitative, and the evaluation by forecasters of the magnitudes of anticipated invasions and breeding was similarly approximate and qualitative. The only area in which consistent attempts were made during the last major plague to estimate and *quantify* plague populations of hoppers and adults was East Africa (Joyce 1962). Such quantitative estimates are essential, however, not only for understanding Desert Locust population dynamics but also for immediate practical needs to improve forecasting and to evaluate control requirements and results; and it is to be hoped that in future they will be attempted to an increasing extent.

The extensive area in which the Desert Locust occurs during *recessions* (Fig. 2.1) is desert or sub-desert (Fig. 2.7b), and the greater part of it is either empty or only sparsely inhabited. Most of the information on incidence and breeding of recession populations has accordingly to be obtained by special surveys.

During recession, the majority of reports refer to populations at low densities (Section 2.3.2), while reports of hopper bands or swarms are, as a rule, few; the observed swarms are usually small and thin (diffuse). Populations which are not in swarms, on the other hand, show a wide range of sizes and densities, and may sometimes comprise tens of millions of locusts scattered over tens of thousands of square kilometres (Section 2.3.2 and Roffey *et al.* 1970).

Whatever their density and phase, however, recession populations remain mobile and they displace downwind between the breeding areas of successive generations, which may be hundreds or thousands of kilometres apart; in general their displacements take place in the same weather systems as those of plague populations. But in contrast to day-flying swarms, low-density populations remain settled by day and fly by night (see Section 3.2).

The breeding areas of recession populations show some seasonal zonation, reflecting shifts of rainfall between summer, winter and spring zones (see Section 2.5 and Figs. 2.7 c,d,e). The actual siting and extent of breeding within these seasonal zones depend on the distribution of variable or erratic desert rainfall and, like the latter, vary from year to year.

The ecological characteristics of recession breeding areas have been described by Popov (1965); for West Africa and parts of the Sahara they have been further discussed in the *Manuel du Prospecteur,* issued by FAO (1975). The local characteristics of the breeding habitats of recession populations are known to survey personnel and used by them in their seasonal search for locusts.

As Desert Locusts move about the recession area, intermittently one or more of the contemporaneous populations experience conditions which lead to their concentration, multiplication and gregarisation — i.e. there is an outbreak, and the formation of some bands and young swarms. The environmental and behavioural factors bringing about the concentration of locusts on the macro- and micro-scales are discussed in Section 2.6, with examples of situations leading to grouping of different stages; successful breeding needs good rainfall, and all known cases of outbreaks have been associated with such rains.

Once an outbreak occurs, the populations produced may occasionally persist in the swarming state for more than one generation. More often, however, the locusts may be only partially gregarised and they apparently dissociate in the course of their migrations, merging with the contemporary low-density populations. Eventually such mixed populations, or their immediate or more distant progenies, may encounter conditions leading to another outbreak, or the next outbreak may involve different locusts altogether.

Conditions which initiate a plague upsurge are similar to those leading to local outbreaks, but for a *plague* to develop there must be a sequence of widespread heavy rains falling over the same or complementary breeding areas and providing opportunities for rapid multiplication and gregarisation through several successive generations Longer than LO (see Section 2.7, and Waloff 1966, Pedgley and Symmons 1968, Bennett 1976). Since the incidence of such rainfall sequences is still unpredictable, the present strategy of plague prevention involves the control of *outbreaks* — in case these develop into the more serious upsurges.

In monitoring recession populations, the detection of movements of night-flying, *low-density* locusts over largely unpopulated areas presents obvious difficulties; often immigration into breeding areas can be detected only by special surveys and counts. Similarly it has been seldom possible to track the mainly isolated recession *swarms*, a large proportion of which has remained unconfirmed. There are very few cases when ground observers sighted a recession swarm more than once. Moreover, intensive aerial searches carried out in East Africa to find recession swarms reported by ground observers were equally without success (Hemming, Popov *et al.* 1979). It is highly probable that some of these failures to get a second sighting of recession swarms were due to their unstable and ephemeral nature.

Because of the difficulties in detecting recession populations while they are in transit, forecasters get little information from which they could follow their migrations (either currently or in retrospect) in the way this has been done with plague swarms. The problem of monitoring airborne recession populations could perhaps be overcome eventually with the help of radar (Schaefer 1976). The use of radar, from ground and from the air, would make possible not only the detection, but also the assessment of flying populations, and facilitate the search for concentrations and swarms. So far, however, radar has been used primarily as a research tool, and its widespread deployment, which would be required for effective monitoring of migrating Desert Locusts throughout the recession area, does not seem likely in the foreseeable future.

The present strategy of outbreak and plague prevention requires the timely identification of areas where good rains have fallen and locusts are breeding, and the application of prophylactic control measures to all dangerously large and concentrated populations of parent locusts and their progeny.

The distribution of localities in which locusts have gregarised in the past is shown on Fig. 2.8 and discussed in Section 2.6. Abdallahi *et al.* (1979) give the most up-to-date map of such areas in West Africa and parts of the Sahara, where considerable progress has been made in delimiting such areas and defining the drainage, soil characteristics and vegetation formations which would favour grouping and gregarisation, always provided there is good rainfall and locusts immigrate into the area. The description and mapping of such habitats throughout the recession area would help both survey and forecasting personnel.

To assure the detection of all dangerous breeding populations, surveys at present have to cover very large areas, and in order to reduce them some organisations (notably in West Africa) adopt a sequential survey technique, in which green habitats made suitable for breeding by rains are first located from the air, and then inspected from the ground for the presence of locusts.

But survey coverage is very unequal over the immense recession area, large parts of which remain unsurveyed, including those where unhindered building up of very large populations have occurred in the past, such as south-eastern Arabia in 1948–49, 1967 and 1977 (see Section 2.7 and Roffey 1979). Even in the surveyed parts not all dangerous populations are detected and controlled in time, and escapes of large low-density and sometimes swarming populations continue to occur. There is an obvious need both to improve the survey and to extend it over the whole recession area. Some work has been done on the application of remote sensing techniques to further these aims.

The feasibility of detecting suitable breeding sites has been demonstrated by comparing Landsat imagery with the actual distribution of vegetation on the Red Sea coast of Arabia (Pedgley 1974c), and the state of vegetation has also been monitored in the Sahara (Hielkema and Howard 1976). Satellite imagery has also been used to monitor the distribution, timing and amount of rainfall, and further developments can be expected with the introduction of new sensors and methods of analysis. Daily analyses of satellite imagery have been used operationally to prepare rainfall maps accompanying the Desert Locust situation summaries and forecasts prepared by the FAO forecasting service. Satellites also have the potential of providing ground temperatures (for the estimation of egg incubation periods) and winds (for the estimation of locust movements).

12.2 SUGGESTED STUDIES TO AID FORECASTING DURING RECESSIONS

One of the main problems facing forecasters during recessions is the detection of situations liable to lead to any large-scale and concentrated breeding. Yet both the incidence and the scale of breeding are dependent on the incidence of rains, and on the winds transporting locusts into areas of rainfall, and are therefore largely unpredictable in advance.

The routine and timely recognition of potentially dangerous situations will accordingly continue to depend on the systematic and continuous consideration of current and recent locust reports, of the current synoptic weather situations which may affect the locusts, and of information on abundance and distribution of rains (see Chapters 10 and 11). But it would be a help to forecasters if they were aware of all the circumstances in which outbreaks and upsurges have occurred in the past, and the following biogeographical and biometeorological studies are suggested to provide them with additional information.

A valuable line of investigation would be the undertaking of detailed *case studies of past outbreaks and upsurges,* records of which can be obtained from, e.g., Waloff 1966, Skaf 1978, Hemming *et al.* 1979, Rainey & Betts 1979, Roffey 1979, or simply from the monthly Desert Locust situation summaries prepared by DLIS in London, and later at FAO in Rome.

From the point of view of the forecaster, any situation resulting in dangerous breeding will attach special interest not only to the conditions of breeding (i.e. habitat and rainfall), but also to the origin and nature of the parent population(s) and the mechanisms transporting and concentrating them.

It has been suggested, for example, by Rainey & Betts (1979) that outbreaks and upsurges arise mainly from breeding by populations which remain large (and at least partially gregarised) from generation to generation throughout recessions. As these authors themselves point out, however, there is as yet no analytical evidence in support of the proposed putative relationships and migration links between the populations which they list. It follows that until such analyses are carried out in the light of all the relevant locust and meteorological data, their suggestion has to be considered as hypothetical.

It must also be borne in mind that the environmental factors bringing about the *concentration* of locusts on the macro-scale (such as convergent winds or selective settling on restricted sites, see Section 2.6) might in some circumstances lead to the production of dangerously large parent populations out of initially separate smaller ones. For this to occur, either numerous populations distributed over an extensive area would have to be gathered together by winds coming from a large area into an intense convergence system, or the trapping of large numbers within restricted sites would require nightly migrations over such sites during a protracted period (cf. Section 2.6), in the course of which immigrants could arrive from several sources. The possibilities of concentrating widely dispersed populations by either of these mechanisms or by their combination appear all the more plausible since it has been found by radar observations (Schaefer 1976; see Section 3.2) that night-flying, low-density locusts may displace at ground speeds which could enable them to traverse several hundred kilometres in a single night.

It is suggested that case studies on outbreaks or upsurges should include the following.

- Critical evaluation of the possible relationships between the initial parent populations and all known current and recent locust populations in the affected and neighbouring regions, taking into account the respective generations, locust numbers and population types. The data on locusts are obtainable from the archives of COPR, though in some cases it could probably be supplemented by information in the archives of local locust organisations.
- Assesment of the most probable derivation of the parent population by means of biometeorological analyses, such as investigations into the.weather systems involved in bringing the rains and the locusts to the sites of concentrated breeding. This would involve study of the patterns of winds, the areas (and hence the locust populations) which could have been affected, and the intensity of convergence, on the lines of Rainey's (1965a) examination of the October 1948 tropical cyclone in Oman (Section 2.7.2), or Cochemé's (1966a) study of a re-assembly of scattered locusts into a swarm in Pakistan.
- Back-tracking locusts from areas of outbreaks by back-tracking the air for periods when locusts most likely arrived (particularly useful when assessing the sources of populations concentrated by selective settling).
- Further studies of rainfall patterns and sequences in space and time which allow locusts to breed with success and increase in numbers through several successive generations. This would follow up earlier studies on rainfall required for successful breeding (Magor 1962, Bennett 1976). Such sequences for the Saharan and Sahelo-Saharan zones in West Africa, for example, and for the Central Regions have been discussed in, respectively, Abdallahi *et al.* (1979) and Pedgley & Symmons (1968). Whereas in the past the actual distributions and amounts of relevant rainfall remained unrecorded in many parts of the recession area, now such gaps may be filled by rainfall information obtainable from satellite imagery as well as from the augmented gauge networks that have been introduced in some countries.

It may also prove of interest and provide guides in forecasting to:

- prepare maps showing the amounts and distributions of rains falling on a succession of occasions (as well as maps of cumulative rainfall) for areas and seasons in which marked population upsurges have occurred, or are known to be taking place;
- examine the locust data in context of such maps (always bearing in mind the effects of relief and drainage).

In addition to case studies, the continual gathering of locust reports into a growing archive will make it possible not only to update and improve the *frequency maps* of occurrence of *swarms and bands* but also to prepare similar maps for *scattered populations.* Likewise, the growing sequence of small-scale monthly distribution maps will enable more analogues to be used.

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Names of countries and states are included, but not those of provinces or other administrative or geographical regions. For each country or state, references are given to both general discussion and particular examples of events such as breeding and invasion. Note that these particular events are illustrations only; the Manual does not include all known examples.

Bold figures refer to pages where words are defined. Further definitions are given in F.A.O. 1980.

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