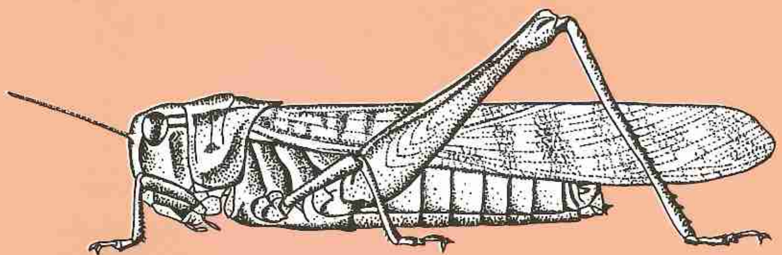
ATLAS OF DESERT LOCUST BREEDING HABITATS



Food and Agriculture Organization of the United Nations

ATLAS
OF DESERT LOCUST
BREEDING HABITATS

Descriptive commentary
by
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LIST OF ACRONYMS

AETFAT	Etude Taxonomique de la Flore de l'Afrique Tropicale
ALRC	Anti-Locust Research Centre, London (predecessor of COPR and NRI)
ARTEMIS	Africa Real Time Environmental Monitoring using Imaging Satellites
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Montpellier, France
COPR	Centre for Overseas Pest Research, London (subsequently ODNRI-NRI)
DLCO-EA	Desert Locust Control Organization for Eastern Africa (successor to DLS)
DLFM	Desert Locust Forecasting Manual
DLS	Desert Locust Survey (created in 1948 by the fusion of MEALU and EAALD)
EAALD	East African Anti-Locust Directorate, Nairobi
EMPRES	Emergency Prevention Systems (FAO Program)
FAO	Food and Agriculture Organization of the United Nations
GPS	Global Positioning System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation Organization)
ITCZ	Intertropical Convergence Zone
ITF	Intertropical Front
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer
MEALU	Middle East Anti-Locust Unit, Cairo
NRI	Natural Resources Institute (successor of Overseas Development Natural Resources Institute (ODNRI)
OCLA	Organisation Commune de Lutte Antiacridienne
OCLAV	Organisation Commune de Lute Antiaviaire
OCLALAV	Organisation Commune de Lutte Antiacridienne et de Lutte Antiaviaire
ODNRI	Overseas Development Natural Resources Institute
PRIFAS	Projet de Recherche Interdisciplinaire Français sur les Acridiens du Sahel (currently a unit under GERDAT a department of CIRAD)
RSGA	Red Sea and Gulf of Aden area
SGR	Desert Locust, *Schistocerca gregaria*
SNPV	Service National de la Protection des Végétaux
TATA	Timetrine - Adrar des Iforas - Tamesna - Air area in the Nigero-Malian Sahara
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSF	United Nations Special Fund (predecessor of UNDP)
UNSO	United Nations Sudano-Sahelian Office

PREFACE

In 1984 Desert Locust populations were probably at the lowest levels since records began and no populations displaying any gregarious characteristics were reported. During 1985-87, as a result of sequences of successful breeding, frequently in areas inaccessible to control, a new Desert Locust plague developed. In late 1987 and during 1988 there were numerous long range swarm migrations most spectacularly over a period of about three weeks during October and early November 1988, when swarms crossed the Atlantic to reach the Caribbean and northern Latin America. Despite the enormous losses that the locust populations suffered due to those migrations and the subsequent unfavourable dry conditions which confronted the remaining swarms in the Maghreb, Sudan and the Arabian peninsula, the campaigns which eventually suppressed the plague cost in the vicinity of US$ 250 million in human, material and financial resources provided by the affected countries and the international community, including FAO.

There are three simple, clear lessons to be learnt from these dramatic events:

(i) the Desert Locust, if it encounters favourable breeding sequences, has the ability to attain plague proportions in the space of about two or three years and recent environmental changes that have occurred within its distribution area have not impaired this ability;

(ii) the organizational structures intended to detect and prevent locust plague upsurges are inadequate and measures are needed to make them more efficient and effective;

(iii) plague suppression utilising current technology, even in its relatively early stages, is very expensive, uncertain in effectiveness and poses potential long term environmental risks. Thinking ahead to the possibility that future plagues may not be totally preventable, it is essential to make their suppression more cost-effective and environmentally safer and to explore the potential of new technologies in realising this objective.

Various actions are currently under way to meet these demands. The UNDP/FAO Scientific Advisory Committee on Locust Research has formulated a Desert Locust Management System aimed at identifying rapidly and precisely areas where successful breeding may occur through the integration of locust, weather and habitat information in a Geographic Information System (GIS), complemented by research into and development of, environmentally acceptable control strategies. While it is gratifying to record how some of these activities are being undertaken in collaboration with research institutes in developed countries it is recognised that it is essential to strengthen the capacities of the locust affected countries to conduct adequate monitoring and preventive control measures and to involve them in research. To this end FAO has implemented the Emergency Prevention System (EMPRES) for Transboundary Animal and Plant Pests and Diseases programme to strengthen monitoring, early warning and control activities for Desert Locust, together with associated training and research, which will initially focus on the Central Region.

The publication of the Atlas and this accompanying commentary constitutes another practical contribution towards the overall aim of preventing further Desert Locust plagues. It is hoped that the series of detailed maps on the distribution and frequency of breeding during recessions, together with maps, descriptions and illustrations of the breeding habitats will assist those in charge of locust operations to determine where and when locusts are likely to breed and to decide on appropriate action. Studied in conjunction with enhanced satellite imagery, it should be possible to pin-point more accurately the potential danger spots, thus improving the precision and reliability of forecasting, the efficacy and cost effectiveness of surveys and the early detection of dangerous locust populations. The series of maps on the distribution of swarm breeding during plague periods, highlights the high frequency breeding areas where the majority of breeding is likely to occur if ecological conditions are suitable. This knowledge should contribute towards more cost-effective planning, logistic preparation and deployment of resources during control campaigns.

The maps in this Atlas, the text and the illustrations were prepared by George Popov, who has unrivalled field experience of the Desert Locust dating back to 1943. During 1958-64 he led the FAO/UNSF Desert Locust Ecological Survey which gave him knowledge of large parts of the distribution area of the Desert Locust. This work contributed considerably to the evolution of the present strategy of plague prevention, which essentially consists of conducting surveys in seasonal breeding areas and controlling any gregarious or significant gregarising populations. The acquisition of the data and mapping were assisted by Ms Helen Palmer. The final drawings of the maps were done by Ms Fiorella Marcon d'Andrea of the Cartographic Unit of FAO under Mr. C. Capucci and the printing was done by the FAO Printing Unit.

It gives me pleasure to record FAO's appreciation to the Government of Belgium, the United Kingdom and the United States of America which funded the preparation and the printing of this valuable work.

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As author of the Atlas I wish to place on record my profound gratitude to the many who have in innumerable ways contributed to it, either through their own work (cited as appropriate), or by helping me to acquire knowledge and experience. My earlier, formative, years (1943-58) which coincided with two, nearly continuous, major plagues of the Desert Locust, were spent in the service of the Middle East Anti-Locust Unit and its successor, the Desert Locust Survey and Control Organization (now DLCO-EA), mostly in the field, but with periods between campaigns working at the Anti-Locust Research Centre, London (subsequently Centre for Overseas Pest Research, now Natural Resources Institute, Chatham).

My mentors included such renowned entomologists, naturalists and acridologists as Prof. John Kennedy, Sir Boris Uvarov, D. Vesey-Fitzgerald, Donald Gunn, O.B. Lean, R.C. Rainey, T. H. C. Taylor, Zena and Nadia Waloff, while among my colleagues who shared many of my field experiences were Clifford Ashall, Adefris Bellehu, Nick Jago, Kenneth Guichard, Christopher Hemming, John Hewitt, Jeremy Roffey, Gurdas Singh, W. J. Stower and James Tunstall. During 1958-64, within the programme of the FAO/UN Special Fund (later Development Programme) Desert Locust Project, I had the privilege to lead the Ecological Survey studies throughout the distribution area of the locust, jointly with the botanists Charles Rossetti, W. Zeller and the meteorologist J. Cochemé. This period spanned the decline of the major 1950-63 Desert Locust plague and the onset of the long recession period. Further studies on recession conducted during subsequent service with ALRC (subsequently COPR) during 1964-82, then FAO during 1982-84, and continued after my retirement in a series of consultancies, mostly sponsored by FAO, one of which resulted in the compilation of this Atlas. An abridged list of contributors to the Atlas is as follows:

Historical data: NRI (the original ALRC archives); extraction and interpretation of data mostly on the 1939-63 plague period assisted by Joyce Magor, Judith Pender and David Pedgley;

Original reports, observations and personal communications

OCLALAV: Jean Roy, J. M. Castel and prospectors, Babacar Fall, Din Atane (Mauritania); M. Coulibaly, A. BenBaye, Aguissa Ambarkawana (Mali); Mohamed Aoutchiki, Ayouba Ali, Boucary Ali and Abdou Mamane (Niger);

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Last but not least I wish to offer my thanks to FAO in the persons of Lukas Brader and the late Rafik Skaf for their unfailing support, interest and encouragement, to Jelle Hielkema for assistance with the procurement and interpretation of remote sensing imagery, and particularly to Jeremy Roffey and Laury McCulloch for the many useful discussions and for editing this text, and to Helen Palmer for help with the preparation of the prototype maps for the Atlas and to the Graphics Section of FAO, particularly to its Chief, Mr. M. Capucchi, and the cartographer Fiorella Marcon-d'Andrea, for the production of the definitive drawings including the text figures. Thanks are also due to Laura Pela, and Angelo Baggiossi for typing the text.

G.B. Popov
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ATLAS OF DESERT LOCUST BREEDING HABITATS

1. INTRODUCTION

This Atlas has been prepared to assist those concerned with the problem of monitoring and controlling the Desert Locust by identifying and describing the preferred areas and the habitats (biotopes) where the Desert Locust lives and breeds during both plague and recession periods.

During plagues, Desert Locusts typically occur in the gregarious phase as bands of nymphs (hoppers) or as swarms of winged adults. The invasion area which can be reached by swarms during plagues, known as the Invasion Area, extends from the west coast of Africa to Assam in eastern India and from Uzbekistan to southern Tanzania (Map 1a). During the periods between plagues, the recession periods, locusts typically occur as solitarious individuals living singly, and only occasionally, following the processes of concentration, multiplication and gregarisation (Roffey & Popov, 1968) as bands and swarms. Recession populations, inhabit the Recession Area, which roughly corresponds to the more arid Central Zone of the invasion area (Map 1b).

The distribution of high frequency breeding by Desert Locust during plagues is presented in Maps 2(a-e) and for the recession periods in Maps 3(a-e). Maps 4(a-d) show the annual variations in locust populations in Western Africa during the period 1950-1960. The remaining maps show the distribution of locust breeding habitats, which on historical evidence are of particular importance during plagues and recession periods. Their characteristics, as revealed by the seasonal distribution of locusts in relation to environmental factors (meteorological, geomorphological, soil and vegetation), are illustrated cartographically by the maps which are drawn according to appropriate scales, and are discussed in detail in the accompanying text. In addition the principal characteristics of the habitats and their estimated potential ecological value for Desert Locust survival, breeding and gregarisation on a qualitative scale are summarised in a series of Habitat Tables (Annex 1).

Since the publication of the Atlas maps further advances have been made in the field of locust research and control, especially thanks to the stimulus of the dramatic if short-lived 1987-89 Desert Locust plague. The lines of research that are particularly relevant to the theme of the Atlas and are complementary towards its use are as follows:

(i) The publication of the third edition of the Desert Locust Handbook (Steedman, 1990). This is an expanded version of the second edition, in particular the parts dealing with the seasonal movements and breeding areas of Desert Locust during plagues and recession, the outbreaks and origin of plagues, control strategies and choice of control equipment have been revised.

(ii) The publication of a series of FAO Desert Locust Guidelines covering locust biology and behaviour, survey, information and forecasting, control and campaign organization and execution. The Guidelines are primarily for use by national and international organizations and institutes involved in Desert Locust survey and control.

(iii) A detailed study of Desert Locust habitats in the Western Region (see Popov, G.B., Duranton, J.F. and Gigault, J., 1991). The habitats are described in a standardised, uniform and analytical way. Twenty six biotopes are defined within three eco-climatic zones (Saharo-Mediterranean, Saharan and Saharo-

Sahelian) where Desert Locust populations develop during recessions; habitats of the Mediterranean and the Sahelian zones chiefly colonised during plagues, are also described. Beyond its locust control interest, this study constitutes a useful description of the Saharan environments supplemented by colour illustrations of all the major habitat types in the Region.

(iv) Mapping of Desert Locust habitats using remote sensing techniques. This study was conducted as part of the GTZ Integrated Locust Research and Control Programme by Drs. F. Voss and U. Dreiser of the Geographical Institute of Berlin with the participation of G.B. Popov and the Plant Protection personnel of the countries concerned. The criteria used in the selection of the pilot study areas and evaluating the potential ecological value of the habitats were the same as those used in the preparation of the Atlas maps, but here the use of high-performance equipment, notably the Global Positioning System (GPS) for the geographical delimitation of the habitats, and the processing and the interpretation of the LANDSAT Thematic data used in the preparation of the maps by means of the digital image processing enabled a very high degree of accuracy and precision to be realised. The limitations of costs and availability of data restricted the study to three pilot areas, each 1-2 degrees square, namely the Tokar Delta on the Red Sea coast of the Sudan; part of the Tilemsi and the Adrar des Iforhas area in northern Mali and the Atar-Akjoujt area of Mauritania. The parallel use of these maps in conjunction with the corresponding Atlas maps will broaden and enhance their usefulness in monitoring and interpreting Desert Locust situations.

(v) The development of two computer models to assist FAO locust forecasters to predict locust behaviour. The first estimates the development rates of locusts from the laying stage to fledging based on temperature. The second estimates trajectories of locust adult and swarm migrations using wind direction and speed, temperature, relative humidity and pressure at various heights above see level. The data that drives the model is derived from the latest and must sophisticated weather models, and it is received daily at FAO.

2. DATA AND METHODS

2.1 Sources of Data

The data used in the preparation of the Atlas originate from many sources. The historical data on the 1939-63 plague period come from the archives of the Anti-Locust Research Centre, now housed at the Natural Resources Institute (NRI) at Chatham, England. Those for the 1964-1987 recession period are largely from FAO records kept at the FAO Desert Locust Information Service, Rome. For some regions and countries additional information was used; for the Western Region, additional information is from OCLALAV and for the Central Region records from the Agricultural Research Centre in Jeddah, the Locust Control Office in Hodeidah, and the Locust Control Unit in Aden. Other sources of data and information on both plague and recession periods that were used or consulted are cited. In addition, valuable notes and verbal communications were contributed by the field personnel of the many regional and national locust control organizations throughout the Desert Locust distribution area, as well as by colleagues at FAO, NRI and PRIFAS, which have greatly enriched the information contained in the text and the habitat maps.

2.2 Compilation of the Maps

2.2.1 The General Maps

The two general small scale maps (Maps 1a and 1b) show the distribution of the Desert Locust during plagues and recessions; Map 1a shows the breeding areas and major movements of locusts during plagues and Map 1b shows the breeding areas and major movements during recessions. They have been prepared from frequency maps and the Desert Locust Forecasting Manual (Pedgley, 1981) and are intended as a general introduction and as a guide to the regions and to the subsequent maps.

2.2.2 The Maps showing breeding during plagues and recessions

Map 2(a-e) and Map 3(a-e) show more precisely and in greater detail the distribution of breeding during plagues and recessions. The breeding records from original plottings on 1:1 million, 1:2 million or 1:4 million scale maps or from unplotted locust reports were transferred as accurately as possible onto a 1:5 million base map with a quarter degree resolution basis. However, it should be noted that only records for which actual locations or coordinates were identified are included. Where records of breeding are only given as a degree square, a range of degree squares or as a broad geographical area without any reference to actual locations, they are not shown. Thus in some areas data appear to be under represented. Furthermore, due to the scale of the maps, the number of dots in a particular area does not accurately reflect the frequency of breeding, although the higher frequency breeding areas are characterised by having more dots than the lower frequency areas (compare maps 2(a-c) and 3(a-e)).

2.2.3 The Habitat Maps

On the detailed maps of some of the more important high frequency areas during both recession and plague periods (Map 5(a-c), 7(a-b), 8a, 9a, 10a, 11, 12, 13(a-d), 14(a-d), 18, 19, 20) an attempt is made to show the major habitat types and environmental units/regions in as much detail as the scale and the available information permit. The most detailed are the maps of the Timetrine - Adrar des Iforas

- Tamesna - Air (TATA) area in the southern Sahara (Map 7(a-b)). Originally, the habitats, or more precisely the principal plant communities, were plotted on 1:200,000 scale maps, using as sources of information the author's personal knowledge of the area, information provided by experienced OCLALAV field personnel, and LANDSAT imagery for September 1980 (at the time, these images were the best available to show the vegetation at its maximum development). The results were then transferred to a 1:1 million base map onto which were plotted all the records of Desert Locust nymphs and occurrences of gregarisation (Maps 6(a-b)). Their correlation with certain types of habitat is seen to be quite pronounced.

Other habitat maps are less detailed, either because the information was not so complete or in some cases, for example, the Red Sea coast of Arabia, the annual variability of the habitat is such that insistence on too much detail is unrealistic.

In conjunction with these maps are records of incidence of nymphs, and in some cases adults, for each degree square. These were extracted from the ALRC monthly frequency maps for the 25-year plague period 1939-1963, and the FAO maps for the 22-year recession period 1964-87 (but excluding 1968 and 1978 as these were plague years). The addition of the data on adults is particularly useful in providing some indication of the distribution of low density solitarious populations, in which the hoppers are difficult to find and often remain undetected.

The ecological characteristics of the high frequency areas are discussed in Parts 3, 4 and 5 of the text and are also summarised in a series of Habitat Tables. The tabulated information on the soil, geomorphology, physiognomy and composition of the vegetation for the major habitat types is accompanied by an assessment of their potential value for the survival (S), reproduction (R) and gregarisation (G) of locust populations during plagues and during recessions, and also the frequency (F) of their potential liability to invasion/colonisation by locusts. These potential values, expressed on a 0-5 abundance scale, are qualitative assessments based on the global interpretation of the available historical published and unpublished information and field observations and records by the technical locust control and research personnel. Due adjustments are made to allow for the reliability of the data as discussed in the next section.

2.3 Reliability of Data

The quantity, quality and reliability of data are subject to considerable spatio-temporal variation. This is due to many causes, foremost among them being:

- variation in the availability of material resources; funds, means of transport, communication and support facilities to permit regular survey;
- variation in the ease of access to target areas; e.g. distance, nature of terrain, flooding, lack of security, etc.;
- the wide variation in the quality of the observers and reporters ranging from trained locust control and plant protection officers to the much less experienced personnel such as military and civil personnel, travellers and local people;
- Yet another source of variability consists of climatic and environmental changes, including those which result from recent land use changes, all of which may in due course, influence the distribution of locusts;

- Finally, an important element is the nature of the locust populations - whether they are present in readily visible bands and swarms or as isolated or scattered individuals, detectable only by a trained observer.

Evaluation of the reliability of data is certainly of fundamental importance in its interpretation, but this is a difficult task to accomplish objectively and is often difficult even at the source. One of the best on a geographical scale is OCLA's attempt to evaluate the reliability of their 1950-1961 data. This was done by degree square units for the whole area under their control and is presented in Maps 4(a-d) reproduced from the UNSF/DL/ES/1 report (FAO). It is evident that the reliability of the data varies very considerably, with some parts of the area virtually never having been surveyed. While this was perhaps of small account in the Djouf area of the Sahara (20-24°N, 3-8°W), where rain and locust breeding are probably extremely rare, the absence or scarcity of surveys over much of south-eastern Mauritania and parts of Mali that lie within the summer breeding belt is likely to have underestimated their importance. For the Malian Tamesna which is an important high frequency breeding area (described in more detail in Section 5.4) this was almost certainly the case during both plagues and recessions).

In Niger, Tamesna is traversed by a major trans-Saharan route passing through Tamanrasset to Agadez and Zinder which provides a relatively easy means of access and during the 1953-61 period an OCLA team regularly surveyed this area from bases in Agadez and In Abangharit. The Malian Tamesna has no such easy access; the second trans-Saharan route from Tessalit to Gao passes along the western flanks of the Adrar des Iforas. Indeed, the surveys here were in the nature of occasional visits. However, subsequent studies during the 1960's revealed the ecological value of the habitats in the Malian Tamesna and the frequency of breeding in them during recessions to be fully equal to that of their counterparts in Niger (Map 6a). Therefore, it is evident that, at least in this case, the recorded frequencies of 0, 1 or 2 for the degree squares 17-20°N, 2-4°E should be treated with caution. This is probably also true for south-eastern Mauritania (15-17°N, 5-7°W). In short, the value of the frequency figures must be judged in the light of the frequency of the surveys and the reliability of the information sources. The interpretation of the data in the text is made with such considerations in mind, but with no adjustments to the original data in the Atlas maps.

3. PRINCIPAL CHARACTERISTICS OF THE DESERT LOCUST DURING PLAGUES AND RECESSIONS

3.1 Distribution (Maps 1a and 1b)

During plagues the total area subject to invasion by swarms of the Desert Locust is some 29 million km^2; however, breeding occurs over only about 13.6 million km^2. The location and the extent of breeding are subject to annual and seasonal fluctuations so that only some parts of the potential breeding area are active simultaneously in any single year.

During recessions Desert Locust populations are confined to the central and more arid part of the distribution area, covering some 16 million km^2.

The differences in the distribution of plague and recession populations are due principally to differences in their flight behaviour (Section 2.4) and the enhanced response to habitat conditions by solitarious locusts not dominated by gregarious "drive" and inertia. Thus the intensive gregariousness of individuals in swarms frequently results in swarms overflying habitats suitable for non-swarming populations, while the latter flying by night and thus subject to lower temperatures, fail to reach areas attained by swarms. As a result, the area which can be reached by swarms, the Invasion Area (Map 1a) is almost double that of the Recession Area (Map 1b).

3.2 Biology and Ecology

The Desert Locust has no obligatory diapause at any stage of its development, but it is capable of facultative suspension of maturation under adverse environmental conditions, notably low temperature and/or low moisture. This faculty contributes largely towards its survival under desert conditions, for otherwise the species is very demanding of moisture. The eggs are relatively unprotected and following laying must be able to absorb their own weight of water from the soil to complete their development (Shulov, 1952). Likewise, from the time of hatching, the nymphs (hoppers) must have access to fresh green vegetation of which they consume approximately their own weight daily during the course of their development (Davey, 1954). Thus reproduction in the Desert Locust is intimately dependent on the occurrence of rain. To a large extent the physiology of the adult and the behaviour of the female at the time of laying provide safeguards. Sexual maturation is closely dependent on rainfall (Magor, 1962), and the female locust normally only lays eggs where adequate soil moisture exists.

The settling of swarms is largely independent of the suitability of the soil for laying (Popov, 1958). With the exception of the occasions when swarms settle at sites already occupied by laying locusts, settling of swarms as a rule occurs towards dusk and can be largely ascribed to the physiological condition of locusts, e.g. (hunger, fatigue) the structure of the habitat (topography, vegetation) and the weather and light conditions. Reproductive activity, laying preceded by copulation, does not normally start until sometime the following morning after a period of basking and descent to the ground and it is only at this stage that the suitability of soil conditions can be tested by the female locust.

Typical laying sites are patches of bare sandy soil within or along the edges of areas of vegetation. While exposed well-insulated dry soil surface is preferred, laying does not take place unless moist soil can be reached by the ovipositor: the maximum depth in sandy soil being 10-15 cm. Several successive attempts may be made to oviposit during which remarkable ability is shown in locating the most appropriate moisture conditions. However, if suitable conditions are not found within about 3 days, the eggs are abandoned on the surface of the ground or vegetation and desiccate (Popov, 1958).

The breeding grounds of the Desert Locust during plagues cover a very wide range of habitats and it is not surprising that laying has been recorded in many different habitat types to the extent that it provokes the common saying that "locusts lay anywhere". Yet, within the spectrum of available habitats, selectivity for some sites is shown by swarms at the time of laying and is even more marked in solitarious locusts. There is a tendency for settling swarms to respond to features of relief such as hillsides, dune ranges, wadis and areas of contrasting vegetation, as in the contact zone (ecotone) between two physiognomically distinct plant communities, e.g. along a woodland bordering a steppe. Thus, during studies by the FAO Ecological Survey Team in India, 112 eggfields representing 132 cases of oviposition during the 1960-62 period were studied in an area of four degree squares centred on Jaisalmer in Rajasthan (Popov *et al*, 1965). Here laying was most frequent in sandy, non-saline soils bearing an open steppe of tussock grasses, herbs and sometimes scattered trees and shrubs. Within the range of the available habitats this choice was highly significant. It was further found that heterogeneous conditions were preferred and most eggfields included two or more plant communities; only two were entirely within a habitat with completely uniform vegetation. Many of the habitats were altered and often made more suitable for laying by changes in land use, e.g. deforestation, cultivation, pressure of grazing, etc.

The choice of contrasting habitats is consistent with Uvarov's (1957) views on dual requirements in Acridoidea for a food/shelter habitat with appropriate vegetation for the development of nymphs and an oviposition habitat, usually bare patches of soil, for the development of eggs. It is evident that areas that offer a wide range of such conditions will attract settling and laying more frequently than more uniform terrain.

3.3 Phase Polymorphism

Locusts differ from grasshoppers by their ability to gregarise, i.e. to form persistent hopper bands and swarms in response to an increase in population density. This ability, or aptitude, to use Pasquier's (1952) terminology, differs between species. The Desert Locust is the best locust of all in its aptitude to gregarise, i.e. in the readiness of its solitarious populations to gregarise under suitable conditions and in the high level of activity, mobility, cohesiveness and persistence of its gregarious populations. There are marked behavioural, physiological and morphological differences between locusts that occur in bands and swarms and which belong to the gregarious phase and those that live in isolation in the manner of grasshoppers, and which belong to solitarious phase. When solitarious individuals are crowded together they change their behaviour and, if kept crowded for a generation or more, they change their shape to that of the gregarious form. The process of phase transformation is reversible. At their extreme, the two phases *solitaria* and *gregaria* are so different in their form and coloration that they were originally described as different species. There are also numerous biological differences that affect all the life stages. These are described in Uvarov (1966, 1977) and the Desert Locust Forecasting Manual (Pedgley, 1981), but what is of particular relevance here are behavioural differences between the phases, most notably differences in their flight behaviour which largely affect their seasonal distribution and their choice of habitats.

3.4 Flight Behaviour

A major faculty which contributes to the survival of Desert Locusts (but at times may also lead to their destruction) is their outstanding flight ability, both as swarms and as isolated individuals. For instance, during the 1987-89 plague there were repeated crossings of the Mediterranean and during October and November 1988 there were three separate crossings of the Atlantic; taking off from the coast of Western Africa, the swarms remained airborne for some 120 hours, many locusts eventually reaching virtually all islands in the eastern Caribbean and the north-eastern coast of Latin America (I. Thomas, unpublished).

During plagues swarms migrate between the seasonal breeding grounds that are often hundreds and sometimes thousands of kilometres apart. During recessions locust flight is less spectacular and certainly much less observed since, whereas swarms fly by day and are easily observable, the solitarious locust, characteristic of recessions, fly singly by night (Roffey, 1963; Waloff, 1963).

The most direct evidence on night flight by individual locusts (and some other insects) comes from radar studies. Of greatest relevance here are those conducted by a joint COPR/Loughborough University Project led by Professor Glen Schaefer, in the southern Sahara in Niger, during September-October 1968 (Roffey, 1969; Schaefer, 1972, 1976). These studies established *inter alia* that:

- Desert Locusts flew on every night when the radar was in operation;

- the average area densities were of the order of 1 locust/hectare;

- the maximum height of flight was 1.8 km, but the majority flew below 400 m above ground level;

- flight was generally in the low level jet stream giving ground speeds from 15 to 65 km/hr, with an average of 35 km/hr;

- orientation was almost invariably down-wind, even on dark, moonless nights;

- typically no locusts were flying at sunset, but numbers appeared about 20-30 minutes later, reaching a peak about 40-50 minutes after sunset. Numbers then decreased, but occasionally this was interrupted by passage of waves of locusts at higher densities; often such increases were associated with a wind change. On some nights locusts continued to fly until well after dawn.

Although individual locusts could only be detected by radar up to a distance of about 2.8 km, it was felt from the general performance and characteristics of the flying locusts that their displacements were frequently over considerable distances of tens or even hundreds of kilometres a night. Further evidence of this is circumstantial. The most convincing to this day are the early observations by Ramchandra Rao and his colleagues (Rao, 1942) who used biological markers to postulate a seasonal displacement of solitarious populations between the winter-spring breeding grounds in Makran and summer breeding grounds in the Indian desert, analogous to what was already known for the swarms. This was based on the observations that spring-bred locusts in Makran often had green algae on their hind wings, while those produced during the summer in the Indian desert were frequently infested with red mites. The appearance of mite-bearing locusts in autumn in Makran and of algae-bearing ones in the Indian desert at the start of the monsoon season constituted convincing evidence of solitarious migration.

3.5 Seasonal Breeding and Migrations

These subjects constitute the principal themes of the Desert Locust Forecasting Manual (DLFM) (Pedgley, 1981) and are treated in considerable detail, and supported by numerous case studies. The combined use of the Atlas and the DLFM will help define the areas and thus the habitats where breeding is liable to occur.

What is perhaps useful to point out here briefly, by way of an explanation for the maps, is that the chronology of seasonal breeding agrees with that of the main rainfall seasons, and that migrations between seasonal breeding areas and belts are generally with prevailing winds and towards the zones of convergence where rainfall is liable to occur. This system is particularly clear during plague years (Rainey 1951, 1989; Pedgley, 1981), when the seasonal breeding areas are more clearly defined. Winter-spring breeding occurs in the north, following the winter-spring rains associated with middle latitude depressions in a belt that stretches from North-West Africa, through northern Arabia and Iran to Baluchistan and North-West India. Summer breeding occurs in a belt extending from Mauritania to India and is associated with monsoon rains along the Inter-Tropical Convergence Zone (ITCZ). The Central Region, comprising the Red Sea and Gulf of Aden basins and Eastern Africa, has a more complex atmospheric circulation and also receives rain in winter. The more arid central belt, corresponding to the Sindo-Saharan desert and the Desert Locust Recession Area, is under the complex, marginal and overlapping influence of all three regimes and breeding can occur in any month.

3.6 Pattern and Frequency

The aim of this section is to discuss briefly the pattern and frequency of outbreaks and upsurges in the regions with special reference to the role of the habitats in the processes involved. The terminology and criteria used are identical with those in the DLFM (Sections 2.6, 2.7 and 2.8).

First it is necessary to define and explain some terms. An outbreak is a marked increase in the numbers of locusts as a result of concentration, multiplication and gregarisation (Roffey & Popov, 1968), as a rule starting with solitary-living individuals, and 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 adults and nymphs due to their independent reactions to external environmental factors (Kennedy, 1939). Concentration can occur in many ways, but essentially there are two scales; (a) the large scale, (on a geographical, or meso-scale) probably when flying adults are redistributed from a larger to a smaller area by convergent airflow (Rainey, 1951, 1963, 1989) or by selectively settling in habitats which they encounter during their flight (Roffey & Popov, 1968); (b) on the smaller scale by subsequent movement into preferred micro-habitats, in order to roost, shelter, bask, feed, or lay (Roffey and Popov, 1968). Due to continued arrivals, concentration is often protracted and numbers will continue to rise so long as habitat conditions remain favourable and arrivals continue to exceed departures.

Multiplication, as distinct from protracted concentration, is an increase in numbers as a result of breeding (Waloff, 1966). Since a female Desert Locust lays 50-160 eggs per pod and usually two or three egg pods, the period of breeding is potentially one of multiplication. However, natural mortality is usually so high that even under favourable conditions the actual rate of multiplication is seldom more than a tenfold increase (Greathead, 1966; Joyce, 1962). For rough estimates of multiplication rates under favourable conditions the figure of a tenfold increase of each generation is a realistic estimate (DLFM) which can be applied to both scattered populations, and swarms.

Gregarisation is the acquisition of the behavioural and other characteristics of the gregarious phase (Section 3.3); its most significant outcome is the formation of hopper bands and swarms.

Outbreaks occur over a wide range of areas, ranging from less than a hectare to tens of thousands of square kilometres; they can occur over one, generation, or span several generations. The significance of an outbreak is likewise very variable: it depends on the number of locusts involved, on the success of their breeding and on their relevance to the overall locust situation; larger outbreaks are precursors to plague upsurges, which, according to DLFM, are defined as periods, 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.

Plagues may initially be confined to one region (regional plagues) but as a rule they tend to expand to involve the other regions (major plagues). Examination of the intervals between the major and the regional plagues has failed to establish any regular periodicity in the occurrence of plagues (Waloff, 1976).

3.7 Plague Prevention

The fundamental role of habitats in furthering the processes which lead to locust outbreaks and at times to plague upsurges is crucial so that monitoring Desert Locust habitats by means of satellite imagery, aerial and ground surveys is currently the basis of the strategy for preventing Desert Locust plagues. The aim of such environmental monitoring is to identify as soon as possible areas which are potentially suitable for locusts. Aerial and ground surveys are then mounted to assess the locust situation in those areas and control operations are undertaken against any gregarious or gregarising locust populations present with the overall objective of preventing the occurrence of major outbreaks. The strategy thus depends on the presence of mobile survey teams capable of reaching all potentially suitable breeding areas. But this is not always possible so that upsurges which may lead to plagues continue to occur. The strategy has been criticised on the grounds that it involves the application of pesticides against many populations which will not lead to plagues. The alternative is to delay control until most locusts have already formed into discrete gregarious populations, but unless these can be controlled with certainty before migration occurs this strategy carries with it high risks.

4. GENERAL DISTRIBUTION OF BREEDING AND THE DISTRIBUTION OF HIGH FREQUENCY BREEDING AREAS DURING PLAGUES

Comparing the breeding Maps 2(a-e) and 3 (a-e) with climatic, topographic, soil and vegetation maps of comparable scale, the following general conclusions can be made:

- during plagues, the two principal seasonal breeding areas in Africa (associated with the spring Mediterranean rains in the north and the summer-autumn tropical monsoon rains in the south) are well separated by the vastness of the Sahara, except in the west where they are bridged by a broad zone of less frequent breeding that may occur sporadically with the infrequent, but occasionally abundant, rains that may fall here in the winter and spring.

- In the Arabian peninsula there is a similar north-south separation but in Indo-Pakistan the separation is east-west and there is some overlap between the winter-spring and summer breeding areas.

Fig.1a/b (reproduced from the Desert Locust Forecasting Manual) shows schematic streamlines over the Desert Locust invasion area, showing examples of the principal wind systems often present during (a) the northern winter and (b) the northern summer.

4.1 The Western Region

4.1.1 The summer breeding belt (Maps 2a, 2b , 4, 5a and 5c).

4.1.1.1 General

The bulk of summer breeding occurs between the mean annual isohyets of 200 to 600 mm, but in places it extends into areas of higher and, particularly, of lower annual rainfall. The latter correspond to areas of major relief, notably the Mauritanian Adrar, the Adrar des Iforas in Mali, Air mountains in Niger and Ennedi/Darfur in eastern Chad and western Sudan. Here, soil moisture is considerably enhanced by the combined effects of orographic rain and run-off, and the breeding belt extends to the 100 mm isohyet and even less, especially in the western parts of the Sahara, where such relief features as the Adrar Soutouf, Zemmour and Hank, can benefit from exceptional winter-spring rains and occasionally create favourable breeding conditions, as was the case during October 1987 - March 1988 and again in 1994-95.

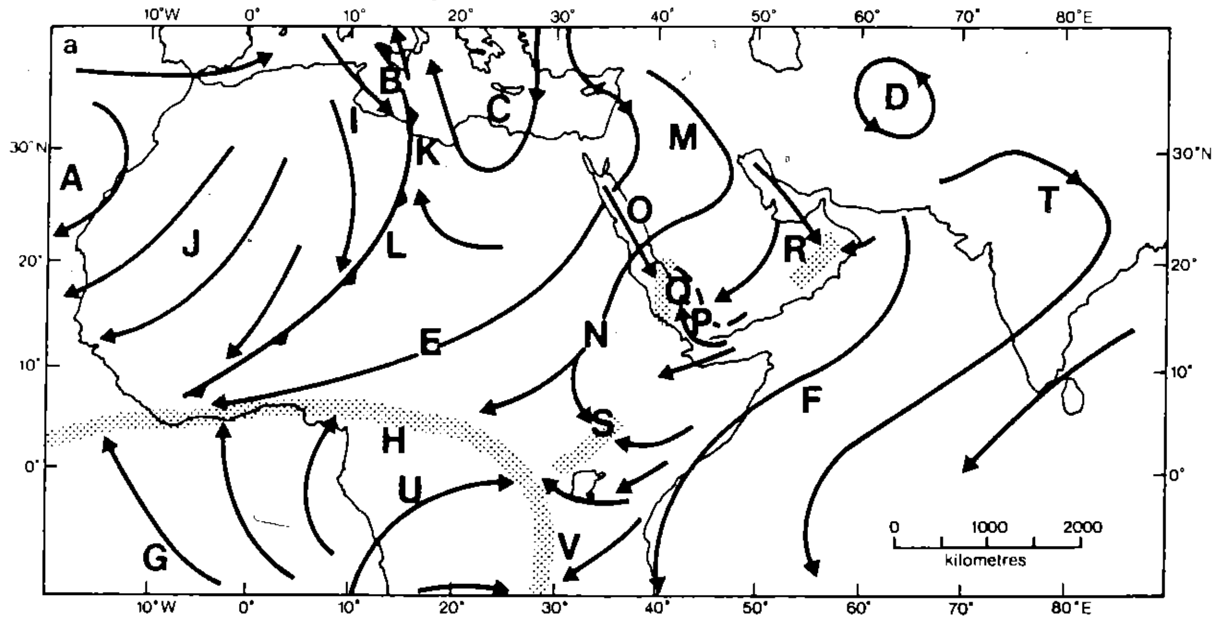
In terms of the major vegetation types, as defined on the UNESCO/AETFAT/UNSO vegetation map of Africa (White, 1983), the summer breeding belt lies astride the Sahel *Acacia* wooded grassland and deciduous woodland to the south and the northern Sahel semi-desert grassland and shrubland to the north. Breeding seldom extends southwards beyond these limits except in western Senegal, where it spreads into the undifferentiated Sudanese woodland zone and even reaches the lowland rain forest and secondary grasslands of the Guinea zone. The pronounced southward extension breeding in this region (it was particularly marked in 1988, when some laying was recorded in northern Guinea Bissau) could be due to the dual effect of the weather systems and to the general degradation of the vegetation due to the pressure of land use. The latter suggestion is prompted by the fact that much of the high frequency breeding in this region (including western Senegal) occurs in areas where, according to the FAO/UNEP/UNESCO Provisional Map of Present Soil Degradation Rate, soil

Figure 1 (a)

Schematic Streamlines over the Desert Locust Invasion Area, Showing Examples of Wind Systems often Present during the Northern Winter

(Reproduced from the Desert Locust Forecasting Manual, Fig. 3.17 and .2, pp 76,77)

Key to wind systems often present on weather maps.



Principal northern winter 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 making the change at any given place from rising temperature ahead to falling temperatures behind.

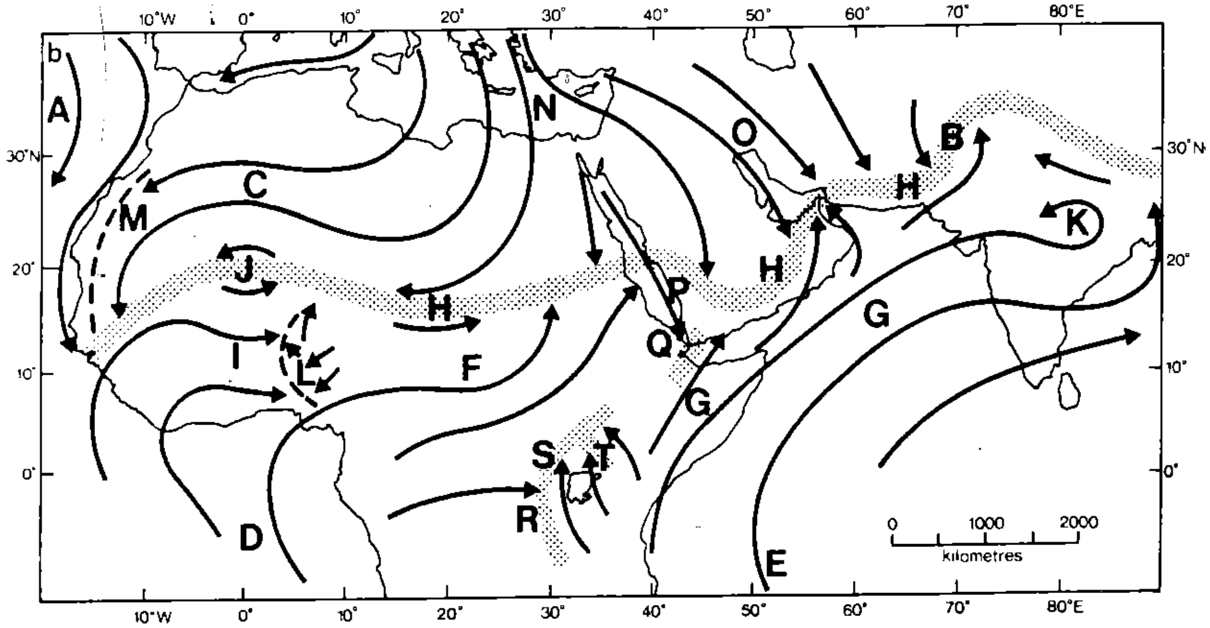
distortions due to highlands

- 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 Asia 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 Q 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 boundary) between U and F

Figure 1 (b)

Schematic Streamlines over the Desert Locust Invasion Area, Showing Examples of Wind Systems often Present during the Northern Summer (Reproduced from the Desert Locust Forecasting Manual, Fig. 3.17 and .2, pp 76,77)

Key to wind systems often present on weather maps.



Principal northern summer 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

degradation, especially due to wind erosion, is high. Thus the summer breeding belt corresponds to a well-defined climatic zone with its characteristic vegetation types. This coincidence is brought about by the dynamics of the Inter-Tropical Convergence Zone (ITCZ) along which swarms accumulate between May and July and, depending on their position within the ITCZ, and the position of the latter, may spread westwards under the influence of the tropical easterlies (the Harmattan) or eastwards under the influence of the monsoon winds (see Fig. 1b). However, the striking feature is that breeding only starts when the ITCZ reaches about 15°30-17°N in West Africa, usually around July, and not before, even though swarms may start arriving several weeks earlier (in 1995 for example). Meanwhile there is a tendency for an eastward spread of the swarms. The eastward displacement of swarms during April-July 1988 in Mali provides a particularly clear example of this occurrence. The first swarms arrived in early April, when some were reported in Kayes area; other arrivals followed on a wide front, extending to the Adrar des Iforas. Swarms continued their southward progression to reach the ITCZ, at that time positioned at about 13-14°N, then, transported by the monsoon, they began to move east; other swarms followed. With the advance of the ITCZ northwards, the position of the line of west to east progression also gradually shifted north, to reach 15°N in June. Throughout this time the swarms remained immature. It was not until they and the rains reached the 16th parallel in early July that maturation and laying began, first in the Yelimané-Nioro area, later in the month spreading to the Lakes zone of the central Niger delta and the Gourma. The timing and the distribution of breeding agree fairly closely with what was recorded during the 1939-63 plague period (Map 2a). On this evidence it seems that such climatic and environmental changes that might have taken place during the last 30 years have not substantially altered the pattern of reproduction in the summer breeding belt of Western Africa. Whether the second monsoon generation in 1988 an event considered to be uncommon during earlier plagues but according to Magor (personal communication) probably rather more frequent than formerly thought, or the extension of breeding into Guinea Bissau (unrecorded before) are exceptional or may become a regular feature of future plagues remains to be seen.

There is considerable variation in the extent and the distribution of breeding from one year to the next, reflecting the source, the timing, the biomass, the phase and thus the behaviour of the invading populations. The records published by the Organisation Commune de Lutte Antiacridienne (OCLA) for the period 1950-61 (FAO, 1962a) illustrate this clearly (Maps 4(a-d)). The 1950-61 plague in the Western Region followed a brief recession in 1948-49 and terminated with the onset of the major recession in 1961. During the initial build-up period in 1950-53, breeding was largely within the limits of what is now recognised as the recession area. As it further built-up in 1954 and 1955 the plague spread to the Sahelian belt and reached its peak in 1955-1959, then declined in 1960, with some swarms continuing to be present in the Sahelian belt until October 1960. Swarms disappeared in North-West Africa by March 1961, possibly as a result of control operations. The changes in distribution from year to year are such that no two years are the same; nevertheless, it is evident that some areas have a very much higher and more frequent incidence of breeding than others.

4.1.1.2 <u>Description of the Habitats</u>

4.1.1.2.1 <u>The Senegal River Valley</u>

Only rare isolated adults have been recorded from the Senegal River valley during recessions (Map 3a), but it is regularly invaded by swarms during plagues (Map 2a). Laying is frequent on both the Mauritanian and the Senegalese sides of the valley in open, less-wooded habitats, such as pastures and fallow fields. On the habitat map (Map 5a) this is shown as "Gallery forest and wooded grassland" but much of the landscape is anthropogenic, the woody cover having been cleared and replaced by semi-permanent cultivation and bush fallows. During the 12-year period 1950 to 1961, heavy breeding occurred in the western part of the valley in 6 years, including every year from 1957 to 1961.

4.1.1.2.2 The tall-grass savanna

The northern limit of the tall-grass savanna on deep sandy soils, i.e. in the absence of drainage, coincides with about 450 to 500 mm of rainfall. Rossetti (1965) placed it at 450 mm at Hombori (Mali), 440 mm in Kobenni and 350 mm at In-Tillit, but the limit has subsequently shifted southwards. Only limited relics of the savanna remain having been replaced, as a result of cutting and burning, by an annual grass and forb prairie with some remaining, largely fire-resistant, predominantly combretaceous trees and shrubs. On firmer luvisols and lithosols, under more pronounced relief and drainage, pockets of savanna may develop further north under lower rainfall (of as little as 350 mm) as for instance in the "brousse tigrée" on Dahr Néma (Audrey and Rossetti, 1962). Here a much wider range of plant communities may develop. However, the habitats in areas of higher rainfall (above 500 mm) which are associated with swarm laying are the more open communities resulting from increasing land use. Among them, pioneer communities of annual grasses and chamaeophytes which develop on land left fallow after cultivation, are overgrazed and trampled and have an abundance of bare patches are the most characteristic laying habitats. Conversely, the denser scrub and thickets that occur in this zone are avoided, as are the more humid low-lying marshlands. The frequency of breeding soon declines above the 500 mm isohyet.

4.1.1.2.3 The Sahel wooded grassland

This type of vegetation is found on sandy soils in areas with an annual rainfall of 250 to 500 mm. The most abundant woody species is *Acacia tortilis* but other species that are also important include: *Acacia laeta, Commiphora africana, Balanites aegyptiaca, Boscia senegalensis, Maerua crassifolia, Leptadenia pyrotechnica,* with a grass sward dominated by annuals such as *Cenchrus biflorus, Schoenefeldia gracilis, Aristida pallida (sieberana)* and *Tragus racemosus.* In the more heavily grazed areas *Boerhavia coccinea* and *Tribulus terrestris* become widespread. The woody cover is being reduced due to human interference, a situation which has been exacerbated by the prolonged and severe droughts of recent years.

The Sahelian zone between 250 and 500 mm rainfall corresponds to the main summer breeding belt during plagues; breeding is particularly frequent in the neighbourhood of major relief features, Assaba, Affolé, etc., where a wider range of habitats provide greater opportunities for breeding than the uniform sandy annual prairie where the distribution of breeding is more scattered and less frequent. During recessions locusts occur at very low densities in sandy habitats. Residual populations may persist in low numbers. There is marked association with presence of preferred food/shelter plants e.g. *Tribulus, Heliotropium, Moltkiopsis.*

4.1.1.2.4 Semi-desert and desert grasslands

Grasses becomes the dominant vegetation where the annual rainfall is less than 250 mm. On rocky outcrops and areas of sufficient moisture scattered small bushes are found. The woody species of the semi-desert grassland are similar to those that occur further south in the wooded grassland except here they are usually less than 2 m in height. The dominant grasses are the annual species that also occur further south, but *Panicum turgidum* and *Stipagrostis pungens* increase in abundance further north.

Patches of desert grassland extend as far south as the 250 mm isohyet and are found on the crests of the taller dunes. Here the perennial species *Panicum turgidum* and *Aristida sieberana* are the dominant species although *Cenchrus biflorus* often colonises the lower dune slopes and inter-dune hollows. In the drier areas, with approximately 100 mm a year, *Panicum turgidum* becomes dominant and woody species are absent. Where the dunes are more mobile *Stipagrostis pungens* gradually becomes dominant.

4.1.1.3 High frequency breeding areas

As Map 2a clearly shows, the distribution of breeding along the summer breeding belt is not uniform. In particular breeding is more frequent in the areas bordering major relief features. This can be ascribed to the wider range of suitable habitat conditions they provide and which remain suitable for longer periods than more uniform environments. One example is the northern margin of the broken plateau of Affolé which has accumulations of sandy soils, numerous wadis and a predominantly steppe and bushland vegetation comprising tussock grasses such as *Panicum turgidum, Lasiurus hirsutus, Aristida pallida, Cymbopogon schoenanthus,* annual grasses such as *Cenchrus biflorus, Aristida mutabilis, Eragrostis* sp., and numerous herbs including *Indigofera* sp., *Tephrosia* spp., *Boerhavia repens, Mollugo cerviana, Gisekia pharnacioides* together with some scattered *Acacia raddiana, Balanites aegyptiaca, Leptadenia pyrotechnica* and *Boscia senegalensis* and which provide a number of habitats of high ecological potential. The more arid borders of the Tagant and further north the borders of the Adrar, the hilly areas and wadis of Inchiri south of Akjoujt, and even the remote inselberg of Kediet Idjil all to some extent promote more frequent laying.

However, the highest frequency of breeding occurs along the lower part of the Senegal valley and in the sandy steppes and annual prairies of the lower Brakna to the north. Apart from the high ecological potential of this area, there is another factor which may contribute to the concentration of laying in this area. During the summer months, when breeding takes place, this area lies at the junction of the Inter-Tropical Convergence Zone (ITCZ) and the windshift line (trade front) between the cool trade winds around the sub-tropical anticyclone and the hot continental easterlies (the Harmattan) (see Fig.1b) thus creating a pocket where the swarms, arriving from their breeding grounds in the north, tend to accumulate. The changing orientation of ridge dunes and the presence of aklé ("fish-scale") dunes in this area, clearly shown on the 1:1 million map, seem to bear out this suggestion. The high frequency breeding area continues northwards to Inchiri and the Mauritanian Adrar, an area where the frequency of breeding is also high during recessions.

Further east the more important breeding areas are as follows:

- south-eastern Mauritania, the borders of Affolé and Hodh Gharbi (Hodh Chargui is probably under-reported);
- western parts of the Sahara, breeding not frequent but occasionally important (e.g. in 1987-88);

- in Mali the borderlands of the lakes in the central Niger delta; eastern Gourma along the Niger river (northern Gourma is probably under reported);

- the Adrar des Iforas with its network of valleys and the Tilemsi valley; Timetrine and Tamesna including southern Tamesna and the Azaouak valley are also probably part of this area (as in 1987-88). This complex is also a high frequency breeding area during recessions;

- in Niger, Air and Tamesna there are also high frequency breeding areas during recessions;

- the Tanout-Gouré, Termit and Dillia area (but not a high frequency and generally a low-density breeding area during recessions);

- in Chad, the Bahr el Ghazal valley, the northern border of Ouaddai, the Ennedi and Mortcha (breeding is much less frequent during recessions).

In Tibesti, breeding is infrequent, but occasionally important, more so during recessions.

There are multiple factors that potentially influence the frequency and the scale of breeding within the tropical breeding belt. The principal ones are: the wind that transports the locusts and may at times concentrate them in certain areas; the rain that creates the right breeding conditions; and the ecological characteristics of the areas that are particularly favourable and to which locusts respond.

The seasonal migration of swarms with prevailing winds into major areas of atmospheric convergence represent examples of concentration on a geographical scale. There are examples of further more local concentration. For instance, as discussed in more detail later, the high-frequency breeding in north-western Senegal and south-western Mauritania could result from concentration of swarms funnelled down from their spring breeding grounds in the Maghreb by tropical easterlies (the Harmattan) meeting the cool tradewinds around the Azores high pressure area along a windshift line situated inland and parallel to the coast.

The second major factor influencing the distribution of breeding is rainfall and the associated run-off. The spatio-temporal distribution of rainfall has a fundamental influence on the distribution of laying and therefore need to be monitored routinely as a guide to the location of the potential breeding areas. Otherwise in the summer breeding belt, the high frequency breeding areas are predominantly areas of relief and drainage which provide a particularly wide spectrum of breeding habitats and, between them, offer suitable laying conditions over a longer period of time. Thus, in the lakes area of Mali, the earlier laying (at the height of the rains) in humid conditions occurs on well-drained hill-sides and even the tops of the mesas, and on dune slopes, while later laying under drier conditions occurs in the more humid depressions. In the more arid areas receiving lower rainfall, drainage promotes the development of suitable habitats and this explains the occurrence of high frequency laying in the highland areas of the southern Sahara during both plagues and recessions. Conversely, breeding in the uniform sandy steppes of the northern Sahel is likely to be randomly scattered at an overall rather low density and, in the absence of pronounced drainage, is unlikely to be successful in areas of less than 200 mm mean annual rainfall, except in the event of exceptionally heavy rains.

4.1.2 The Spring breeding belt in North-West Africa (Maps 2(a-b)), 8(a-b1))

The chronology and the distribution of spring breeding during plagues strongly underlines the importance of landform, relief and the general characteristics of the habitats as well as of the weather conditions, the wind systems and temperatures described in the Desert Locust Forecasting Manual.

According to the 1939-63 plague period frequency maps, there are virtually no swarms in North-West Africa during September. Swarms originating in the summer breeding grounds of the Western Region, sometimes augmented by others from summer breeding grounds in the Central Region (and occasionally somewhat later by others from winter-spring breeding grounds in the western and southern Sahara), begin to arrive from October onwards, some crossing the Sahel directly, others skirting it to the west. Initially, during October, swarms occupy the south-western part of the breeding belt, north to latitude 33°N and east to longitude 2°W. During November, there is usually little further progression northwards by the most northerly swarms although the more southerly ones continue to move north, but there is a marked spread eastwards to reach Tripoli (15°E) a distance of some 1,500 km from the eastern limit in October.

During December to March there is a further expansion of swarm distribution eastwards and also northwards, but the frequency of swarm records in the coastal areas of the Mediterranean remains low until April. This spread is clearly revealed by the changes in maximum degree square frequencies for successive months in different areas. Thus, the maximum degree square frequencies in Morocco occur in January (15 and 16), in Algeria in February and March (10 and 11), in Tunisia in March (7) and in Libya in April (8 and 9); however, later in the season, increases in frequencies are due to the appearance of new generation swarms.

The chronology of occurrence and distribution of the hopper bands follows a similar sequence, allowing for an appropriate delay for maturation and egg development. The first bands are reported in February, but not in numbers until March, with the highest degree frequencies in Morocco (5) and Libya (3) but fewer in Algeria and Tunisia (1 and 2.). Hopper infestations become more widespread in April: maximum frequencies being 8 in Morocco, 6 in Algeria, 4 in Tunisia and 5 in Libya. The peak of infestation is in May, but frequencies already begin to decline in Morocco. In June the infestations are still very high, but now show a shift northwards towards the coastal areas of the Mediterranean; there is a general decline in July. From May onwards swarms of the new generation begin to leave the spring breeding grounds.

As explained in the DLFM, the northward and eastward movement of summer swarms into the spring breeding belt occurs against the prevailing tropical easterlies and is associated with southwest winds around the eastward-moving mid latitude depressions. On reaching the barrier of the Atlas Mountains, swarms tend to move eastwards south of the ranges; some may become trapped in cul-de-sacs like the Souss valley. The detailed plotting of the distribution of laying sites and hopper bands (Map 2a) shows them to be closely associated with major relief features and suggests that much of the displacement of swarms is channelled along the major valleys. Such routes provide easier access for swarms onto higher plateaux and also lead them towards drainage basins where swarms, especially on reaching maturity, split up and penetrate into the rainfed tributary valleys where laying takes place.

From south to north, and west to east, the principal areas where concentrated laying has been recorded are: the succession of wadis draining the Anti-Atlas range into the extensive Oued Draa valley, leading to the catchment basin of Oued Draa itself, at Ouarzazate. Beyond the Draa to the edge of the Grand Erg Occidental, there are several more wadis, including the important Oueds Daoura and Saoura where some of the earliest laying takes place. They are warmer but drier than the remainder of the area; the mean annual rainfall in the main Draa valley is little more than 100 mm although it is certainly higher in the headwaters of the valleys, and significantly laying is largely confined to the wadis which benefit from run-off. Nearly all the breeding is on the northern, Anti-Atlas, side of the Draa valley, with very little on its south side.

Another high frequency breeding area is along the coastal plain extending from Guelmime to Tiznit and beyond it to the Souss valley, where it spreads into several branches of the Souss basin.

The high watershed separates the breeding areas in the Souss basin from those in the Draa, while the High Atlas is a barrier between them and the extensive breeding grounds in the Essaouira-Marrakech basin and the coastal plain towards Rabat and Kenitra. This is the area with the highest frequency of breeding in Morocco. Breeding usually occurs during April and May, but may begin in March, perhaps by the early-arriving swarms recorded in October, while temperatures are still sufficiently high to allow the crossing of the High Atlas at its lower western extremity. There are pockets of high frequency breeding in the upper Sebou basin at Fez, Taza and Taounate, but not in lower Sebou, which is marshy.

There is relatively little breeding in Rif, but there is another high frequency area in north-eastern Morocco in the Moulouya basin and adjacent valleys, where, yet again, most of the breeding is along the sides and the tributaries (being especially high around Oujda) rather than in the main Moulouya valley.

Further east in Algeria, the pattern is fairly similar with more high-frequency areas in the wadis draining the Atlas Saharien, notably north-east of Bechar along the north-eastern tributaries of the Saoura (partly in Morocco). Another important and extensive high-frequency area is around Laghouat, extending south to Ghardaia, with another narrower belt along the slopes of the Nementcha hills north of the Chotts.

To the north of this belt lie the Hauts Plateaux, where breeding is almost entirely confined to their margins, perhaps because of the prevailing salinity of the soils, or because the swarms continue to follow the edge of the higher ground to the north and to the south of the plateaux. The highest incidence of laying along the coast is around and to the east of Algiers.

In northern and central Tunisia, where south of the northern coastal mountains and the escarpments the mountains break up into scattered, isolated ranges, the pattern of breeding is similarly scattered, without well-marked high frequency areas. However, south-eastern Tunisia marks the western end of the largest high frequency breeding area in North-West Africa which extends along the coastal range south of Medenine, then in an arc eastwards to Gefara and for some 400 km along the Libyan coast to Misurata. Hopper infestations are recorded over practically the whole of the coastal plain north of the Libyan plateau escarpment. Elsewhere in Libya, the remaining recorded breeding is sporadic and at low frequency; the most important is in the Mizdah area in northern Hamada El Hamra.

During recession periods, only the habitats at the two extremes of the northern part of the spring breeding belt, in Hamada El Hamra and the wadis draining towards the bay of Sirte, and the Oued Draa in Morocco (which forms the northernmost habitat in western Sahara) are known to be reached, albeit rarely. Only swarms, therefore, are known to breed in northern parts of the North African spring breeding grounds.

Laying occurs in a wide range of habitats, characteristically these are sandy wadis and steppes with shrubs and bushes such as *Retama and Artemisia,* for example in Gefara on the Libyan coast towards Sabratah, or the Alfa *(Stipa tenacissima)* steppes, over much of the less mountainous ground. In the higher rainfall areas the arable land is cultivated and much of the laying occurs in fallows and abandoned plots, and also on hillsides that are often stony and reserved for grazing. In extreme cases, eggs may be laid on rocky mountain sides, egg-pods being deposited in small pockets of soil amongst rocks.

Finally, the complexity and the difficulties of controlling breeding populations in this zone need to be stressed. The distribution of breeding is potentially subject to considerable variation, depending on the source areas of invading swarms, their biomass and the timing of their arrival. While the principal swarm invasion route through western parts of the Sahara and Morocco is potentially subject to greater and earlier risks than Algeria, Tunisia or Libya, there are, as described in the Desert Locust Forecasting Manual, many other possibilities that can only be revealed by synoptic analysis of the situation at the time. Similarly, the identity of the breeding areas among the many that potentially exist, can only be forecast on a very short-term basis. In view of this complexity and the logistical difficulties in tracking individual swarms and hopper bands in broken mountainous country, with the added consideration that much of the breeding occurs within, or in close proximity to crop areas, there is every incentive to control swarms as early as possible before they penetrate, split up and begin to breed in the mountains.

4.2 The Central Region (Maps 2(b,c,e))

The Central Region is dominated by major physiographic features: the eastern African and the western Arabian highlands separated and cleft by the Red Sea, the Gulf of Aden and the Ethiopian-East African rifts. These result in complex atmospheric circulations and rainfall patterns, which duly determine the spatio-temporal distribution of locust breeding.

In the northern part of the Region (the North-Central Region of DLFM: Chapter 6) breeding takes place in summer, winter and spring. The summer belt where swarms breed on rains falling south of ITCZ is a continuation of the summer breeding belt in the Western Region and runs through Sudan, Ethiopia, Eritrea and on the opposite side of the Red Sea, through southern Arabia (Maps 2b and c). The spring belt where breeding takes place on rains brought by eastward-moving mid latitude atmospheric disturbances, extends over the Middle East, over much of the Arabian Peninsula and along both sides of the Red Sea. Winter breeding occurs mainly in the Red Sea coastal areas of Sudan, Ethiopia, Eritrea and Arabia and to a lesser extent on the Gulf of Aden coast of Yemen on rains associated with the Red Sea convergence and eastward-moving disturbances. Due to the overlap between different rainfall regimes around the southern Red Sea and over southern Arabia, breeding can continue with scarcely any interruption, leading to a rapid production of several successive generations (DLFM: p. 125).

The weather and hence the movement and breeding of swarms in the southern part of the Region (Map 2c) are dominated by the seasonal movement of the ITCZ. The more rapid southward retreat of the ITCZ is associated with the Short Rains and breeding during October to January and its slower northward advance is associated with the Long Rains and breeding between March and July. The belts where breeding during the two seasons occurs largely coincide, but the spread and the chronology of the breeding follow a reversed sequence.

The breeding belts extend through eastern Africa from eastern and southern Ethiopia and Somalia south of the northern coastal escarpment to Kenya and northern Tanzania (Map 2e). Summer breeding during July to October may also occur along the southern flank of Ethiopian highlands in the Ethiopian Rift and in north-western Somalia, as an extension of the summer breeding belt further north. To the south summer breeding is restricted to parts of south-west Ethiopia, north-western Kenya around Lake Turkana and occasionally adjoining parts of Uganda and south east Sudan (Maps 2 c and e). In addition winter breeding also occurs on the northern coastal plains of northern Somalia. The breeding areas and habitats are discussed in the following order; Sudan and Ethiopia, the Somali peninsula and East Africa and finally Arabia and the Middle East

4.2.1 Sudan and Ethiopia

4.2.1.1 General

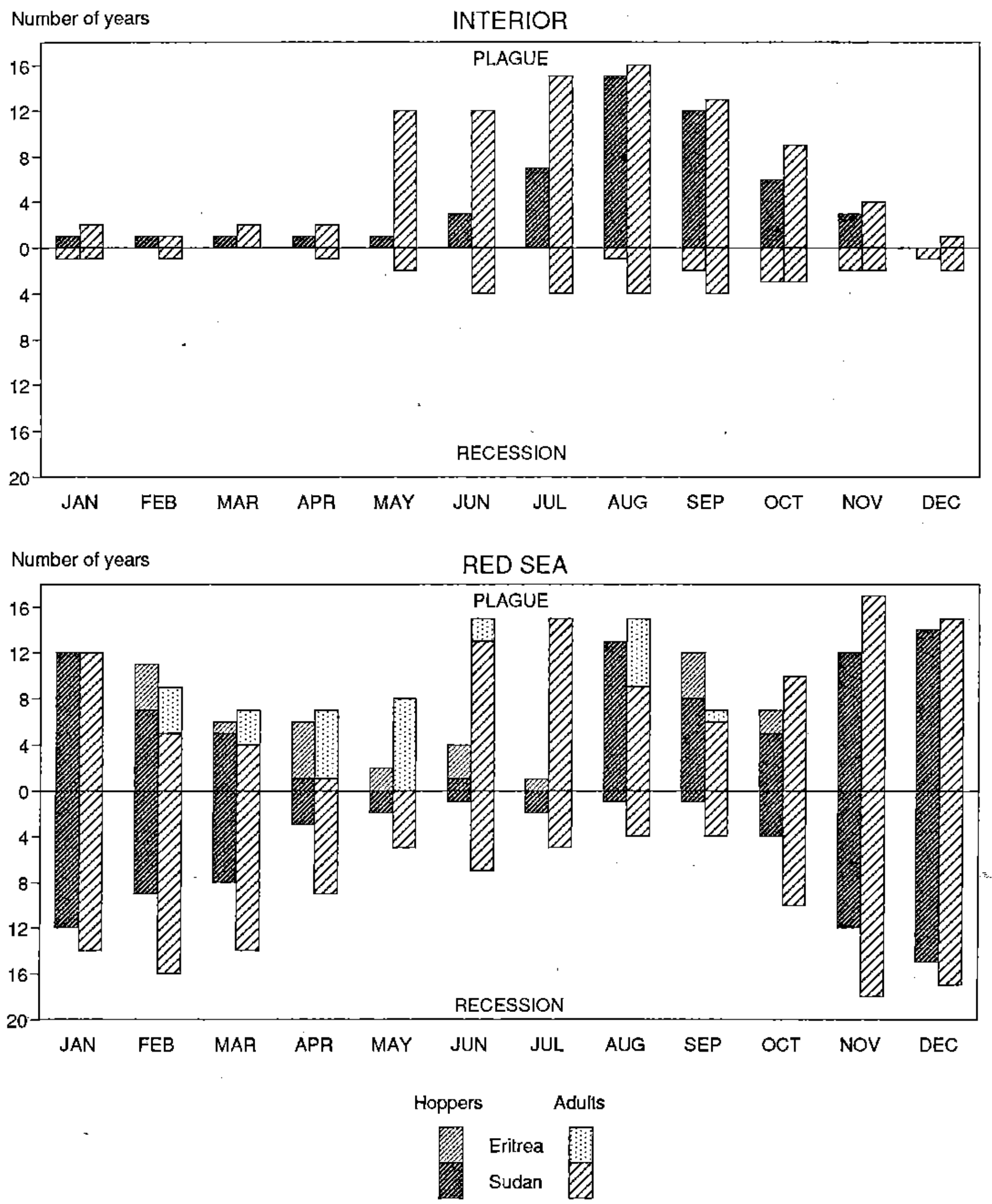
The maximum monthly degree square Desert Locust frequencies recorded in the interior and on the Red Sea coast of the Sudan during the 25 year plague period (1939-1963) and during the 20 year recession period (1964-1984, less 1968) are presented in Fig. 2. These indicate that while high frequency summer breeding occurs in the interior during plagues, it is much reduced during recessions, when it usually follows only after major breeding and swarm formation on the Red Sea coast. On the other hand breeding on the Red Sea coastal plains is frequent during both plagues and recessions and is highest in winter. Since the plague and recession breeding areas on the Red Sea coast coincide, and the ecological conditions and the choice of habitats are more critical during recessions and upsurges, the Red Sea habitats are discussed only under recessions, but the summer breeding belt in Sudan and Ethiopia and also the Short Rains and Long Rains belts in the Somali peninsula and Eastern Africa, which are largely free of locusts during recessions, are described under plagues.

4.2.1.2 The summer breeding belt (Maps 2(a-e); 10(a-d))

It is evident from Maps 2(a-e) that the summer breeding belt is continuous with the summer breeding belt in the Western Region and finds its greatest development both in extent and frequency of breeding in the Sudan and the adjoining parts of Eritrea (Maps 10a-d). This can be attributed to a combination of several factors: the higher frequency of reporting, the dynamics of swarm movements and the environmental conditions. The former is probably associated with the fact that Sudan has a larger rural population in the summer breeding areas than in the Western Region and it has large and long established plant protection and locust control organisations. The dynamics of swarm movements are probably an even more important element, since the swarms involved in breeding in this part of the summer belt may originate from several sources and thus tend to be more numerous and their presence more frequent than in the Western Region. The principal populations involved are: those produced in the spring breeding areas of the Central Region; the spring generation swarms from the Western Region which at times continue to move east to reach the Sudan (as for instance in 1988); and the Long Rains generation swarms produced in the southern part of the Central Region (see section 4.2.3). The third set of factors: winds, weather, geomorphology and habitat conditions enhance the

Figure 2

Maximum Monthly Degree Frequencies During Plagues (1939-1964) and Recessions (1964-1987, less 1968, 1978) in Sudan and Eritrea)



* *Shown when frequency exceeds that in Sudan*

frequency and success of breeding in this sector. From the Sudan-Chad border eastwards through Darfur and Kordofan, the summer breeding belt extends between 13°N and 17°N latitude with the highest breeding frequencies recorded between 14° and 16°N, or roughly between the 200 mm and 400 mm annual isohyets. The individual high frequency areas are not well-defined, and the records tend to be grouped in small clusters around individual localities such as Kutum, El Fasher, Sodiri, and are therefore almost certainly an artefact of reporting. But on a larger scale it is possible to associate the more frequent breeding with some of the major geomorphological features in northern Darfur notably the dissected plateau of Dar Zaghawa, and the outlying Teiga Plateau and the Meidob hills, an area resembling the Ouaddaï of Chad, a landscape of hills, low dissected plateaux and mesas with accumulations of sand and more or less extensive intervening gravelly and sandy plans dissected by wadis. The vegetation varies from scrubland with *Acacia* and *Combretum* species dominant, together with *Balanites aegyptiaca, Commiphora* spp. and the smaller *Maytenus senegalensis* and *Boscia senegalensis,* with the associated undergrowth of bushes and annual and perennial herbs and grasses, in short a vegetation characteristic of the Sahelian zone described for the Western Region (Section 4.1.1.2.3). Here also the principal breeding habitats are in sandy areas around the major relief features which benefit from drainage. Further north are extensive alluvial plains traversed by Wadi Hawar. Following rains annual vegetation much valued for grazing and termed "gizzu" develops here; it includes such food/shelter plants as *Colocynthis, Tribulus* and *Schouwia* and could be expected to constitute an important locust habitat. Indeed locusts have been recorded here in the past (Maxwell-Darling, 1936) but the recorded frequency is low, probably because this remote area is surveyed so infrequently.

Further east the frequency is high through the Goz dune country of Kordofan and particularly along the valleys of Wadi el Milk and Wadi Er Ril north of Sodiri. Much of the country consists of open rolling sandy plains under millet cultivation with secondary scrub and annual vegetation. *Calotropis procera* and *Cenchrus biflorus* are the two dominants.

East of 30°E the belt expands abruptly northwards to 19°N to include the Hassaniya-Bayuda area in the bend of the Nile. The frequency is particularly high for some distance on both sides of the Nile valley with a maximum of 15 during the 25 year (1939-63) period in the Shendi area. The habitats here are mostly anthropogenic, consisting of fields and communities of weeds in fallows, abandoned land and heavily grazed pastures and barren gravel and clay pans with local dune formations such as the Qoz abu Dulu. Given adequate rain the sandier parts and especially the drainage network of wadis provide suitable breeding conditions, in that many of the weeds and the plants such as *Aerva javanica, Heliotropium* spp., *Dipterygium glaucum, Cassia* spp., *Tephrosia apollinea, Solanum* spp and *Datura* spp., are of low palatability to livestock but are suitable food/shelter plants for locusts. The irrigated land around the periphery of the fields is an added attraction to laying swarms, particularly under low moisture conditions.

East of the Nile valley lie extensive plains of hydromorphic clays that are the northern extension of the Butana. Much of the substrate consists of packed clays with or without a covering of coarser sands, gravels and stones, and do not constitute suitable Desert Locust habitats. High frequency laying is concentrated along the main river valleys, the Atbara and the Gash and especially in their deltas, where fluvial silts and sands accumulate and are often blown into barkhans and drifts under vegetation. Both rivers are important crop growing areas of mainly cotton, sorghum, millet and to a lesser extent groundnuts and vegetables. Laying occurs in the fallows around the fields and the adjoining pastures and wastelands which usually support some small trees, bushes and shrubs such as *Acacia tortilis, A. ehrenbergiana, Capparis decidua, Salvadora persica* and, locally *Acacia seyal* and *Hyphaene thebaica,* and particularly the mesquite *Prosopis glandulosa* (syn. *Prosopis juliflora)* with an undergrowth of the smaller *Indigofera spinosa, I. oblongifolia, Cassia* spp. and *Pulicaria crispa*. The breeding belt continues eastwards to the foothills and on to the watershed extending roughly from 14° to 19°N with the frequency being highest between 15-16°N. Here it extends southwards into the Eritrean highlands, but while in Eritrea breeding continues to be frequent and widespread, further south in Ethiopia breeding is largely confined to the Ethiopian and the Danakil rifts and is rare on the main Ethiopian plateau (Maps 10a-d). Frequencies gradually decline southwards but are still high in the railway area between Dire Dawa and Awashü. South of latitude 10°N breeding is more frequent during the Long Rains (March to June) and is continuous with the Long Rains breeding in Somalia.

In the inland plains and valleys of the Red Sea mountains of the Sudan, the breeding habitats are principally along the wadis and their tributaries where finer soils accumulate. The dominant community over much of the area is *A. tortilis-Panicum turgidum*, often with addition of *Capparis decidua, Calotropis procera, Salvadora persica, Boscia senegalensis, Maerua crassifolia, Cadaba* spp. while the undergrowth includes *Lasiurus hirsutus, Eleusine compressa, Cassia* spp., *Aerva javanica, Indigofera spinosa, I. oblongifolia, Dipterygium glaucum* and *Chrozophora brocchiana* and locally *Schouwia thebaica.*

The frequency Map (2c) suggests that the Musmar area is particularly important but this may be the result of more frequent recording along the railway and the major road linking Port Sudan with Atbara.

The frequency of breeding on the Eritrean plateau, where much of the land is below 1500 m, continues to be high with the highest frequencies close to the Keren-Barentu-Tessenei road (here again frequent communication along the main road probably enhances the frequency of reporting). The landscape over much of the terrain is of sandy and gravelly lateritic plains with scattered hills and mesas. Parts are cultivated, the remainder is a sparse xerophilous woodland, subject to much cutting for domestic use. The principal elements are *Acacia* spp., *Salvadora persica, Boscia* spp., *Commiphora* spp., *Cadaba* spp.; the undergrowth is dominated by plants favoured by grazing, among them species belonging to the genera *Cissus, Aloe, Cassia, Aerva Hypoestes, Cucumis, Hibiscus* , and *Pulicaria*. In the Sudan, summer breeding has not been recorded in the eastern foothills and is rare on the Red Sea coast but in Eritrea summer breeding is fairly frequent particularly in the foothills, especially south of latitude 16°N.

In Ethiopia the frequency of breeding is generally low on the plateau and practically unrecorded at high altitudes. This is clearly evident from Map 2c and Map 10b which show that the distribution of breeding is closely associated with the major relief features and is much more frequent in lowlands, particularly along the eastern flank of the Ethiopian plateau along longitude 40°E and also to a somewhat lesser extent to the west of it in the Takazze valley. But the highest breeding frequency is in the Railway Area between Djibouti and Awash, which follows the Ethiopian Rift, where it is high during both summer breeding season (August-September) and the Long Rains breeding season (April-June). The following factors are likely contributors to this high frequency: the major relief formed by the plateau and the rift in canalising swarm movements and enhancing rainfall and moisture conditions; suitable breeding conditions ensured by the abundance of sandy soils, good drainage and scrub and steppe vegetation (similar to that described for Eritrea above), and good reporting along much frequented routes. On the other hand, the Danakil depression away from major routes is likely to be under reported.

4.2.2 Somali Peninsula and East Africa

4.2.2.1 The Short and Long Rains breeding belt

In late September-early October, long rains generation swarms which remain concentrated in northern Somalia without breeding in July and August, together with swarms of the summer generation invading the Region, begin to spread south and south-west over the Somali Peninsula and East Africa and mature and lay. The hopper frequency maps for 1939-63 period show (Map 2c) there are practically no records of hoppers in August or September, but by October, breeding occurs in a belt located mainly between 9° and 4°N with the highest frequencies (5) in the Ogaden area of Eastern Ethiopia. During November the breeding area extends rapidly south-westwards to reach northern Tanzania and attain their highest frequencies of 12 and 13 in several areas, notably the Ogaden and the adjoining Mudugh Province and the Webi Shebeli and Juba areas of Somalia with much of the intervening parts between 9° and 2°N having high frequencies of around 8 to 11. During December the highest frequency declines to 10 in Juba but there is a further spread of breeding into Tanzania, albeit at low frequencies. During January there is a further decline to 6 in the River Tana area of Kenya with only infrequent reports of hoppers during February in Kenya and Tanzania and none in Somalia and Ethiopia except for winter breeding in coastal areas of the Gulf of Aden.

The newly formed swarms of the Short Rains generation become the main source of the ensuing Long Rains breeding during March to June or July. Before the start of the northward advance of ITCZ and the associated rainfall and breeding there is a tendency for the swarms to move west so that the distribution of high frequency Long Rains breeding is located somewhat to the west of that during the Short Rains. Another reason is probably because the distribution of rainfall generally declines from west to east. The breeding frequencies are high in May and June reaching 10 to 12 in the Haud and the Railway area of eastern Ethiopia, but are also generally high at the level of 7 and 8 in a wide belt extending north of 6°N westwards to 42°E and eastwards to 47°E and in places to 51°E.

From Map 2e, the distribution of breeding is on the whole rather uniform but some clustering and grouping is evident. This is particularly marked in north-eastern Somalia north of 9°N where Short Rains breeding frequencies are low but are higher during the Long Rains when the most pronounced clustering is along the Daror depression at approximately 10°N, 50°E. According to Hemming (1973) conglomerates and alluvial deposits with local accumulations of sand form the floor of the depression. Vegetation grows more abundantly on the sand and characteristically consists of the low tussock grasses *Dactyloctenium robecchii* and the less common *Chysopogon aucheri* with small bushes and shrubs such as *Iphiona rotundifolia, Euphorbia cuneata* and *Jatropha villosa.*

Over much of the remainder of the eastern lowlands of northern Somalia soils are gypseous, stony, occasionally saline; vegetation is sparse and conditions are mostly unsuitable for breeding. They improve south of the 9°N and particularly the 8°N parallel, south of which frequencies increase and records of breeding become more uniformly distributed. This coincides with a vast area termed by Hemming (1966, 1973) as the Haud-type mixed bush (roughly equivalent to the "broken xerophilous open woodland" of Pichi-Sermolli, 1957), which extends from the Haud proper (an area located partly in the south western area of northern Somalia and partly in the adjoining area of Ogaden of Ethiopia) southwards through Ogaden, much of Somalia, to northern Kenya. The characteristics of the Haud lie in the nature of its soil, calcareous reddish loamy sands with a high clay fraction, thus being both absorbent and retentive of moisture and in the generally flat nature of the terrain; as a result rainwater is soon absorbed or forms temporary generally small seasonal ponds or ballehs, and there is no incised drainage system. The two rivers that traverse this area both have their source in the highlands of Ethiopia. The annual rainfall ranges from 300 mm in the west to 150 mm in the east. Environmental conditions in the Haud are very uniform.

The vegetation of the Haud is extremely rich and varied, with numerous species attaining local dominance (Hemming, 1966). However, physiognomically the vegetation is fairly uniform. It is essentially woody and the principal species are shrubs 1-5 m high with occasional trees to 10 m. Most of the area is wooded but there are also treeless areas (bans).

The predominant vegetation type is *Acacia-Commiphora* bush with numerous species, particularly in the latter genus; included is a scatter of taller trees consisting usually of *Acacia tortilis, Albizzia anthelmintica, Delonix elata, Gyrocarpus hababensis,* and a lower shrub layer with species of *Grewia, Cadaba, Jatropha,* and the smaller *Melhania, Iphiona, Indigofera, Solanum* and numerous other chamaeophytes and. Among perennial grasses Hemming (1966) cites *Chrysopogon aucheri* as the most important and generally distributed tussock grass species with *Aristida kelleri, Cenchrus ciliaris and Latipes senegalensis* second in importance.

Under comparable conditions of grazing pressure the reduction of rainfall in the Haud from west to east is paralleled in a reduction in height and density of the *Acacia-Commiphora* bush and it is also paralleled in a reduction in the frequency of breeding which otherwise conforms in its uniformity of distribution with the uniformity of the habitat.

In recent years as a result of drought and pressure of grazing and cutting for domestic uses, large areas are now treeless (J. Roffey, personal communication), it remains to be seen what repercussions such environmental changes could have on the distribution of breeding in the event of future plagues, but it can be predicted on the basis of similar experience elsewhere that given adequate rain and a survival of ground vegetation the disappearance of trees and shrubs alone is unlikely to result in a marked decline of the ecological potential of the habitat for locusts and might even to some extent improve it.

Further south in Kenya the frequency of breeding is much higher in the north-eastern lower, drier and sandier part of the country and along the Rift valley where the environmental conditions are similar to the Haud, than in the highlands, and the more forested southern and coastal parts (compare Maps 13a and 13c). Coincidence of the distribution of breeding with the major soil types (viz. Maps 13c and 13d) also shows agreement in general terms in that the bulk of the breeding occurs in the extensive area of sandy soils in north-eastern Kenya. Long Rains breeding during April-May shows a greater southward and westward extension than the Short Rains breeding during December-January, and is particularly important in the area around Lake Turkana, where breeding may also occur in summer during August-September, when it can extend into adjacent parts of southern Sudan and Ethiopia.

Turkana is the best example of an area where the excellence of the habitat is not reciprocated by a high breeding frequency during plagues and a continued presence during recessions. Turkana is a vast sandy plain which forms the western part of the Lake Turkana basin; it is bounded to the west by the Karamoja plateau of Uganda and is traversed by numerous seasonal water courses draining towards the lake. The average annual rainfall is under 200 mm, distributed over three more or less distinct rainy seasons. Swarm breeding is fairly frequent during plagues with production of two and on occasions three generations per year. The vegetation is typically "Sahelo-Saharan" in aspect with many identical or closely related elements such as *Salvadora persica, Panicum turgidum, Maerua crassifolia, Boscia* sp., *Heliotropium* spp., *Acacia* spp., etc. (Hemming and Trapnell, 1957; Popov, 1958). On ecological grounds it is indeed very difficult to find any valid reason why the Desert Locust should not become established there in numbers particularly as some of the larger Acridids, which frequently share the same habitat *(Cyrtacanthacris, Anacridium, Truxalis, Locusta)* appear to do very well. Yet apparently *Schistocerca* fails to do this. Thus, according to Johnston and Buxton (1949), the solitary phase of the Desert Locust was present in considerable numbers throughout northern Turkana in 1930. These were probably the progeny of swarms which had been entering the area at intervals since early 1928. When this area was visited during the early months of 1934, only a single specimen of the species, which exhibited morphometrics of extreme solitaria was recorded. None were found in a certain area where they had been particularly abundant in 1930, though a small population of *Locusta* was found there.

The most plausible explanation of this puzzling phenomenon lies in the inherent mobility of *Schistocerca* and the relative isolation of Turkana from other similar semi-desert areas. Thus solitarious individuals, once airborne, would sooner or later be likely to be carried outside Turkana into surrounding dense "bush" country where the chances of survival would be slight and the likelihood of a subsequent return and repopulation of Turkana remote. Their absence would thus have nothing to do with whether Turkana *per se* is suitable or unsuitable for their survival. The implication of this argument is that the importance of a Desert Locust habitat depends not only on its ecology, but also to a great extent on its geographical position in relation to other areas with which it could form a migratory circuit permitting a seasonal exchange of populations.

It thus follows that the maintenance of locust populations depends on migrations between seasonal breeding areas. The geographical position of these areas in relation to each other and the wind systems linking them together is of paramount importance for on this depends the success or failure of locusts to find the next seasonal breeding habitat. If and when outbreaks occur, the process usually involves several successive stages and a number of geographically distant areas - a process discussed in relation to plague upsurges in Chapter 5.

4.2.3 Arabia and the Middle East

4.2.3.1 General

An appraisal of the chronology and the scale of locust breeding and occurrence of adults during plagues and recessions is made in Fig. 3, by a comparison of maximum monthly degree frequencies for the Red Sea coast, the interior of Saudi Arabia and also for the Yemen. This shows that during plagues there is a well-defined spring breeding season in the interior of Arabia; swarms appear in December, and increase during January and February; some breeding may already begin at this time, but does not reach its full scale until March and then remains high until May, declining rapidly in

June, with swarms of the new generation in turn declining during the following month. The presence of swarms and bands at other times is infrequent. On the Red Sea coast breeding is at its height in winter-spring from December to March, declines during April-July, then increases somewhat during August to November. In Yemen the frequency of breeding is highest during August and September, but remains fairly frequent in other months, the lowest breeding frequency is during March to July. Taking the coastal areas of the Red Sea and the Gulf of Aden (the RSGA area) as a whole, medium to high frequency breeding has occurred during plagues in every month as a result of the overlapping rainfall regimes in this area and the mild winter.

To recapitulate, there are three major breeding areas during plague periods in Arabia:

(a) the winter-early spring breeding in the Red Sea - Gulf of Aden (RSGA) area which is contemporary with the breeding on the African side;

(b) the main spring breeding in the interior which involves much of the Middle East up to latitude 40°N; and

(c) summer breeding in south-west Arabia, which is an extension of the summer breeding belt across Africa.

Breeding during all three seasons is recorded in Oman albeit less frequently and even more rarely along the intervening southern coast of Arabia which is probably under-reported.

Winter-early spring and summer breeding occur during both plagues and recessions in much the same areas and habitats and to avoid repetition are discussed under recessions (Section 5.5). The main spring breeding belt is discussed below.

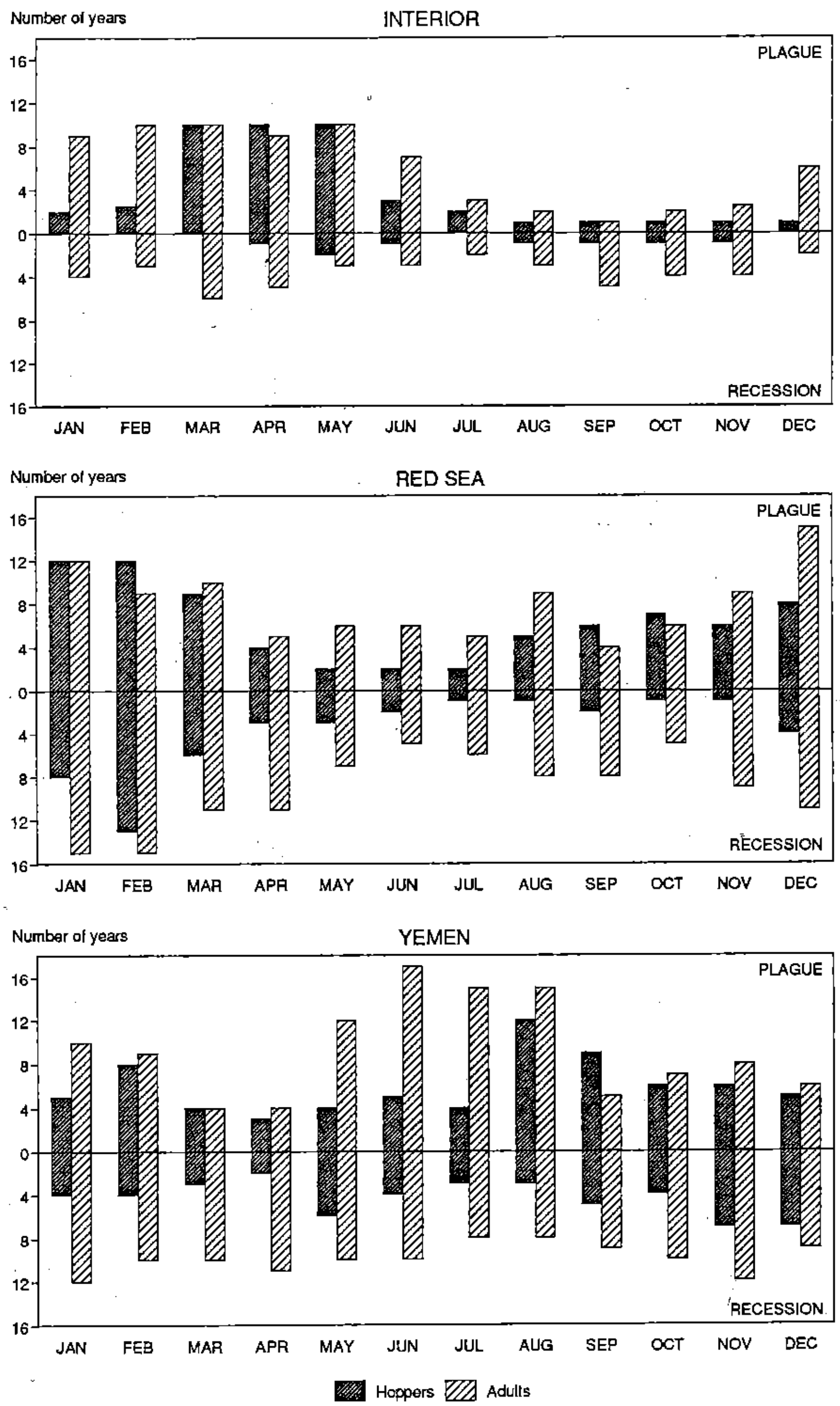
4.2.3.2 The main spring breeding belt

Much of the interior of Arabia is arid and the distribution of breeding coincides closely with the areas of higher rainfall, relief and drainage. These are also areas of denser human settlement and indeed the breeding frequency (Map 2c) shows a striking coincidence with human population distribution. This suggests that frequency figures are likely to be influenced by this factor. Temperature is another factor which influences the distribution of breeding, which starts in western and central Arabia in February, increases in area in March, reaching Jordan and southern Iraq, and by April-May much of the remainder of the spring breeding belt, which at the height of a plague may extend to south-eastern Turkey.

In relation to physiographic features high frequency spring breeding in the interior of Arabia occurs along the inland slopes of the Asir and Hejaz mountains and in the Steppes of Nejd, particularly in proximity to relief features and drainage. Popov and Zeller (1963) describe the common locust habitats in northern Hejaz as sandy wadis with scattered trees and shrubs, mainly *Acacia* and *Lycium* species and a steppe vegetation of semi-halophytic bushes and tussock grasses, principally *Hammada elegans, Haloxylon persicum, Salsola* spp., *Siedlitzia rosmarinus* and the tussock grasses *Panicum turgidum, Lasiurus hirsutus* and *Cymbopogon schoenanthus,* together with various therophytes and geophytes belonging principally to the genera *Fagonia, Plantago, Lotus, Medicago, Colocynthis* and *Heliotropium.*

Figure 3

Maximum Monthly Degree Frequencies During Plagues (1939-1963) and Recessions (1964-1987, less 1968, 1978) in Arabia



The interior of Arabia away from plantations is largely treeless and the breeding habitats are principally sandy or silty steppes; drainage is again an important element but due to slight gradients, wadis are shallow and spreading, some like Wadi Rimah and Sirhan are broad valleys where flood waters tend to stagnate. Soils are generally a mosaic of gravels, sands and silt and salinity is often evident. The vegetation is frequently rich consisting of dwarf shrubs such as *Lycium* and occasionally stunted *Acacia* spp. but most elements are chamaeophytes, geophytes and therophytes. There are numerous plant communities reflecting the diversity of soil and moisture conditions. The principal ones are described by Vesey Fitzgerald (1957a and 1957b) and, with special reference to Desert Locust oviposition habitats, by Popov and Zeller (1963). On the basis of the study of 23 egg-fields the latter concluded that in gravelly terrain the plant community with the highest preference rating was the *Hammada elegans -Helianthemum lippii* community (common associates *Plantago* spp., *Polycarpaea repens, Triraphis pumilium*). In sandy terrain, it was the *Hammada elegans -Ephedra alata* community, usually associated with *Plantago cylindrica - Medicago aschersoniana* and on silty terrain with the *Hammada elegans-Ferula* sp. community. Physiognomically most of the laying habitats were often steppe communities of dwarf shrubs, woody herbs and tussock grasses and more rarely communities of geophytes and therophytes. In general no absolute preference for any particular plant community was detected, the community with the highest record of laying being also the one with the highest area distribution. There was, however, a marked tendency for laying to occur along the transition zone (ecotone) between two or more communities. There was also some evidence of the importance of croplands as potential breeding habitats. In particular, borderlands of irrigated crops can be particularly attractive in otherwise dry conditions. Further examples of this were seen in early spring 1989 when following a swarm invasion of Arabia during the preceding December, the residual locust populations were found sheltering in crops in many localities in northern and eastern provinces. In particular breeding, albeit by a small residual population, was observed along the field margins in the Wadi Dawasir area

North of the Arabian Peninsula, high frequency spring breeding areas occur along the Wadi Aqaba - the Dead Sea rift; in Mesopotamia of Iraq where breeding occurs during April; and along the Euphrates valley in Syria in May, extending higher up the valley and its tributaries into Turkey in May and June. This pattern of distribution again shows the coincidence of the main breeding with the alluvial soils of valleys and plains and the main drainage systems since these are also the main agricultural areas this highlights their vulnerability to locust attack in the event of a plague. As elsewhere, the potential breeding habitats are not so much within the fields, as along their margins and in fallows colonised by communities of weeds. Other breeding habitats are pastures outside the crops in valleys and hillsides supporting a steppe vegetation, either uniform or more often patchy, comprising dwarf woody shrubs, bushes, tussock grasses and various annuals on lighter soils ranging from loams to sands and gravels, but excluding compact and especially saline silts and clays. Such habitats are common in the Middle East and indeed, under pressure of grazing, are on the increase.

4.3 The Eastern Region (Map 2d)

4.3.1 General

The Eastern Region forms the eastern part of the distribution area of the Desert Locust, and is situated east of the western border of Iran.

The main physiographic features of the Region are: the Himalayas which extend west as the Hindu Kush in Afghanistan and form the north-eastern border of the region: the system of lower ranges rising to 2000-3000 m enclosing several large basins which occupy Iran, most of Afghanistan and western Pakistan, the major river basins of the Indus and the Ganges which enclose the great plains of northern India, the lowlands of Khuzistan in south-western Iran and the lowlands of Turkmenistan and Uzbekistan which are reached by swarms very rarely.

The weather systems which dominate the region are similar to those in the Western Region (DLFM 5.3). In winter the region is dominated by eastward-moving mid latitude disturbances which bring rain principally to the western part of the region during November to April and, in the summer by the ITCZ, which brings monsoon rain, principally to the eastern part of the region between June and September. There is thus one rainy season in Iran and Afghanistan, in winter-spring; one rainy season in south-eastern Pakistan and northern India, during the monsoon, and two rainy seasons in western and northern Pakistan and in northern India.

4.3.2 Seasonal distribution of breeding during plagues and recessions

On the basis of the seasonal distribution of rainfall (Fig. 4 (a-d)) and of breeding, three major breeding belts and seasons are identified:

(a) The monsoon breeding belt covering eastern Pakistan and north-western India, where breeding occurs from July to early November;

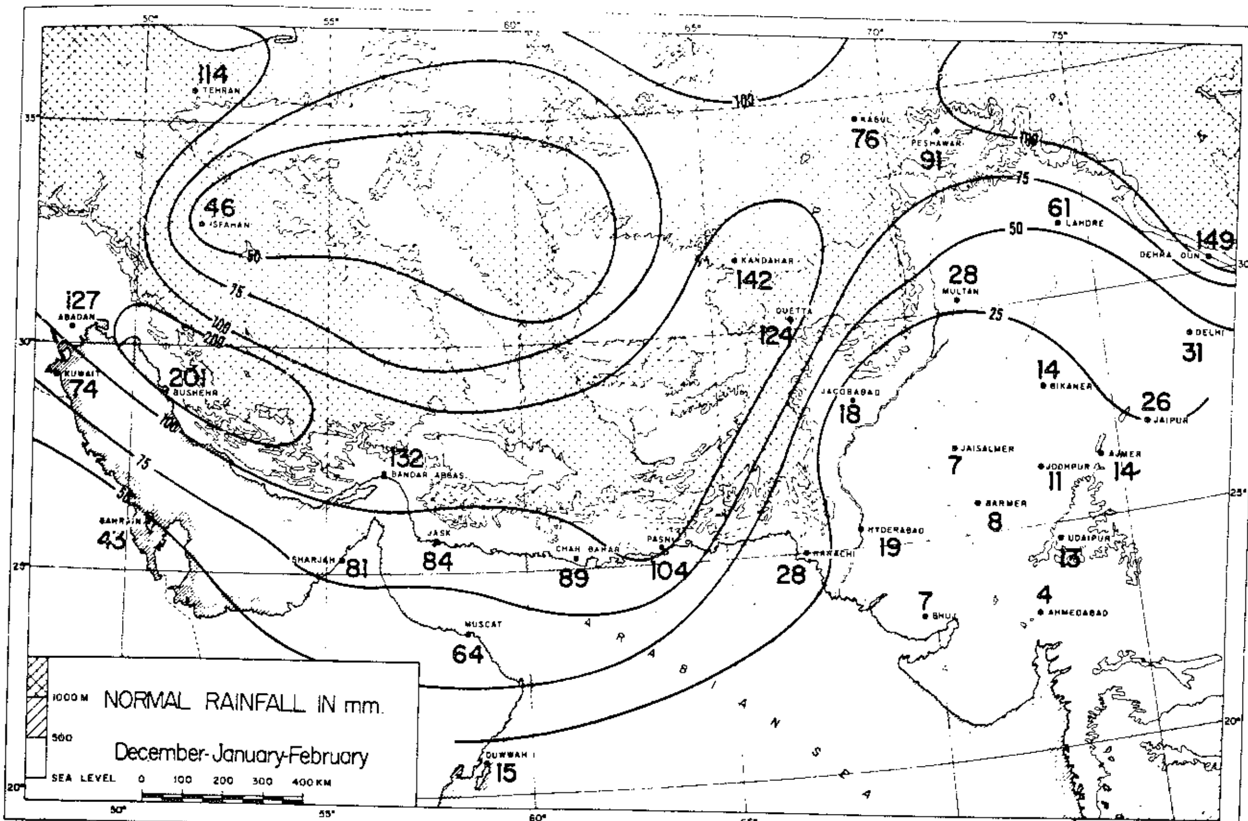
(b) The winter-early spring breeding belt on rains brought by eastward moving depressions which occurs in a relatively narrow belt stretching from southern Iran and Makran, where it usually starts in February to Punjab and northern India, where it can start as early as November;

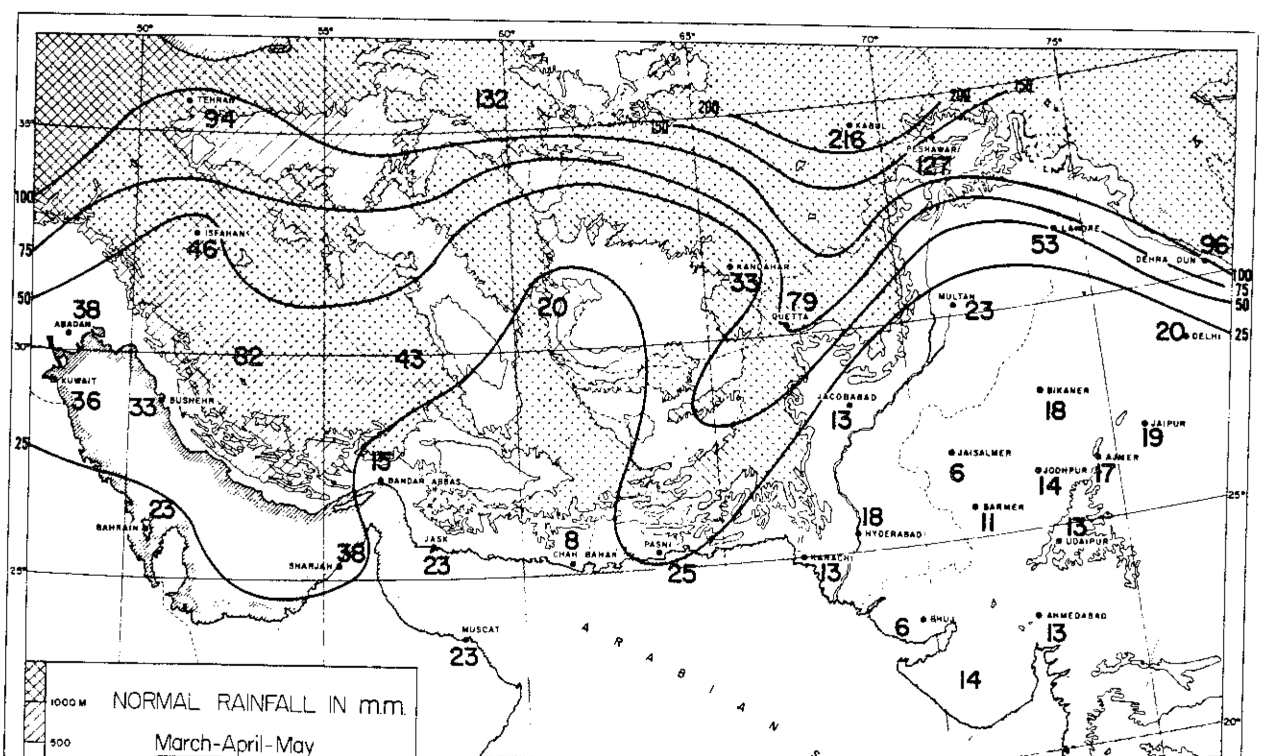
(c) The main spring breeding belt also on rains brought by eastward moving depressions which involves a large area covering most of Iran, Pakistan, northern India, southern Afghanistan and occasionally Central Asia during spring and the early summer months; only the warmer southern margin of this area is reached by recession populations.

While some parts of the Region have a single breeding season, others have two or even three. Thus the south-eastern part of the monsoon breeding belt has a single monsoon breeding season although in the event of prolonged rains two or even three generations may be produced. The main spring breeding belt in central Iran and Afghanistan also has a single breeding season. In southern Iran and Makran on the other hand, where winter temperatures are higher, a winter-spring generation may be produced in addition to the main spring generation. In northern Pakistan and north-western India where the rainfall regimes overlap, breeding may occur in all three breeding seasons.

Figure 4(a-b)

Normal Rainfall during December-May in the Eastern Region (Popov et al 1965)

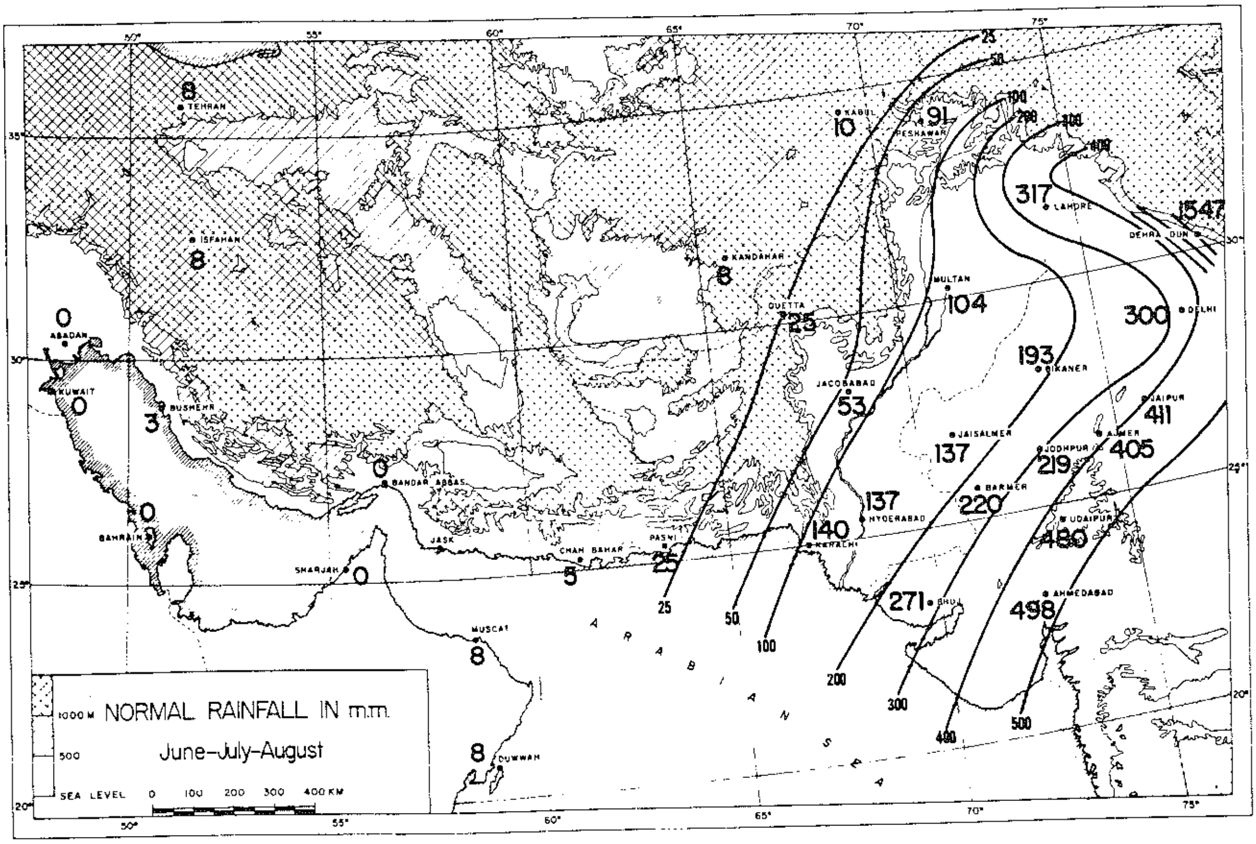


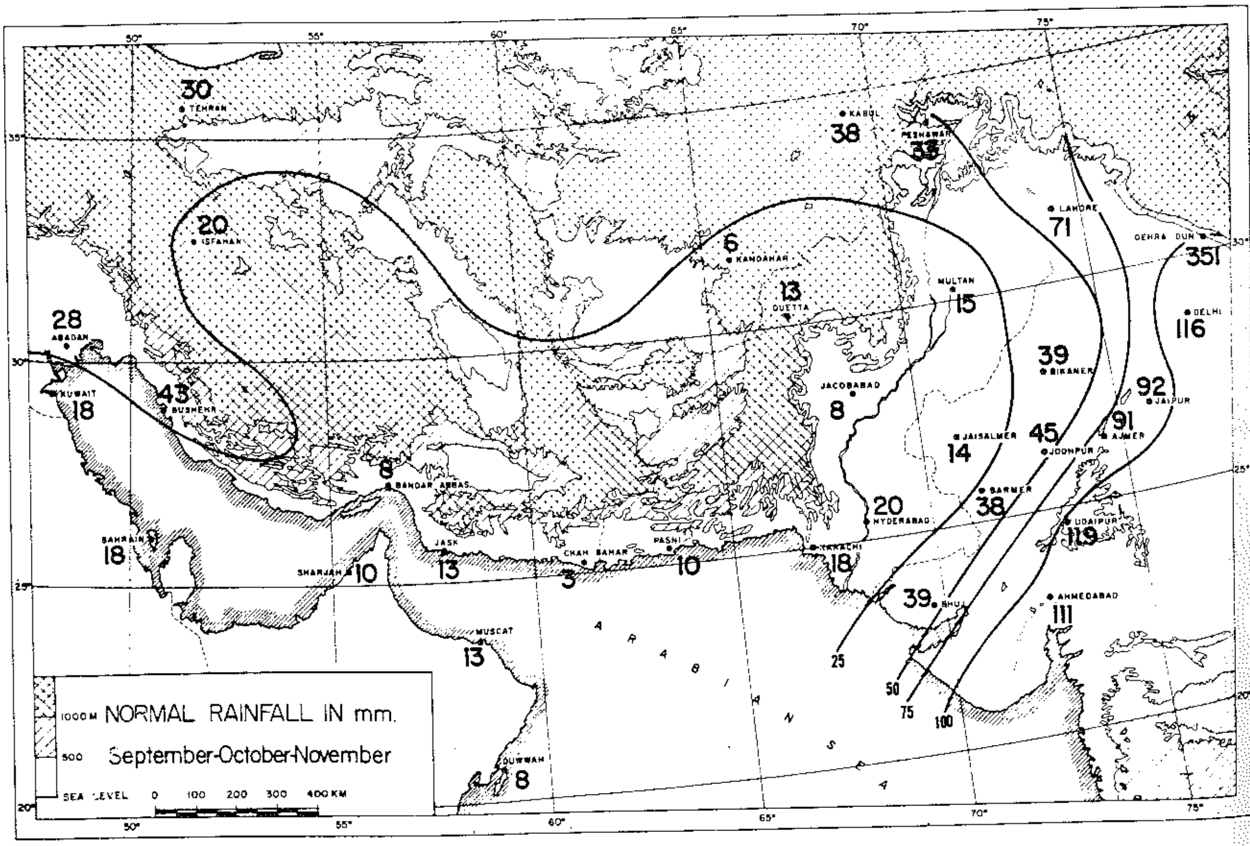


Seasonal rainfall over the area. In winter the northern westerly depressions affect the Persian Gulf, western Makran and the Asiatic land mass. In the spring the rainy zone has moved north in the west and intensified in the north-east; the Persian Gulf, Sind and Rajasthan areas remaining dry.

Figure 4(c-d)

Normal Rainfall During June-November in the Eastern Region (Popov et al 1965)

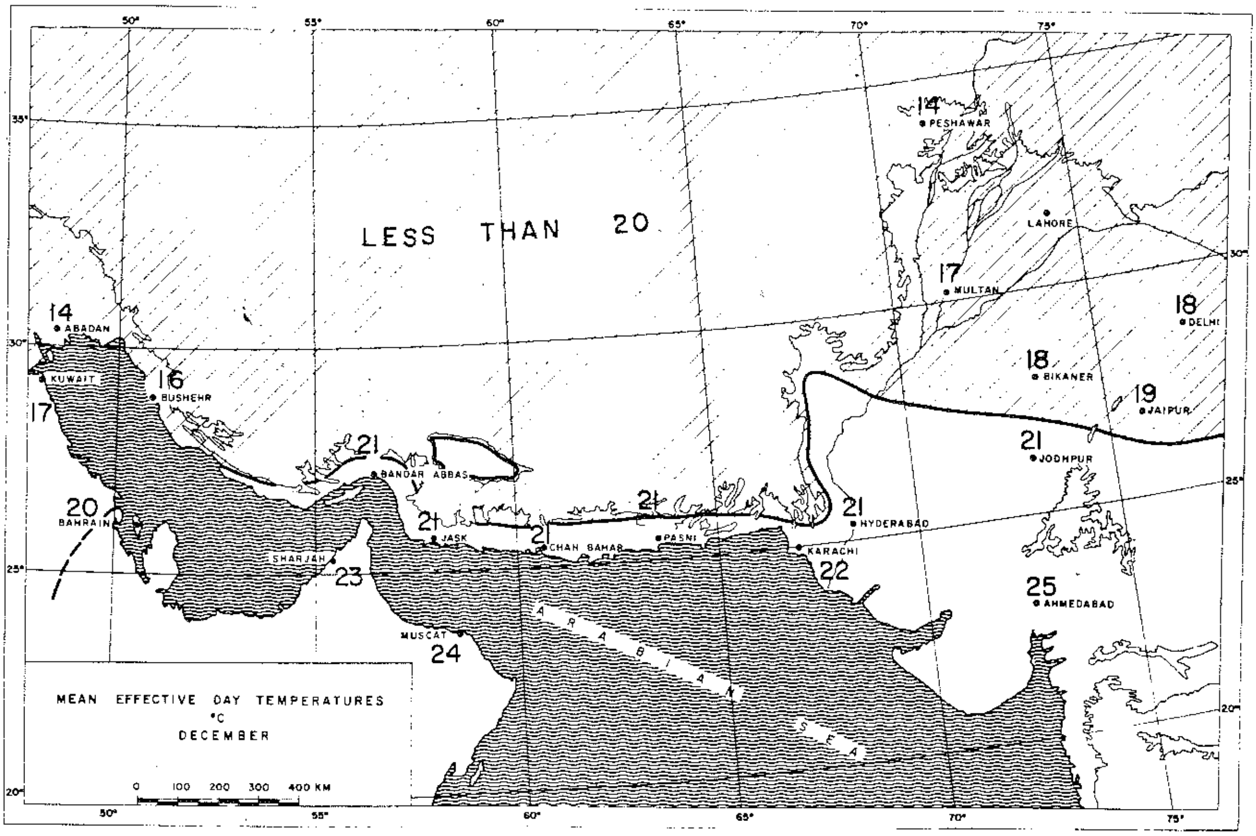


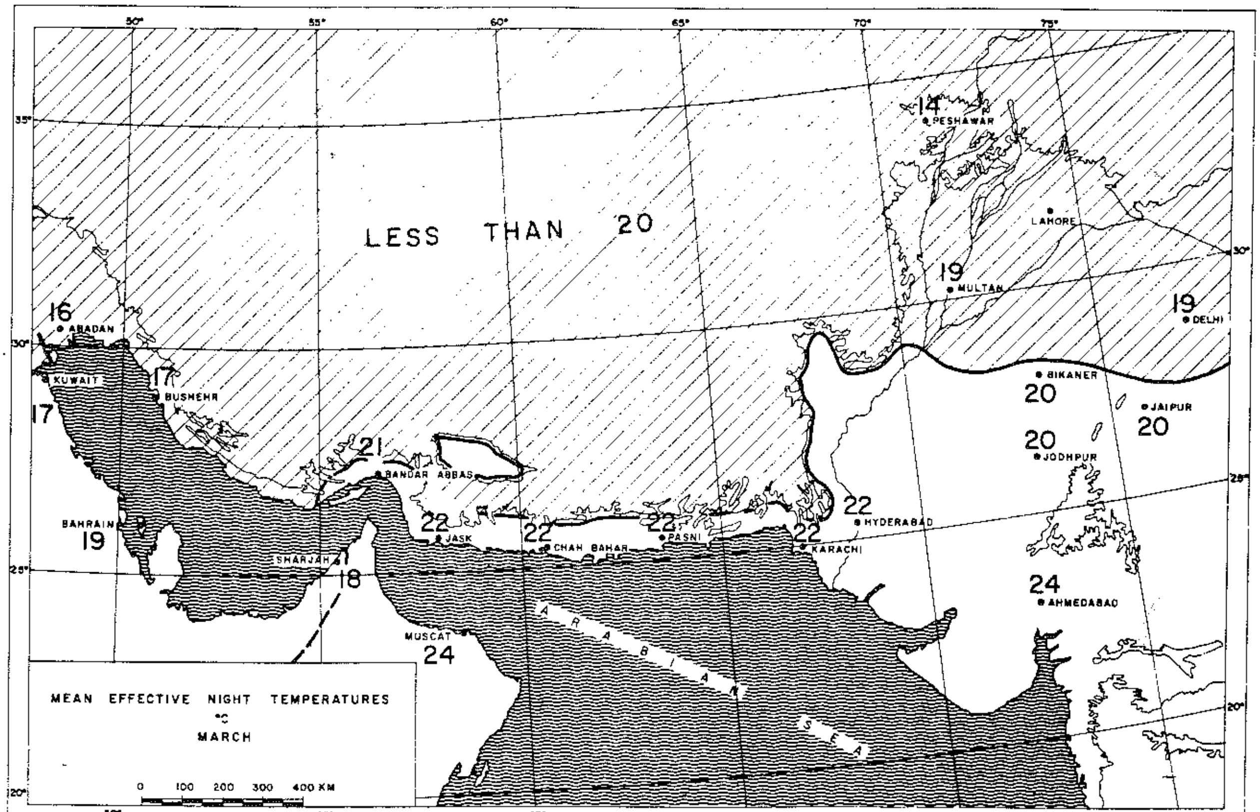


The monsoon rains have come to the summer breeding zone. There is a very rapid decrease in seasonal amount north-westwards. The rest of the area is very dry. During the beginning of the autumn the summer breeding area still receives some rain from the retreating monsoon, and at the end of the period westerly depressions begin to affect the north of the Persian Gulf. Elsewhere it is still dry.

Figure 5

Average Day Temperatures in the Eastern Region for December-March (Popov et al 1965)





Day temperatures in December suggest that swarm movements by day are limited on most days to the coastal plain of the south of the Persian Gulf and Arabian Sea and the southern part of the summer breeding area whilst night flying is inhibited. Night temperatures in March imply similar restrictions on night flying whilst swarms are free to move over most of the area by day.

In the summer breeding areas, there is a close correlation in space and in time between the occurrence of rain and of laying, which usually starts within a fortnight of the onset of the monsoon; the high frequency breeding areas fall between the 80-400 mm isohyets. In the winter breeding areas, however, temperatures below about 20°C limit both the distribution and timing of breeding (Fig. 5). Such a restricting influence is more pronounced in the case of the night flying solitarious populations than with day-flying swarms.

There is a closer spatial and temporal coincidence between plague and recession breeding in the Eastern Region than in the other regions. This is evident from a comparison of the frequency maps and readily seen in the histograms showing the maximum monthly frequencies of hopper and adult occurrence during the plague and the recession periods for each of the three main areas Iran, Pakistan and India (Fig.6).

In Iran breeding is principally during the winter-spring months, and mainly between January and June. Records during recessions are lower during the early part of this period, but this could be an artefact of reporting, due to the difficulty of detecting the solitarious nymphs. During recessions localised breeding in more humid habitats may persist till October, but during plagues not after June as a rule.

Although swarms begin to arrive in Iran from September, breeding is exceptional before February. During recessions breeding is confined to the warmer southern parts, to areas generally below 1000 m altitude south of 30°N latitude and east of 54°E longitude, although adults have occasionally been recorded further west at the head of the Gulf.

The records for Pakistan show the influence of winter-spring rainfall, which affects Makran, Baluchistan and northern Punjab, and the monsoon rainfall which affects the Sind-Tharparkar and Cholistan areas in summer. The timing of plague and recession breeding coincides fairly closely in both the regions, but in their distribution here, as in Iran, recession populations are confined to the warmer parts of the winter-spring breeding areas situated at lower altitudes and latitudes.

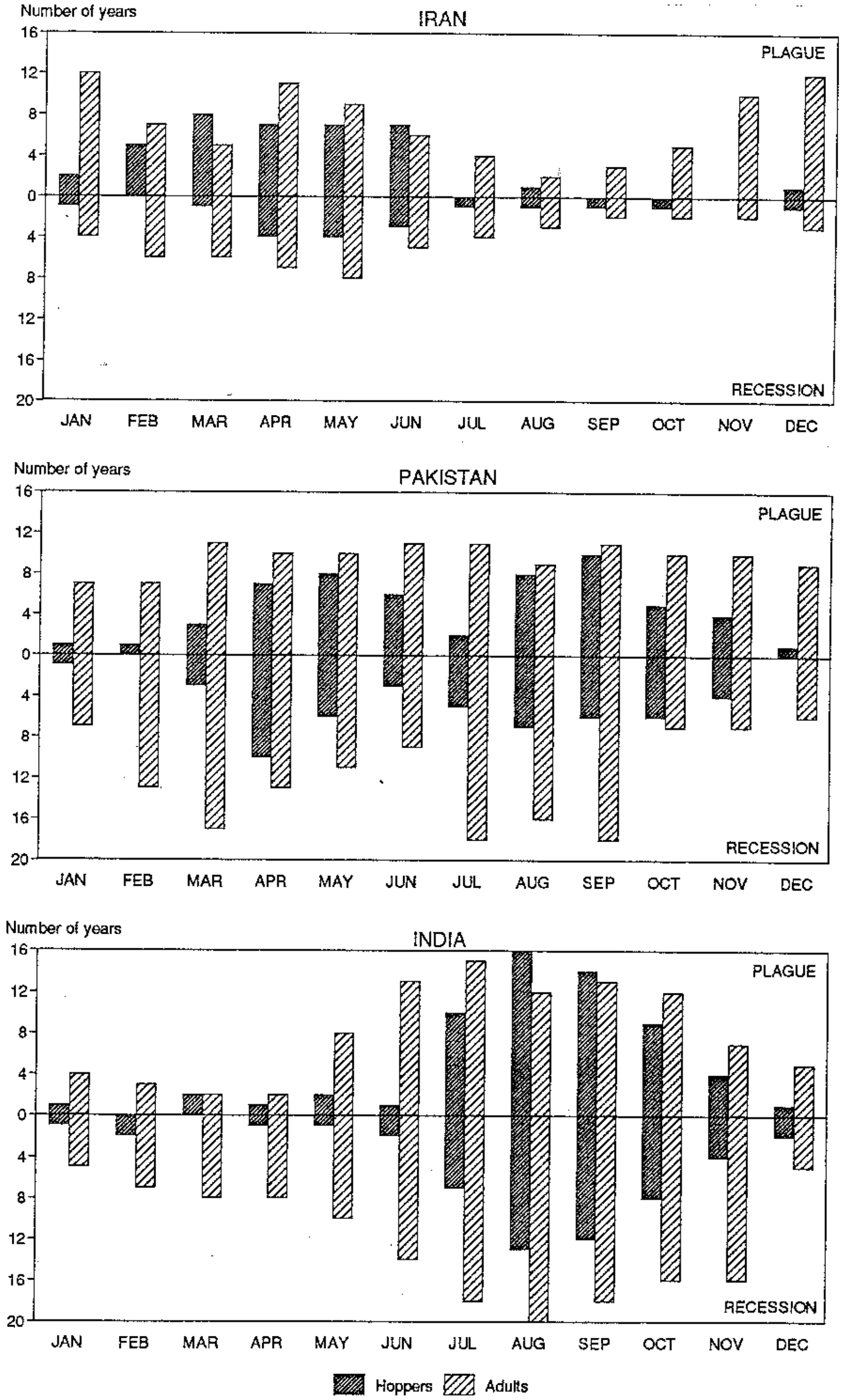
In India most breeding is monsoonal although some gregarious breeding can occur in winter and spring in northern India. Here also, Fig. 6 shows that the frequency of breeding during plagues and recessions is rather similar, but the extent of breeding during recessions is much less. Thus recession breeding during August extends over 33 degree squares, while during plagues up to 100 degrees can become involved. However, the high frequency areas during plagues and recessions agree fairly closely. Therefore, to avoid repetition the main characteristics of breeding belts are outlined here but the description of the high frequency breeding habitats is given under recessions.

4.3.3 Main vegetation zones

The breeding areas of the Desert Locust in Iran, Pakistan and India, like those in the Arabian Peninsula and Africa are part of the vast hot arid and semi-arid region known as the Sindo-Saharan desert. It extends between approximately 15°N and 35°N latitude and 17°W and 75°E longitude, and includes desert, semi-desert and steppe zones.

Figure 6

Maximum Monthly Degree Frequencies During Plague (1939-1963) and Recession (1964-1987, less 1968, 1978) Periods in Iran, Pakistan and India



In the Eastern Region two bioclimatic zones can be distinguished, one warm, mainly tropical, with summer rainfall, the second cool with predominantly Mediterranean rainfall. Figures 4 and 5 show the seasonal distribution of rainfall and the temperature gradient. The two regions are discussed briefly below.

4.3.3.1 The warm region

The following vegetation zones can be recognised in this region:

4.3.3.1.1 The shrub steppe

The shrub steppe is dominated by tussock grasses such as *Pennisetum divisum, Panicum turgidum* and *Lasiurus sindicus* in the region with annual rainfall of less than 150 mm, together with shrubs, notably *Calligonum* (on dunes) and *Capparis* (inter-dune). The shrub *Hammada elegans* becomes dominant in places, evidently due to some degree of salinity. Trees are rare and confined to sheltered depressions, where some *Prosopis* survives. In Baluchistan this zone is represented in the drier parts of the coast and some of the valleys of the interior. In the sandy areas in the lowlands it has a specific composition similar to that of Sind and Rajasthan, but much of the area is composed of plains of finer alluvium where salinity is pronounced and here a salt-bush steppe comprising principally species of *Salsola* and *Suaeda* occurs. Because of the pronounced relief there is an extensive network of drainage channels, which locally create better moisture conditions and allow the establishment of some shrubs and trees such as *Tamarix, Prosopis, Capparis, Salvadora* and others which properly belong to the areas of higher rainfall. The same conditions also allow the development of irrigated agriculture (dates and cereals) on a limited scale. This zone can be compared to the "Saharan region" of Mauritania (Rossetti, 1962) and to the sub-desert steppes of Arabia (Popov and Zeller, 1963).

4.3.3.1.2 The wooded steppe

The wooded steppe is dominated by tussock grasses and scattered thorn trees, especially *Mimosaceae,* which develop in the zone receiving 150-350 mm of rain. Vast areas can be allocated to this zone, including parts of western Rajasthan, Cholistan (Bahawalpur), Tharparkar, part of Baluchistan and southern Iran. It contains varieties of landscapes comprising many different habitats. Common floristic characters are the predominance of tussock grasses belonging to the genera *Panicum, Lasiurus* and *Cymbopogon* and the omnipresence of thorn trees. The distribution of vegetation is strongly influenced by orography. On more or less level terrain composed of deep soils, a diffuse cover of tussock grasses and trees commonly develops (Rajasthan, Sind), while in the valleys and depressions a contracted type of vegetation is typical (Baluchistan).

This zone may be sub-divided into two sub-zones: the drier receiving 150-250 mm and the wetter 250-350 mm of annual rainfall.

(a) The drier sub-zone is best characterised by the two trees *Prosopis cineraria* and *Tecomella undulata. Prosopis cineraria,* is a common drought-resisting species which colonises the same habitat as *Tecomella undulata,* but also extends to the tops of dunes as well as to rocky terrain, where it becomes established due to its highly developed root system. Its foliage has high forage value and the trees are consequently regularly lopped. Unlike Tecomella, *Prosopis* extends through southern Iran and is thus a good indicator of this zone.

Other trees such as *Salvadora, Tamarix, Ziziphus, Acacia,* and numerous other shrubs and herbs as a rule have pronounced soil requirements and are therefore considered at the level of vegetation communities. It should be noted, however, that *Cymbopogon schoenanthus,* which is absent from the shrub steppe becomes a prominent element in the wooded steppe. This sub-zone can be compared with the northern part of the Sahelo-Saharan region and with the wooded steppe of Arabia.

(b) The wetter sub-zone receiving 250-350 mm of rain is best characterised by the genera *Acacia* and *Ziziphus.*

In this sub-zone, *Prosopis* is largely replaced by the genus *Acacia;* the dominant species is *Acacia nilotica* which, together with *Ziziphus nummularis,* colonises deep soils on the plains, and *A. senegal,* which colonises predominantly rocky formations at sites receiving some local run-off. Mesophilous perennial grasses such *Saccharum spontaneum* and *Desmostachya bipinnata* appear in depressions. This sub-zone can be compared with the southern part of the Sahelo-Saharan region and the wooded steppe of Arabia at the southern limit of its distribution.

In the wooded steppe zone, human activity is much more intense than in the shrub steppe zone. The activity is still largely a pastoral one, but in some parts, notably in Rajasthan, cultivation of *Pennisetum* is widely practised on monsoon rains. Sorghum is cultivated on a more limited scale in the wetter sub-zone, in depressions providing better moisture conditions, where during exceptionally wet years some wheat may also be planted during the cool season. In the Thar desert, chick-peas (*Cicer arietinum*) are grown on the dunes and a mixture of chick-peas and wheat are grown in the depressions. In Bahawalpur large parts of the area are irrigated and planted with wheat. Considerable parts of this zone are given over to grazing in Baluchistan, Sind and Rajasthan.

The combined impact of planting and grazing in this zone has caused degradation and led to the accumulation of shifting dunes, notably in the Thar and to a lesser extent in Rajasthan, while pronounced erosion is typical of Baluchistan. Under such conditions perennial grasses become replaced by annual species giving rise to an altered but nevertheless typical physiognomy, much in evidence in Rajasthan, consisting of an ephemeral grassland dotted with trees, notably *Prosopis cineraria* in the drier part and *Acacia nilotica* in the wetter.

The frequency of locust breeding decreases progressively and rapidly in the area receiving more than 350 mm of rain per year. Nevertheless some breeding has been recorded even in areas having a mean annual rainfall exceeding 750 mm.

4.3.3.2 <u>The cool region</u>

Within the cool region the following three vegetation zones may be recognised:

4.3.3.2.1 <u>The open steppe zone</u>

This zone receives less than 250 mm of rain. It is dominated mainly by *Artemisia herba alba,* which develops on flat stony and silty plains. In saline sections it gives way to a halophytic steppe of *Salsola* and *Haloxylon*, while locally sandy areas a shrub steppe of *Haloxylon, Persicum* and *Calligonum* develops. On rocky terrain small, woody, frequently spiny bushes, chiefly *Astragalus*, become dominant.

The low rainfall and scarcity of ground water allow only limited irrigated cultivations, mainly of the oasis type. Wheat and barley are the staple crops. For the same reason the pressure of grazing is moderate compared with that of the higher rainfall zones. Cutting for firewood is, however, intense even in the remote areas, and the disappearance of trees such as *Pistacia* spp. from the valleys where they may have been common is almost complete.

4.3.3.2.2 The deciduous shrub zone

This zone develops in the area between 250 and 500 mm of rain. In the Zagros mountains of western Iran the zone is dominated by *Amygdalus* and *Pistacia*, often found associated with *Pyrus* and *Crotalgus*. Here *Artemisia* becomes largely replaced by perennial grasses such as *Agropyrum* and *Bromus*. In the Baluchistan region of eastern Iran and western Pakistan, however, *Artemisia* persists longer, reaching the zone of the xerophilous woodland, being associated with other woody bushes such as *Acanthophyllum* spp. and *Astragalus* spp. The wetter part of this zone allows dry farming which is practised extensively wherever soil conditions permit it. The human and the domestic animal population has been comparatively high for centuries and the present condition of the vegetation shows the inevitable consequences of the intense land utilisation. Much of it is secondary, comprising grazing-resistant or unpalatable species such as *Peganum harmala*, *Alhagi* sp. and *Astragalus* sp. The original *Pistacia* groves are now confined to the less accessible mountains.

4.3.3.2.3 The montane woodland zone

This woodland develops in the region receiving more than 500 mm of rain. To a large extent it probably lies outside the breeding zone of the Desert Locust. The forest of the dwarf Persian oak (*Quercus persica*) predominates in the mountains of south-western and western Iran, but not in Baluchistan, where *Juniperus* woodland is common in the mountains above Quetta.

4.3.4 Winter-early spring breeding

As can be seen in frequency maps, winter breeding can occur in India, Pakistan, and in coastal areas of Iran. Early spring breeding with hatching from February onwards may occur in the coastal and southern inland (Garmsir) areas of Iran and Pakistan, the latter coincide with recession breeding areas and are discussed in Section 5.6.2.1.

The habitats where winter-early spring swarm breeding took place in early 1963 in northern Punjab in Pakistan, were studied in March 1963 under the FAO/UNSF Ecological Survey Project (Popov *et al*, 1965). The studies were conducted at 36 egg fields, two of them at the actual time of laying, when detailed observations were made on the influence of the individual environmental factors, temperature, soil moisture, texture and compaction, micro-relief and structure of vegetation. On the whole, laying behaviour was very similar to that described by Popov (1958) for mass laying by swarms under semi-dry conditions. Popov's earlier general conclusions were confirmed and can be summarised as follows:

- On the micro-ecological scale the Desert Locust shows a marked preference for laying in sandy soils, but in their absence it may lay in soils ranging from light clays to fine gravels. Provided soil and soil moisture conditions are acceptable to laying females, the position of laying is influenced by micro-meteorological conditions, especially temperature, vegetation structure, relief and gregarious inter-attraction. In certain cases, however, such soil factors as soil moisture, resistance to penetration and soil salinity may have paramount importance.

- The most suitable oviposition sites are to be found in areas of pronounced soil mosaics offering a combination of coarser sands on the surface, with finer sands and silts below; the coarser surface sands facilitate digging by locusts, permit rapid percolation of rain water and its subsequent conservation from evaporation, while the underlying silts maintain the moisture nearer the surface and conserve it better than the sands. Such soils are chiefly to be found along wadis (Khors) and in sandy areas of marked relief.

- The Desert Locust may tolerate some degree of soil salinity at the time of laying but the maximum tolerated salinity as well as its effect on the development of incubating eggs still remains to be investigated, preferably under controlled laboratory experiments.

- The lowest tolerated soil moisture was found to be in the order of 1.9% water by weight; below this level eggs desiccate, or enter a dormant stage.

- There is some evidence that the frequently observed higher soil moisture within large dense groups of egg-pods may be due not only to the more humid nature of the group site, the usual reason for its selection in the first place, but also to the hygroscopic nature of the egg-pods themselves.

- On the meso-ecological scale the habitats and the plant communities at the 36 egg-fields ranged from crops of chiefly *Triticum* (wheat) and *Cicer arietinum* (chick peas), both irrigated and rainfed, to pioneer communities which become established in fallows and abandoned cultivations, to progressively more advanced communities, among which were recognised several stages of succession and degradation.

- All 36 egg-fields were almost entirely confined to cultivated land, actual fields and associated fallows and wastelands. This permitted an assessment of the influence of biotic factors, cultivation and grazing, on the natural vegetation. To this end it was concluded that many forms of land use tend to favour the creation of breeding sites in many areas where they did not exist before. The denser uniform vegetation cover, unsuitable for laying is replaced by a more open, patchier vegetation containing many bare areas more propitious for laying. Trampling and tilling of soil loosens the surface and leads to the formation of accumulations of sands which provide suitable laying sites. In general, the replacement of climax vegetation by a succession of pioneer communities multiplies the range of available habitats, introduces a greater variety of plant species (comprising some of the favourite food plants of *Schistocerca gregaria*), and so increases the chances of survival and multiplication.

- Finally, while irrigation tends to increase the density of the soil and promotes a denser and longer-lasting vegetation cover such areas on the whole, are not propitious for laying. In times of drought irrigated fields provide additional oviposition sites when laying may be impossible outside them.

4.3.5 The main spring breeding (Map 2d)

The main spring breeding occurs during March to June or July in all the countries of the Region and the frequency is highest in Iran, Pakistan and Afghanistan. Swarm breeding can be widespread and give rise to large numbers of swarms. The populations involved are principally the monsoon generation swarms produced in the Region, which spread during autumn and overwinter in the spring breeding areas of the Region, and are sometimes augmented by swarms produced during winter-early spring breeding in coastal areas of Pakistan and Iran, and/or by incursions of swarms from the Central Region (DLFM). Westward progression of swarms from the summer breeding grounds may begin in September but usually not until October, advancing on a relatively narrow front, generally south of 30°N, following the east-west line of the main valleys of Makran and Baluchistan. Confronted by low winter temperatures inland the migration slows down and the swarms stagnate in the lower latitudes and remain immature until the rise of temperatures in the spring. Maturation and northward advance of swarms begin in February-March and gathers pace in April. As earlier, there is a tendency for swarms to follow lines of major relief; for instance the northward spread is particularly pronounced and early along the Helmand and Harirud river valleys in the border land between Iran and Afghanistan. This aspect is so marked that some of the earlier workers (notably Predtechenskii, 1938) postulated elaborate migration routes to explain and forecast the northward progression of swarms. However, according to the DLFM the 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 depressions which pass across Iran, Afghanistan and Pakistan during the season.

Occasionally, under the influence of warm southerlies and south-easterlies, monsoon swarms may continue to move westwards and even clear the region; alternatively there can be major eastward movements to carry swarms reaching south-western Iran from the Central Region into south-eastern Iran and into Pakistan and Afghanistan. Eastward migrations became particularly marked from May onwards, when they result in the invasion of monsoon breeding areas by spring swarms.

Main spring breeding is widespread and to some extent contiguous with that in the Central Region. It also shows a close analogy with the spring breeding in North Africa. As there, the principal breeding grounds are associated with steppe communities of shrubs, bushes, wood, herbs and therophytes which develop on the lighter soils in the plains and valleys and hillsides. Under the prevailing, generally arid, conditions breeding frequently occur in habitats favoured by run off along wadis and in depressions and also often along the margins of cultivations (Popov, 1954a).

According to the frequency maps in the DLFM and the breeding distribution (Map 2d), spring breeding in Iran is most frequent in the Garmsir region during March-April and often follows on from the earlier winter breeding; the highest recorded occurrence is in Khuzistan, the Lar-Bandar Abbas and the Makran areas. Further inland the incidence of breeding reaches its peak later, during May, or even June. It is more widespread and again is more frequent in the south. The highest incidence of breeding is in the great valleys of the southern Zagros system, notably Kazerun, Firuzabad, Fasa and Darab, also from the more easterly Rafsanjan and Kerman areas, and one of the highest frequencies of breeding is from the Hari rud-Helmand basins on both sides of the Iran-Afghanistan border. In Afghanistan breeding is widespread in the south western lowlands and although the frequency is lower than in the adjacent parts of Pakistani Baluchistan, this could be partly due to under reporting. The breeding habitats during plagues are similar to those during recession and are described under the latter (see 5.6.2).

4.3.6 Summer breeding (Map 2d)

From about May onwards, swarms produced in the spring breeding areas of the Eastern Region begin to move east and south-east towards the monsoon breeding areas of eastern Pakistan and north-western India. In accordance with the chronology of spring breeding the invasion may continue in waves through June into July. These movements may be associated with a variety of weather systems and in some years swarms may be carried eastwards beyond the monsoon breeding areas, but under the influence of monsoon depressions most of the swarms later return westwards. However, occasionally (as in 1955) swarms carried south-east across northern India to Bihar and Orissa, fail to return and disperse without breeding (DLFM: 118-9).

Monsoon breeding within the Region is restricted to India and Pakistan. During plagues it may be widespread, involving some 100 degree squares in south-eastern and eastern Pakistan and north-western India; during recessions the extent of the recorded breeding is only a third as great, but the high frequency breeding areas agree very closely with those during plagues. The main high frequency breeding areas are the Lasbela area of eastern Baluchistan and the Cholistan-Tharparkar deserts in Pakistan and Rajasthan in India. The frequencies are among the highest anywhere in the distribution area of the Desert Locust. The Lasbela high frequency breeding area is shown in Map 18 and described in Section 5.6.2.1, while the Jaisalmer area is shown in Map 20 and described in detail in Section 5.6.2.2 as an example of a high frequency breeding area in Rajasthan during both plagues and recessions.

5. THE SPATIO-TEMPORAL DISTRIBUTION OF BREEDING DURING RECESSIONS AND UPSURGES AND THE CHARACTERISTICS OF RECESSION AND UPSURGE BREEDING HABITATS

5.1 General characteristics

A comparison of the frequency breeding maps during plagues (Maps 2(a-e)) and recessions (Maps 3(a-e)), indicates that the timing and distribution of breeding during recessions show some similarities but also important differences from those during plagues. The main similarity is, naturally, that breeding follows the onset of seasonal rainfall but, because of the increased mobility of swarming adults, there are large areas where high frequency gregarious breeding occurs, but no breeding during recessions. The outstanding examples are the spring breeding grounds in North West Africa, the countries to the north of the Arabian peninsula, north-central India, southern Somalia and East Africa. A number of other areas of high frequency breeding during plagues, for example the spring breeding grounds in the interior of Arabia, the summer (monsoon) breeding grounds in the interior of Sudan and the Short and Long Rains breeding grounds in the Horn of Africa, remain almost completely clear of locusts except during major upsurges, when they may be rapidly invaded by largely gregarised day flying populations albeit some as yet in the transiens phase.

Little is known about flight behaviour of non-swarming, night flying locusts, but the records of monthly occurrence of adults and hoppers show a trend of seasonal changes similar to that recorded for plague populations. The best example of the analogy is in the Eastern Region, where, except for a reduction in their size, the winter-spring and the monsoon breeding grounds coincide fairly closely with those during plagues. In the Central Region many of the principal high frequency plague breeding grounds are not accessible to recession populations so that these are largely confined to the coastal and subcoastal habitats of the Red Sea and Gulf of Aden, where rainfall and flooding, although generally scanty, have a seasonal character. Thus, a comparison of the highest recorded monthly frequencies of hoppers and adults for the individual areas (Fig. 2 and Fig. 3) shows that in Sudan and Saudi Arabia, breeding during recessions, as during plagues, occurs principally between October and March and in Yemen and Eritrea it occurs principally between November and May. In Somalia, breeding is less frequent and can occur in virtually any month, but principally during spring. As in Somalia, the presence of hoppers in small numbers in virtually every month is also recorded in the Sudan, Eritrea, Saudi Arabia and Yemen.

In the Western Region, breeding in the Mali-Niger south Saharan highlands is more prolonged during recessions than in plagues with the maximum frequencies occurring during October-November, instead of July-August recorded during plagues. Moreover low frequency breeding has also been recorded here in every month except April and May. In the Algerian Sahara low frequency breeding has been recorded in every month, without marked seasonality, a characteristic of desert conditions. Here, there appears to be an imbalance between the complementary breeding grounds, with Timetrine-Adrar-Tamesna-Aïr providing the most frequent opportunities for multiplication (and at times gregarisation) with Algeria providing complementary breeding possibilities but less frequently and presumably less reliably.

5.2 The persistence of habitats

A striking feature of Figs. 2, 3 and 6 is the continued reported presence of adults and in many cases of hoppers in each individual country in virtually every month of the year, even in the Eastern Region, where seasonal displacements between spring breeding grounds in Pakistan and summer breeding grounds in India have been shown to exist. This calls for an explanation, especially in view of the following statement made by Vesey-Fitzgerald following his extensive studies of the vegetation and locust habitats in Arabia (Vesey-Fitzgerald, 1957b):

It was hoped that a study of the vegetation of Arabia might assist in defining the types of environment in which the Desert Locust may be able to live permanently. The results of the survey reported in this and the two previous papers (Vesey-Fitzgerald, 1955; 1957a) have suggested, however, that the necessary conditions are not likely to persist in any one type of habitat throughout the year, or a series of years. Although some of the plant associations provide very favourable conditions for the locust during the seasons and periods of their maximum development, the location of such temporarily favourable habitats is not fixed but depends on the erratic distribution of rainfall.

The validity of Vesey-Fitzgerald's comments is not in doubt, but their full implication should be gauged in the light of the following evidence.

Studies on the ecology of the recession populations of the Desert Locust in Niger initiated by the author in August 1965, with the participation of technical personnel from ALRC and OCLALAV, were continued by the latter through the winter months with practically no interruption until November 1966 (Popov 1968a and 1968b). Observations through the period at two study sites, one in Tamesna and the other at Termit, established that at the end of the 1965 summer breeding (and the drying out of the vegetation) there was a general decline in numbers of the new generation adults in October and November although some remained. Of particular interest are the observations conducted by the OCLALAV prospecteur Aybuba Ali from February to November 1966 around Termit at a series of fairly uniform habitats with steppe vegetation on sandy soil extending from 15°10'N to 16°25'N. These observations established that during February the number of adults was low although slightly higher in the north. There were no catches at a light-trap. During March there was a slight rise in numbers and the first light-trap catch occurred at the end of the month, coinciding with a rise in temperature, which continued during April. The first ovarian development was noted following traces of early rain. In June there was a report of locusts in numbers at Ouallaram (latitude 14°45'N the furthest south recorded), the ITCZ being stationary at this latitude during the period. There was a marked decline of adults in the north in July and an increase in the south. Maturation and laying were also recorded. During August and September the numbers of parent adults declined and hoppers appeared, their distribution showing marked association with the presence of *Heliotropium* and *Moltkiopsis* in the habitats. By October the new generation of adults started to appear in the south but numbers started to decline by November together with an increase in numbers in the north. This was followed by an overall decline in numbers of adults. It should be added that all the adult and hopper populations observed were extreme phase solitaria, and, apart from the unconfirmed report of high numbers of adults at Ouallaram (possibly representing a temporary concentration by convergent wind fields along the ITCZ), maximum recorded densities were 37-40/ha.

These observations are important in that they reveal the existence of habitats in parts of the Sahelian zone where locust populations may survive the dry season to bridge the gap between successive generations as is the case in the Indian desert. Parallel studies in Tamesna have also established the presence there of small overwintering residual populations. Earlier, Zena Waloff (1963), in her studies on the behaviour of solitarious and transient locusts on the Red Sea coast of Eritrea, drew attention to the residual populations that remained behind after the departure of the rest of the population, and suggested that the two could be genetically distinct. This important idea still awaits the scientific investigation that it deserves, for it implies that locust survival could be enhanced by such spreading of risks and would cater for the eventuality of catastrophic losses by the emigrant populations.

Most evidence, however, suggests that it is principally the mobile populations that are paramount in the survival strategy of the Desert Locust for, as Vesey-Fitzgerald remarks, the habitats in Arabia (and over practically the whole of the remainder of the recession area) do not provide the necessary conditions for continued survival. The Desert Locust is thus constrained to lead the life of a nomad, moving between the short-term habitats that come into existence in response to the erratic desert rainfall. Indeed many of the best habitats in the Sahara are purely seasonal, and are composed of annual species which are reduced to wind-borne straw at the end of their brief development.

It therefore follows that such survival will be most successful and the frequency of breeding highest in areas or complexes of complementary areas where sequences of rainfall leading to development of suitable ecological conditions are most frequent. The breeding frequency maps for recession periods reveals such areas very clearly. From west to east the principal high frequency areas are: Mauritania/western parts of the Sahara, where summer breeding occurs principally in the south and winter-spring breeding in the north (Map 3a, Habitat Table 1). Next is the Timetrine-Adrar-Tamesna-Air area and the complementary southern Algerian Sahara in the north (Maps 3b and 6(a-b), Habitat Table 2). The Ennedi-Darfur area in Chad/Sudan can provide excellent summer breeding habitats and conditions but the recorded frequency is not high, probably due to an absence of reliable winter-spring complementary breeding areas sufficiently close, the Tibesti being too remote and restricted. Next is the very important Red Sea-Gulf of Aden complex with the highest frequency of breeding of all (Maps 10(a-d), 11,12, 14(a-d), 17(a-d) and Habitat Tables 3-6) and finally the Indo-Pakistan area (Maps 18, 19, 20 and Habitat Tables 7-8). There are, in addition, areas such as Oman, where breeding, although infrequent, has been instrumental on several occasions in contributing to new plague upsurges (Popov, 1988a).

5.3 The ecological value of recession habitats

The ecological potential of a habitat may be gauged in terms of the extent to which it meets the food/shelter and oviposition requirements of the locust. These are not easy parameters to quantify, especially when dealing with a species as mobile and elastic as the Desert Locust, and habitats as diverse and seasonally variable as the ones it inhabits during recessions. To render the interpretation of the value of the habitats as objective as possible, the principal criterion used is the locust's responses to particular habitat conditions in terms of its preferences for certain food-shelter plants and communities and for particular oviposition sites. In more general terms, the measure of the value of particular habitats and areas is the frequency and the extent to which they are seasonally colonised by locusts, and their potential to promote the survival, reproduction and gregarisation of locusts under optimal environmental conditions. The characteristics of some of the more important habitats are tabulated by regions and areas (Annex I : Habitat Tables 1-8). In the tables, the potential values of the habitats for survival (S), reproduction (R) and gregarisation (G) and the frequency (F) with which they have been colonised in the past based on historic evidence are given according to a qualitative six point scale. These are inevitably somewhat subjective estimates. While the (S), (R). and (G) values are based on field observations in those actual or analogous habitats, the frequency figures, as already pointed out (Section 2.3), are biased by the frequency of observations and also by the accessibility of the habitat to locusts, which, in view of our ignorance of the dynamics of recession populations, can only be a subjective estimate. Errors of judgement are inevitable, and it is hoped that future research and experience will ensure the necessary corrections and modifications.

5.4 The Western Region

5.4.1 Mauritania and western parts of the Sahara

5.4.1.1 Distribution of recession and upsurge breeding habitats (Maps 2a, 3a, 5a-c)

The major habitats where breeding occurs in Senegal and Mauritania during plagues and recessions are listed in Habitat Table 1. Recession breeding is rare south of the 250 mm annual isohyet. Reflecting the temporal distribution of rainfall, south of latitude 18°N, practically all the breeding occurs in summer during July to October; between 18°N and 21°N it can occur in any month, while north of 21°N it takes place mostly in spring and early summer, February to May, but it can start as early as November. Apart from the difference in distribution (Maps 2a and 3a) and the chronology of breeding, the recession populations tend to breed in the same types of habitats as swarms many of which are associated with the major geomorphological features. Particularly favoured are the borders of the Tagant and the Adrar massifs and the Khatt El Moinan depression that separates them, and also the hills of Akjoujt and the borders and inter-dunes of the major dune ranges in the Trarza and the Aftouts sectors (see Map 5c). Interestingly, here again there are concentrations of breeding, at times leading to gregarisation, in areas that correspond to disturbed dune orientation and aklés suggesting variable and possibly converging wind fields of considerable duration. One such pocket in the Nimjad area (17°25'N, 15°43'W) was the site of concentrated breeding leading to gregarisation with band and swarm formation during September-October 1974 (Skaf, 1978).

5.4.1.2 Description of the habitats

5.4.1.2.1 The Sahelian zone, annual prairies

The Sahelian zone between 250 and 500 mm rainfall corresponds to the main summer breeding belt during plagues; breeding is particularly frequent in the neighbourhood of major relief features, Assaba, Affolé, etc., where a wider range of habitats provide greater opportunities for breeding than the uniform sandy annual prairie where the distribution of breeding is more scattered and less frequent. During recessions locusts occur at very low densities in sandy habitats. Residual populations may persist in low numbers. There is marked association with presence of preferred food/shelter plants e.g. *Tribulus, Heliotropium, Moltkiopsis, Cleome gynandra.*

5.4.1.2.2 Sahelo-Saharan zone - semi-desert grassland (rainfall >100 mm to 250 mm)

This is the zone of high frequency breeding during recessions, but the frequency of breeding during plagues also remains high. Under the more arid conditions, most breeding occurs in habitats benefiting from rainfall run-off, and higher amounts of rain. As a rule these are in areas of marked relief. Thus, along a given latitude of the Sahel with its north-south rainfall gradients, the amounts and frequencies of rain are higher in areas of marked relief and even relatively modest features such as Termit with an altitude of little more than 100 m above the surrounding plain, seems to attract more rain than the surrounding terrain, while the southern Saharan highlands receive substantially larger amounts. The higher rainfall, coupled with run-off and the diverse soil conditions, create a much wider range of habitats than the surrounding more uniform terrain.

Such habitats being more limited in extent, tend to concentrate locusts and to further their gregarisation. This can occur even in areas of relatively feeble relief as the Aftouts; where the earlier breeding occurs in the drier habitats in the sands consisting of communities of tussock grasses and sedges: *Panicum, Stipagrostis, Cyperus conglomeratus* and herbs such as *Tribulus, Farsetia, Heliotropium, Malcolmia and Morettia.* Later, as these begin to dry out, the locusts move into the more humid, more restricted habitats in the interdune depressions bearing *Lasiurus, Schouwia, Boerhavia, Indigofera, Tribulus* and *Zalea*, where, should conditions be suitable, further breeding may take place.

A much wider range of habitat conditions and greater opportunities for breeding and gregarisation occur in areas of major relief. As an example, those recorded in Khatt el Moinan in September 1973 (Popov, 1974) are described below.

The Khatt consists of a wide shallow valley between the northern edge of the Tagant to the south and the southern border of the Adrar to the north. Both the plateaux consist of metamorphosed sandstones, which here lose their height, breaking into mesas and buttes partly buried under sand deposits, which along the edge of the Khatt, terminate in high ridge dunes oriented ENE to WSW and are thus parallel to the main axis of the valley. The plant communities along a catena from the top of the marginal ridge dune to the bottom of the valley are listed in Habitat Table 1a.

The habitats differ not only in the specific composition of the plant communities, but also in the type of their soil and the amount of soil moisture. Thus, jointly, the various habitats provide a range of conditions likely to meet the requirements of locusts much more adequately and over a longer period of time, than any single habitat could do by itself. Such area of wide spectrum of habitats are of great potential importance in both attracting locust populations and enabling them to multiply and, at times, to gregarise.

Elsewhere, there are expanses of regs, e.g. in Inchiri and parts of the Hodh; surface drainage is high and leads to a wide network of wadis, graras and sabkhas, with an associated wide range of plant communities, ranging from scrubland, e.g. thickets of *Acacia ehrenbergiana* to salt-bush steppes with *Nucularia perrini* and *Salsola* spp., as in parts of Inchiri and margins of some inland sabkhas, to annual prairies with *Aristida* spp., *Schoenfeldia,* occasionally *Lasiurus* and such chamaeophytes as *Aerva* and *Psoralea* as well as the annual *Schouwia*; some of the major wadis and graras are cultivated with sorghum and millet. Locust habitats are associated with the drainage network and particularly with sandier soils along the margins of flood plains and the banks of wadis. Saline soils are avoided, but some laying may occur on drifts and hummocks of aeolian sand under vegetation.

5.4.1.2.3 Saharan zone - Desert grassland (under 50 mm rainfall)

As Monod (1958) pointed out, there is a Sahara of sand and a Sahara of rock. The mean annual rainfall over much of the Sahara is under 50 mm. This means that in the Sahara of sand even exceptional falls of rain do little more than temporarily rejuvenate the few perennial shrubs and bushes and produce a short-lived flush of annuals. Such habitats offer brief possibilities for survival for a transient adult population but practically none for breeding. Thus, the few reports of hoppers from the great Djouf (Mreye) sand desert are all from habitats along its borderlands which, in addition to rain, also benefit from flooding, and there are none from its interior. The importance of run-off and flooding in creating favourable habitat conditions is paramount under Saharan environments and this is found in the Sahara of rock, particularly in areas of more pronounced relief.

Drainage also permits breeding in parts of the arid western part of the Sahara, notably in Adrar Soutouf, Zouerate, Zemmour and Hank which have a mean annual rainfall of less than 50 mm. Here the occasional abundant widespread rains can create suitable breeding conditions, usually during the winter-early spring period; on occasions this has resulted in the production of an extra one or two generations between the summer and the spring breeding and has contributed to a plague, of which the 1987-88 breeding is a good example.

5.4.2 Nigero-Malian and Algerian Sahara

5.4.2.1 Distribution of recession and upsurge breeding habitats

The identity of this complex is well-defined by the clustering of records of hopper incidence around the highlands of southern Algeria and northern Mali and Niger situated roughly between 17° to 30°N and 2°W to 10°E (Map 3b). This area can be readily divided along the 22°N parallel with breeding occurring more often in summer south of it and more often in spring to the north. It has one of the highest Desert Locust recession breeding frequencies. Thus during the 24 year period from 1964 to 1987 control against gregarising or gregarious populations somewhere or other within this area was conducted during 16 years, or 2 years out of 3. However, due to the mobility of the populations and the instability of the habitats, the highest hopper frequency in any degree square is only eleven (Fig. 6).

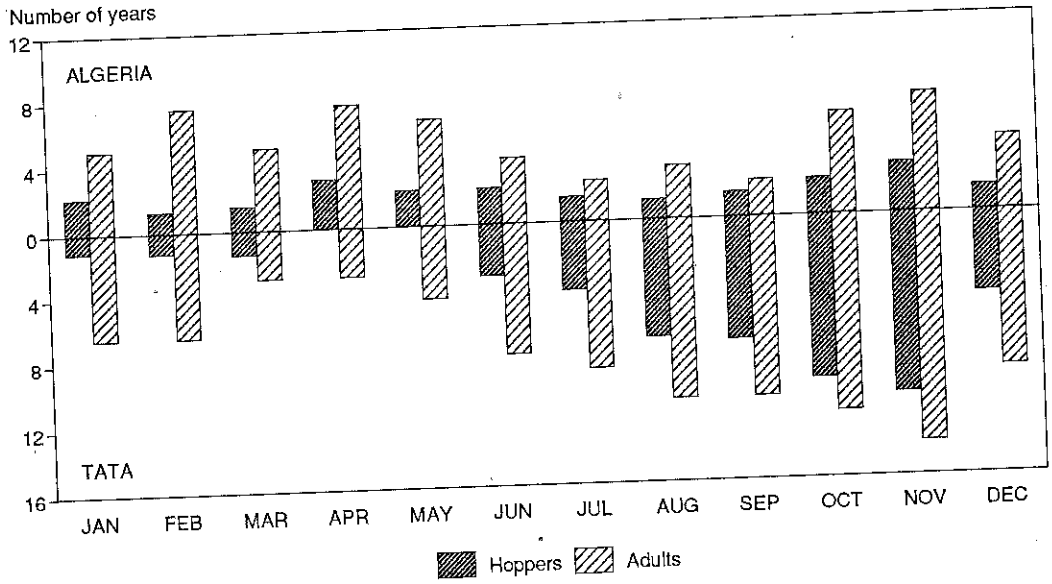
The southern limit of high frequency breeding areas runs roughly along the 17°30'N parallel and corresponds to the mean annual isohyet of 70 mm. South of this parallel there are few records of hopper occurrence and none of gregarisation. Northwards reports are frequent up to the northern limit of Air and Adrar highlands, corresponding roughly to the 20 mm isohyet, then decline rapidly northwards. There is thus a close analogy with the Mauritanian-western Saharan breeding areas, for here, likewise, the breeding in the southern summer breeding habitats is more frequent and prolonged than the more dispersed and sporadic breeding in the Algerian Sahara. Thus comparing the highest recorded monthly adult and hopper frequencies for the two areas (Fig. 7), it is seen that the bulk of the breeding in the Timetrine-Adrar-Tamesna-Air (TATA) area occurs during June to December, tailing off during January to March, with no hoppers being recorded during April and May (although gregarious breeding occurred in the Adrar des Iforas in May 1968).

In the Algerian Sahara, i.e 22-30°N, due to the erratic distribution of the Saharan rainfall, hoppers may occur in any month, generally in low numbers, but somewhat more frequently during April-June, thus being complementary with TATA.

The southern Algerian hoppers present in October-November are an extension of populations in Mali and Niger. Adults are present in both the areas somewhere or other throughout the year but are again more frequent in TATA in summer and autumn

Figure 7

Maximum Monthly Degree Frequencies Recorded during the 1964-87 Period in Tata and Southern Algeria



and in Algeria in spring. This clearly underlines the coincidence of breeding with the chronology of rainfall and the complementarity of the two areas.

5.4.2.2 Description of the habitats

The principal plant communities and the habitats of the Desert Locust in TATA together with the records of solitarious and gregarising hoppers within them, are shown in Maps 6(a-b) and 7(a-b). Originally these maps were prepared in 1983 by G. Popov on the basis of all the available information: published works notably by the Volkonskys (1940); ecological studies during 1964-70 (Popov 1968, 1968a, 1969; Roffey and Popov, 1968), Sitouh (1976); verbal communications by OCLALAV field personnel; OCLALAV and other reports in FAO and COPR archives for the 1964-1982 recession period; LANDSAT imagery for September 1980, as the then best available imagery of vegetation at its maximum development.

The maps have now been updated for inclusion in this Atlas. In addition to the TATA area, the map also includes the adjacent parts of Algeria, but the remainder of the recession breeding area in the Western Region, in view of the scarcity of records in relation to its size, is shown only on the 1:5 million frequency map. The characteristics of the major habitats are given in Habitat Table 2 while the comments below provide additional information to further assist with the interpretation of the map.

A comparison of the distribution of breeding and gregarisation (Map 6(a-b)) with principal geomorphological features and habitat types (Map 7(a-b)) highlights the following points:

- The bulk of the records are associated with the network of wadis, flood plains and valleys that, in addition to receiving direct rain, benefit from run off and flooding. Under the arid Saharan conditions, where the flow of surface water is unimpeded by vegetation, even moderate falls of rain can lead to extensive flooding. Thus, the August-September 1966 rains on the south-west flank of the Tibesti mountains in central Sahara, resulted in the flooding of all the major wadis (enneris) reaching points up to 150 km away from the mountains and creating favourable locust habitats in the desert which itself had received no rain; these then remained suitable for locust breeding until the following January (Popov *et al.*, 1981). At the present time major flooding in TATA is confined to the proximity of the Adrar and Air mountains, and much of the extensive network of drainage that during the pluvial flowed via the Tilemsi and the Azaouak-Dallol Bosso into the Niger, is now transformed into fossil valleys.

- The distribution of hoppers and their gregarisation as recorded during the 1964-87 recession period coincides closely with certain habitats (Maps 7a-b). In particular, the highest frequencies and most of the records of gregarisation coincide with the *Tribulus* and *Schouwia* habitats.

- The annual communities of *Schouwia* and *Tribulus* become established predominantly on characteristic soils of the fossil valleys. These are deeply fissured clays in which the fissures have become filled by wind-blown sand. Such soils have both high permeability and high water-retention, factors of great importance not only for plants but also for locusts by providing them with long-lasting oviposition, food and shelter habitats.

- *Tribulus* and *Schouwia* often form mixed communities but on the whole *Schouwia* grows in more humid and *Tribulus* in drier sites; *Tribulus* is also more tolerant of lighter, sandier soils. There are two species of *Tribulus*: *T. mollis* and *T. pentandrus*; of the two, *T. pentandrus* grows in sandier soils and is generally more widespread, while *T. mollis* occurs in heavier soils, more often in association with *Schouwia*. Their food value to locusts appears to be equally high and on the whole higher than that of *Schouwia*.

The spatial distribution of these communities depends on the combination of special soil conditions and adequate run-off. Thus, Boulet (1966) established that the soil moisture in a typical *Schouwia* habitat in Tamesna was equal to some 300 mm of direct rain, i.e. about 5-6 times the mean annual rainfall for the site. The importance of run-off is also evident both from the distribution of the areas of *Tribulus* and *Schouwia* and the pattern of the vegetation within the individual areas. The areas of vegetation are generally confined to depressions, notably the fossil valleys, which receive considerable run-off, usually as sheet flooding from the surrounding high ground. Areas of *Schouwia* and *Tribulus* are highly localised, representing only a fraction of the total area, and become progressively more restricted northwards, where rainfall is lower. In the Sahara proper, e.g. Ahaggar or Tibesti, *Schouwia* develops only in the flood plains of major wadis (Coste, 1951; Guichard, 1955; Popov, 1968).

Both *Tribulus* and *Schouwia* are strictly annual. The average stand of *Tribulus* lasts about 12 weeks; *Schouwia* is longer lasting and in the event of abundant, prolonged rains, may exceptionally persist in better-watered depressions until February, or even March. However, as a rule in most habitats both species together with many of the associated annual grasses *Pennisetum violaceum, Aristida meccana, A. adscensionis, Stipagrostis plumosa, Schoenefeldia gracilis*, and herbs *Colocynthis, Morettia, Farsetia, Zalea, Geigeria, Fagonia* dry out already at the end of the summer season. With their disappearance, the residual hoppers and adults can then only survive in the shelter of longer-lasting biennial and perennial plants: tussock grasses such as *Panicum, Lasiurus, Stipagrostis acutiflora* and bushes and chamaeophytes like *Aerva javanica, Chrozophora* sp. and *Cornulaca monacantha*. For this reason, areas where the range of habitats also includes, in addition to the preferred *Schouwia* and *Tribulus*, good survival habitats containing longer lasting plant species are particularly important. In this respect the Adrar des Iforas probably offers the best opportunities both for multiplication and gregarisation, and the survival of residual populations during the dry season.

In the Algerian Sahara conditions are even more arid and, except for the high peaks of the Hoggar, the mean annual rainfall within the limits of the recession area is generally below 50 mm. The habitats are confined to the beds of wadis and the flood-plains fed by them. Those in the south, in the wadis draining the northern Adrar des Iforas and the southern Hoggar, are similar to those in Mali and Niger. Further north, some local elements become increasingly more common. There are frequently, though not always, a few trees such as *Acacia raddiana, A. ehrenbergiana* and *Tamarix nilotica*, some shrubs and bushes of *Calligonum, Cornulaca, Salsola baryosma* and *Nucularia perrini* with tussock grasses *Panicum turgidum, Lasiurus hirsutus* and *Stipagrostis pungens* and chamaeophytes and therophytes such as *Aerva javanica, Pulicaria crispa, Schouwia thebaica, Hyoscyamus muticus, Colocynthis vulgaris, Zilla spinosa* and *Morettia canescens*. Such rare and highly localised steppe or shrubby steppe habitats contrast sharply with the surrounding terrain and are a strong attractant and concentrating factor for locusts.

What needs to be emphasised yet again is the temporary nature of all the habitats: an important point to bear in mind in interpreting the habitat maps. The map shows the aggregate optimal conditions and the total recorded occurrences of hoppers and gregarisation. It is highly unlikely that all the habitats will become functional in the same season. What is much more likely is that, given the vagaries of the rainfall, only some of the habitats will develop and that locust numbers in them will also vary according to the numerical and spatio-temporal changes in the complementary source areas. As an example of this variability, the conditions recorded during aerial and ground reconnaissance in the course of four consecutive years in the Tamesna of Niger are summarised below:

- 1964. A year of good rainfall, 55 mm was recorded at In Abangharit, the OCLALAV locust control base, during late August and early September. This led to the abundant development of *Schouwia* and *Tribulus* habitats; the locust population remained low and breeding in August-October did not lead to gregarisation.

- 1965. A year of moderate rainfall and more restricted habitats than in 1964; locust population densities were somewhat higher with early stages of gregarisation noted among hoppers, but without band or swarm formation.

- 1966. A year of poor rainfall, total at In Abangharit for May-September 60 mm. Habitats small, highly localised and poorly developed. Severe competition between locusts and grazing camels, leading in many cases to complete destruction of habitats and failure of locust breeding. Several instances of local, small-scale, largely abortive, gregarisation.

- 1967 (described in Roffey and Popov, 1968; Pedgley, 1981). A year of widespread, abundant rains with 123 mm recorded at In Abangharit in August alone (about twice the annual total), leading to extensive development of locust habitats. Increasing numbers of adults migrating as isolated individuals at night, reached Tamesna during September and October. These probably originated from July-August breeding in the Sahel and preceding spring breeding in Tibesti, Fezzan and south-east Algeria. In Tamesna locusts became concentrated in the *Tribulus* and *Schouwia* habitats, which, while more extensive than during the preceding years, still constituted less than 10% of the total area. Surveys and counts established that less than 5% of the locusts occurred outside the habitats, which suggests strongly that locusts flying singly at night were settling in them selectively. Further counts revealed that while in the area as a whole the average densities were only 0.04-0.08/ha, in the green areas they reached 2000/ha, so that concentration due to selective settling was some thousands of times greater than the average density. Further concentration occurred at the time of laying in restricted sites, where moist soil was still within reach of the digging females. These sometimes led to the onset of gregarious behaviour and laying in dense groups; this in due course resulted in synchronous emergence of large numbers of hoppers, which gregarised at an early stage and formed groups, then fused to form larger groups, then bands, and within a few days began to march and ultimately produced small swarms. This explosive situation prevailed across the whole of Tamesna, over much of the Adrar des Iforas and parts of Aïr, a total of some 15 degrees square. Although control operations greatly reduced the locust numbers, many escaped.

5.4.3 Chad and Libya

During plagues the frequency of summer breeding in the Sahelian zone of Chad is among the highest in Western Africa. Via the Sudan it forms a bridge between the Central and the Western Regions and is subject to invasion by swarms from either source (DLFM). This also happens during upsurges, e.g. in 1967-68 and 1986-87, but considering the high ecological potential of the breeding grounds in Bahr el Ghazal, Ennedi, the Mortcha and the Erdi depression (Popov, 1965) the frequency of the records of recession breeding are below expectation. The area is undoubtedly under-reported; in particular with the closure of OCLALAV base in Chad in the 1970's no surveys were carried out until the mid 1980's. Nevertheless, the low frequency here and further east in Darfur-Kordofan summer breeding grounds is probably real because of the remoteness of complementary winter-spring breeding grounds. While some sporadic breeding occurs from time to time in Tibesti as well as in the Fezzan, the Haruj al Aswad, the Sagiet al Hamra and some other parts of Libya, the enormous distances and the hazards involved in traversing the intervening hostile arid desert must inevitably result in severe locust population losses.

The summer habitats in Chad are very similar to those in Niger and Mali and consist of wide expanses of Sahelo-Saharan tussock grass steppes on the deep sands of the Kanem and Manga, extending north along the Bahr el Ghazal, and east across the Wadi Haddad plains to Ouaddai and Ennedi, becoming progressively more impoverished northwards. Ennedi offers a wide range of habitats in the sands along the flanks of the massif, drained by numerous wadis. To the south-west lies the extensive plain of Mortcha, which, like Tamesna, is traversed by series of wide shallow wadis supporting open or lightly wooded steppe communities, some of which have a high potential value as locust habitats. The conditions in the vast Erdi plain north of Ennedi are more arid, but here, as in northern Tamesna, adequate, albeit infrequent rains from time to time create suitable breeding habitats which include such species as *Colocynthis, Chrozophora, Aerva, Schouwia, Morettia,* as well as *Panicum, Stipagrostis* and some annual grasses.

Given adequate rains, the enneris (major wadis) of Tibesti inundate their deltas and the floods may extend beyond the foothills for some distance into the desert, giving rise to extensive *Schouwia* and *Tribulus* habitats in every respect similar to those of Tamesna. Cumulative breeding leading to gregarisation of hoppers occurred here in 1966 following the August rains and flooding.

As in Tibesti, recession populations in Libya may breed at any time of the year except December to February, when low temperatures inhibit sexual development and greatly reduce all activity, so that any locusts present are likely to be hiding in refuges such as inside denser tussocks of vegetation, emerging only during the hottest part of the day.

The areas where the occurrence of locusts during recessions is most likely are the Fezzan and parts of central and western Libya, especially along the edges of major relief which promote run-off, such as Haruj al Aswad, Jebal as Sowdah and Hamada al Hamra. Suitable habitats for locusts are most likely to be found where drainage from the higher grounds reaches and spills into sandy areas thus creating favourable soil and moisture conditions for the development of vegetation. Some of the potentially suitable areas are already known; examples of them are in the Fezzan in the Wadi Tanezuft near Ghat where scattered breeding leading to gregarisation occurred over 60 km^2 during August-November 1966. Other potential habitats exist along the western edge of Idehan Marzuk as described by Guichard (1955), who recorded congregans breeding in 1954 in the Manakh area. The principal food plants in the habitat were *Malcolmia aegyptica, Trichodesma africanum, Neurada procumbens, Moltkiopsis ciliata, Tribulus pentandrus* and *Fagonia* spp. Guichard emphasised that the sparse vegetation promoted gregarisation among the hoppers, while dense leafy plants, e.g. *Schouwia* tended to inhibit it.

Another potential habitat is in Khor al Jifah and the associated drainage in the Sirte desert, where breeding during August and September 1972 led to gregarisation. The vegetation is predominantly a salt-bush steppe with *Salsola, Hammada, Atriplex, Salsola baryosma* and *Zygophyllum album* and, along the main channel, *Tamarix* sp. and *Retama retam*. In addition to perennials, there were some annual species such as *Fagonia* spp., *Stipagrostis plumosa* and also *Hyoscyamus muticus*, which occurred as a common member of practically every community and in places formed pure stands. This is probably the second factor which enhanced the value of this habitat, for *Hyoscyamus* is known as one of the most important food/shelter plants of the Desert Locust, the principal factor being the soil and drainage characteristics of the site which ensure prolonged maintenance of soil moisture and availability of laying sites for locusts. Khor al Jifah may be said to be typical of the locust habitats in many other parts of the Sahara, whose importance is partly due to their high and durable value as food/shelter and oviposition habitats for the Desert Locust and partly due to their localised and isolated nature in relation to the surrounding vast and largely hostile terrain. It seems probable that locusts originating from several sources gradually accumulate in such habitats, where their numbers further rise due to multiplication *in situ*. Other factors may further contribute to their concentration and ultimately some populations reach gregarising densities, as they seem to have done at Khor al Jifah in the autumn of 1972.

5.4.4 Patterns and frequency of outbreaks and upsurges in the Western Region

Desert Locust outbreaks resulting in production of gregarising populations of adults and hoppers are of frequent occurrence in the region; thus during the 16-year period 1966 to 1981 the regional organization OCLALAV conducted some control during eleven years somewhere or other in the countries under its responsibility. The scale of operations varied from 1,100 ha in 1971 to 150,200 in 1970. The five years 1966, 1972-73, 1977 and 1979 when no control was done, were drought years. The outbreaks in 1967, 1970 and 1980 were particularly serious, and even more so was that in 1986-87. The 1967 and 1986-87 outbreaks culminated in plague upsurges and were accompanied on both occasions by swarm incursions from the Central Region; 1968 was a plague year while 1986-87 was a precursor to the major short-lived 1987-89 plague.

The 1967 outbreak in Tamesna of Niger and Mali provided particularly valuable opportunities to study the processes by which gregarious populations may be produced by the progeny of individuals initially occurring at low densities; a fuller account of this is given in Roffey and Popov (1968) and a summary in Uvarov (1977) and the DLFM (Section 2.6.2.1).

The main trigger was the unusually heavy August rain, with 123 mm recorded at the OCLALAV base at In Abangharit, more than twice the estimated annual average of 60 mm (Popov, 1968), leading to the development of extensive *Schouwia* and *Tribulus* communities in many parts of Adrar des Iforas, Tamesna and Aïr.

Although some of these green areas were tens of thousands of hectares in extent, they nevertheless comprised less than ten percent of the total area (Maps 7(a-b)).

Increasing numbers of solitarious 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 km to the south from an earlier breeding during July-August from parents which might have originally come from central Algeria, where there was another outbreak during March and June (DLFM). Daytime studies on the distribution of locusts established that they were almost entirely confined to the *Schouwia* and *Tribulus* habitats, where in all evidence they must have been settling selectively. It was estimated that concentration on the larger scale due to selective settling by immigrant adults resulted in densities thousands of times greater than the average density in the area studies (DLFM).

As the locusts moved across Tamesna, further concentration occurred on the smaller scale in the *Schouwia* and *Tribulus* habitats which provided food and shelter and promoted rapid sexual maturation. Further concentration occurred at the time of laying with the suitable laying sites becoming progressively more localised as the upper soil became increasingly drier. Densities increased in many sites enough for adults to begin to manifest gregarious tendencies by mutual attraction, grouping, spontaneous short daytime flights, appearance of yellow pigmentation in males, but particularly and most significantly by dense grouping of females at laying sites, where densities typical of gregarious locusts (up to 71 egg-pods in 0.09 square metres) were recorded in places. However, unlike the synchronised laying of gregarious locusts, such groups comprised eggs ranging from those just laid to those ready to hatch.

These observations emphasised the importance of prolonged availability of soil water ensured by the particular structure of the fossil soils of Tamesna which following adequate soaking retain sufficient moisture to remain suitable for breeding at least two months after heavy but not necessarily prolonged rainfall.

The other important factor contributing to the outbreak was good survival of the eggs thanks to the very favourable ecological conditions and the very low predation and parasitisation of eggs and hoppers. Nevertheless natural mortality, probably largely due to mortality of hoppers during early instars, was estimated at 92%, thus the multiplication rate from immigrant parent adults to fourth instar hoppers in the next generation was about sixteen times.

To sum up, the main features of this outbreak were as follows:

(i) widespread heavy rain leading to the formation of favourable but localised food-shelter habitats of predominantly *Schouwia* and *Tribulus* and even more localised egg-laying sites;

(ii) concentration of waves of immigrant adults leading to formation of groups at the time of breeding;

(iii) high rate of multiplication through relatively high survival rates;

(iv) progressive drying out of initially luxuriant vegetation, furthering the concentration and gregarisation of hoppers particularly in shelter habitats (communities of *Aerva* and *Cornulaca*);

(v) extended immigration and breeding further augmenting the effects of (ii) and (iv) above.

Essentially the main difference between this major outbreak and lesser, more frequent ones, was in the much greater scale of (i), the heavy widespread rain, leading to formation of extensive, luxuriant and persistent habitats, and the scale of (ii), the large, immigrant population, which during a single generation and a multiplication rate of about sixteen resulted in the production of gregarious bands and swarms despite control operations. It is probable that the immigrant parent population was the result of April-June breeding in southern Algeria, followed by breeding during July-August in the Sahel.

The 1939 outbreak in Algeria and Niger described by Volkonsky & Volkonsky (1939, 1940) provides another example of the importance of the complementary winter-spring breeding in Algerian Sahara and the summer breeding in the Sahara of Niger (and Mali). On that occasion abundant rain fell during November 1938 over most of central Sahara and in particular the Ahnet, Mouydir and Tademait uplands resulting in heavy flows in the Botha basin. There were further rains and floods in early March 1939. In early May there were numerous adult Desert Locusts along the borders of Mouydir and later in May groups of laying adults. In June there was a mixed population of hoppers and adults, some in bands and swarms. It is possible that breeding might have been in progress since November 1938 (Waloff, 1966). Later, during September-November 1939, concentrations of gregarising and gregarious hoppers and adults were found at several points in Tamesna and the valleys of Aïr.

On the other hand, the 1980 outbreak in the Saharan habitats in Mali and Niger (The TATA area) shows a slightly different pattern (Castel, 1982). On this occasion there was a progressive build up over two overlapping generations: initially in the wadis along the south-eastern borderlands of Adrar des Iforas in Mali, which received exceptionally heavy rains in early June in the area extending from Anefis to Kidal and Tin Essako. There was further widespread rainfall in July over much of the Adrar and Tamesna and more again in August, being especially heavy in southern and western Adrar. Although rainfall declined in September and was low in October, breeding conditions remained suitable until November.

The first mature adults were recorded in early June in the main wadis Edjerer (18°30'N, 02°50'E) and In Oumfassen (18°42'N, 02°28'E) where they reached 200/ha. During July the situation developed rapidly; adult densities rose to 500-2000/ha and hopper densities to 2-20/m^2.; several bands were reported in Edjerer; the total infested area was estimated at 1200 ha. Further concentrations including grey-pink young generation adults reaching 30,000/ha over 200 ha were reported in August at 17°50'N, 00°32'E. During September the situation became more alarming with the appearance of hopper bands in southern Adrar and the spread of new generation adults westwards to Timetrine and eastwards to Tamesna and across the border to Niger. In Niger despite good rains in July and August, locust populations remained low; however, following a fall of rain estimated at 30-35 mm over western Aïr and north-central Tamesna in early September, mature locusts at densities locally reaching 1000/ha were reported in Tamesna at 18°25'N, 06°40'E and 18°54'N, 07°03'E; many of the males were bright yellow.

The situation developed rapidly during September and October and numerous concentrations and bands of hoppers of all instars in various stages of gregarisation were reported at many points north of 18°N and between 5° and 7°E; fledglings appeared from 18 October and aggregated into swarms. Despite control of over 63,000 ha by aerial spraying, there were swarm escapes from the infested areas which by the end of October and in early November involved many habitats throughout TATA from Timetrine to Adrar and Tamesna to western Air, and the adjacent areas of Algeria. During October the infestations of gregarious and gregarising hoppers and adults were reported from 24 degrees square within the area extending over five degrees of latitude (17°-22°N) and ten degrees of longitude (1°W-9°E). During November escaping swarms and scattered adults spread over the north-central Algerian Sahara and southern Morocco, reaching 32°N latitude. The outbreak was prevented from spreading further due to the combined effect of control operations and particularly the cold dry conditions, leading to dispersal and high mortality of the locusts without breeding.

The 1987-89 plague provides another example of a major upsurge in which the Western Region played a not insignificant part. This was a complex event, but enough has perhaps been said above to give a general idea of the pattern of outbreaks and upsurges in the region. What perhaps should be emphasised is that, while these can occur within the region independently, there is often an incursion from the Central Region, and it is particularly such incursions which lead to a rapid escalation of an upsurge. For instance in the wake of the 1967 upsurge, which occurred in the Central Region on an even larger scale than in the western, there were two invasions of the Western Region: the first in late June 1968 by the progeny of the spring generation in Arabia, which reached Niger and north-eastern Mali as maturing and mature swarms, with some scattered individuals reaching Mauritania; the second, and more important incursion, occurred in October by the progeny of summer generation swarms from Sudan with immature swarms reaching Niger and southern Algeria during 10-12 October, Malian Tamesna on 14 October, west-central Mauritania from 17 October, parts of the western Sahara on 20 October and southern Morocco by the end of the month (FAO archives). Fortunately the swarms became concentrated in a relatively small area in southern Morocco, where they were gradually controlled by Moroccan authorities.

5.5 The Central Region

5.5.1 General distribution of breeding during recessions and upsurges

A comparison of hopper frequency maps (Maps 10c, 10d, 16(a-d) and 17(a-d)) during plagues and recessions highlights the following main similarities and differences:

- The distribution and frequency of winter-early spring breeding between October and March on both sides of the Red Sea are very similar and closely agree in the progressive shift of the centre of gravity of the main breeding northwards from southern Yemen where it may start already from July to October, to northern Yemen, and the southern Saudi Tihama during November to January, and to northern Tihama during January to March. This sequence is clearly apparent in Fig.3 and the frequency Maps 16(a-d) and 17(a-d) which show a record of maximum monthly frequencies during plagues and recessions.

- Spring-early summer breeding in the interior of Arabia during recessions is delayed and is on a much reduced scale, and the indications are that breeding on the coast tends to persist longer, lasting well into April-May and that relatively few locusts reach Nejd and Central Arabia. Years of occurrence of spring breeding in the interior are generally years of the heavier infestations and usually some gregarisation earlier on the Tihama.

- Records of breeding during recessions in the United Arab Emirates (UAE) are fewer and in Oman more frequent than during plagues.

- Recession breeding in Somalia is almost entirely confined to the northern coastal and sub-coastal plains where it is recorded in virtually every month with the smallest number of records in August and September, and the highest during the long rains (February to June) when breeding sometimes extends to Djibouti and the Railway Area in eastern Ethiopia. This chronology generally agrees with the plague years. However, the southward early-winter movement and breeding in Somalia in the wake of the retreating ITCZ during the short rains (October-December), a high frequency occurrence during plagues, is an exceptional event during recessions and there are hardly any records of breeding south of latitude 9°N. Another high frequency swarm breeding area which shows a strikingly low incidence during recessions is the summer (monsoon) breeding belt in the Sudan, Eritrea and northern Ethiopia, where the records for July to September are very few and confined to the eastern end of the belt. In contrast they are relatively high for southern Yemen, where summer breeding is often a precursor to winter breeding. Summer breeding may also occasionally take place in Oman, but it is rare on the African side of the Gulf of Aden and the Red Sea. The low incidence of summer breeding might be a result of the scarcity of locusts in the principal source areas of the spring breeding grounds in the interior of Arabia.

5.5.2 The recession habitats in the Red Sea - Gulf of Aden (RSGA) area

Examination of the distribution of the records of the occurrence of hoppers during recessions shows a close association with characteristic vegetation types. On both the African and the Arabian sides of the Red Sea the coastal plain is separated from the interior by high mountains and at times a steep escarpment. The principal habitats are associated with the coastal and subcoastal plains and the numerous wadis that traverse them.

The width of the coastal plain varies and in places it is traversed by ranges of hills, or by flows of lava, but on the whole the following major environmental types occur in varying proportions (Maps 9(a-b), 10(a-d), 11, 12, 14(a-d), 15(a-b), 17(a-d); Habitat Tables 3, 4, 5 and 6 (see also Hemming 1961, 1966 and Vesey-Fitzgerald 1955, 1957a and 1957b)).

(a) The coastal dunes often with communities of halophytic grasses such as *Odyssea* and *Halopyrum* and *Aeluropus*.

(b) Salt flats (sabkhas) either bare or with communities of halophytic predominantly chenopodiaceous bushes and occasionally fringing mangroves.

(c) Raised coral beaches, bare or often with a sparse growth of shrubs (*Acacia*, *Lycium*) and small bushes *Limonium*, *Salsola*.

(d) Central sand plain which may occupy most of the total surface. This usually bears a steppe vegetation with or without small trees and shrubs and in Arabia is generally termed a "khabt" (pasture). Parts of the khabt may be planted with millet wherever and whenever rains are adequate.

(e) Stone and gravel plains (regs) and aprons approaching the hills.

(f) The foothills and lava fields.

(g) The subcoastal plains of varying shape and extent, frequently confined to river valleys (wadis).

(h) The main mountains and the escarpment.

(i) The plateau.

(j) The interior.

(k) The wadis, the larger associated with cultivations and a complex mosaic of diverse habitats

Among these environmental units by far the most important as locust habitats are (d) the khabt; (g) the subcoastal plains and (k) the wadis. Of the others (c), (e) and (f) can provide refuges for adults but rarely breeding conditions of any importance and (j) - the interior which is the high-frequency breeding area during plagues but is seldom reached by recession populations. The principal locust habitats are discussed briefly below for each country.

5.5.3 Eritrea and Ethiopia (Maps 10a, 10d, 11)

The southern part of the Red Sea coast, south of Buri peninsula (15°N, 40°E), is narrow and stony; thus potential locust habitats are localised and limited. The principal ones, where breeding has been recorded, are along the major wadis, particularly Wadis Karna and Saroyta, both of which show a resemblance to the wadis on the Qunfidha Tihama of Arabia. Although the Danakil depression is a land of volcanic activity there are some sandy deposits and numerous sandy wadis with shrubby steppe vegetation which provide potential habitats. This area is only rarely surveyed; thus there are few records of locust occurrence.

North of the Buri Peninsula the coast widens to an average of 30 km and continues for 350 km to the Sudan border and beyond. The ecology of the coastal areas of northern Eritrea is described by Hemming (1961); the habitat map of Northern Eritrea (Map 11) and the Habitat Table 4 are largely based on his description.

Hemming (1961) divided the coastal areas into 5 zones:

i) the littoral zone;
ii) the coastal plains;
iii) the sub-coastal plains;
iv) the lava areas;
v) the basement hill areas.

Each group is then subdivided into several major habitat types characterised by a number of plant communities. (The locust habitats and their potential are identified according to this classification, see Habitat Table 4).

As on the Arabian Red Sea coast, it is the sandy plains and wadis which provide the highest breeding and gregarisation potential. Although the human population density is relatively low here, the habitats may change seasonally as a result of agricultural practices and variations of rainfall and flooding.

5.5.4 Sudan and Egypt (Maps 10(a-d),12)

The highest frequency of breeding on the Red Sea coast of Sudan occurs along the major wadis, particularly in the southern part, in the Tokar delta and the Karora area close to the Eritrean border.

The Karora area is an extension of the Karora-Halibai habitats in Eritrea and frequently breeding and outbreaks occur simultaneously on both sides of the border. This is an extensive plain of consolidated sands, with isolated ranges of hills, traversed by Wadi Karora, which divides into an extensive outwash plain. Relief, drainage and wind action on the one hand and land use on the other, maintain a mosaic of habitats which frequently provide favourable conditions for survival, multiplication and gregarisation of locusts. As on the Arabian Tihama, it is principally the pioneer communities associated with clearance of land for millet cultivation as also the millet crops and fallows with their accompanying weeds, which constitute the principal habitats.

The Tokar delta (Map 12) is a special case; it is the largest established crop growing area on the Red Sea coast. The cropping area, divided into some 80 blocks is situated in the delta of the Wadi Baraka, a major wadi which rises in the Eritrean highlands and provides the water for the crops. Each block is subdivided by the farming community responsible into numerous plots which are planted, according to soil and water conditions and the current needs, with cotton, sorghum, maize, millet, pulses and vegetables, while the fallows and wastelands become colonised with such weeds as *Solanumum dubium, Heliotropium ramosissimum, Dipterygium glaucum, Datura* spp., *Cassia senna, Tribulus* sp., *Abutilon* sp., *Withania somnifera* and *Panicum turgidum.* The low-lying and more halophytic parts of the delta support extensive areas of adleeb (*Suaeda monoica*) and other species of predominantly chenopodiaceous salt bushes, while the higher, sandier, less halophytic parts are colonised by such shrubs as *Calotropis procera, Acacia ehrenbergiana, A. tortilis, Tamarix nilotica* and especially the mesquite *Prosopis glandulosa (= juliflora)* which has colonised large areas of the lower delta. These form extensive, often monospecific communities outside the crop areas, but also occur as patchy colonies within the crops. Coupled with the annual variability of rainfall and flooding, this area provides a particularly wide spectrum of habitat conditions and breeding opportunities. According to the records, however, it is the central plots located along the principal flood and irrigation channels (Map 12) with their sandier soils and higher moisture conditions where breeding occurs most frequently. On the other hand, it is particularly the extensive scrublands of mesquite and adleeb *(Suaeda)* which appear as the principal green areas on satellite imagery, along the northern fringes of the delta and which have a very low potential as locust habitats.

Northwards along the coast, as in Arabia, the frequency of breeding progressively declines and becomes increasingly confined to wadis. The northernmost records of recession breeding along the coast are in the Mount Elba-Shalatein area of south-eastern Egypt between 22°10'N and 23°25'N. This is an area of low hills, and gravel plains with aeolian sand deposits. Vegetation is sparse and largely confined to wadis. It is principally an *Acacia tortilis-Panicum turgidum* community with such common associates as *Acacia ehrenbergiana, Cyperus conglomeratus, Dipterygium glaucum, Aristida* spp., *Zygophyllum simplex, Pergularia daemia, Chrozophora oblongifolia* and *Aerva javanica* .

Contemporaneous and later breeding also occurs in the sub-coastal plains and inland valleys, which receive both winter-spring and some summer rain and may experience flooding.

That some movement of recession adults inland from the coast does occur is evidenced by the quite frequent capture of solitarious adults at light in Asmara, usually in May. While it is doubtful that any substantial breeding can occur on the high plateau, the land northwards in the Sudan is considerably lower and some breeding does occur in such inland valleys as Wadi Di-ib or Musmar (where it is usual in summer during plagues) between July and November, but the frequencies are not high. This could, however, be due to a lack of adequate surveys. The importance of this breeding resides in the fact that it is complementary with the winter-spring breeding on the coast, and thus ensures carry-over and maintenance of the recession populations.

5.5.5 Djibouti

Much of Djibouti is mountainous and most of the land is buried under lava flows. There are extensive areas of inland marshes, mostly saline or alkaline, which are liable to flooding. The locust habitats are thus confined to the limited sandy areas of the coast, the most important of which lie east of Djibouti towards the Somali border, and are contiguous with the Silil area of Somalia (see below); others occur around Tadjoura and Obock.

5.5.6 Somalia (Maps 9(a-b))

During recessions the principal habitats where adults and hoppers are found most frequently are on the coastal and subcoastal plains of western Somalia. South-east of Djibouti, between longitude 43° and 44°E, the coastal plain is at its widest, reaching 70 km at Silil. Eastwards, between longitude 44° and 46°E, it narrows to an average of 20 km. Beyond 46°E the plain narrows still further and east of 47°E it is often less than 10 km wide while in places the coastal hills fall directly to the sea. There are areas of shifting sand dunes, the largest such area is some 10 to 100 km east of Berbera and at Hafun on the east coast. The substrate over much of the remainder of the coast is compact alluvial sand, often with a mantle of gravel and stones or drifts and hummocks of wind-blown sand. Raised coral beaches are a common feature, particularly between Karin (45°45'E) and Bosaso (49°10'E), while at the eastern extremity there are extensive calcareous and gypseous formations often with a stony and rocky surface.

Numerous watercourses, or tugs drain the highland hills and plateaux towards the sea. East of Bosaso the larger tugs have eroded the limestone beds into deep ravines but to the west they are shallow and spreading, with a tendency to form multi-channelled beds and deltas.

The main recession habitats are associated with the finer sandy and silty soils which are deposited along the beds and in the deltas of the tugs and subsequently may be eroded and redeposited into hummocks, drifts and dunes by the action of the wind. The general aspect of the vegetation which develops here, and more sparsely on the adjacent sandy plains, is that of a wooded steppe dominated by such small shrubs and trees as *Balanites orbicularis, Acacia tortilis, A. benadirensis, Commiphora* spp. with an undergrowth of tussock grasses and small bushes such as *Lasiurus hirsutus, Panicum turgidum* and *Indigofera spinosa*. The main channels are lined with *Tamarix nilotica*, while *Leptadenia pyrotechnica* is often found along the minor sandy channels. In the lower estuaries there are often extensive communities of large *Suaeda* *monoica*, salt bushes with stands of *Halopyrum mucronatum* and *Odyssea mucronata* tussock grasses growing on the beach sands. Following rain and flooding there is often a good development of annual vegetation which includes such common food-shelter plants of the Desert Locust as *Heliotropium ramosissimum*, *Aerva javanica*, *Gisekia pharnaceoides*, *Boerhavia* sp., *Cleome* spp. *and Aristida, Latipes, Tragus, Dactyloctenium* and other grasses.

Most of the major tugs where such habitats develop and where the majority of cases of gregarisation have been recorded, are found west of Bulhar (10°32'N, 44°07'E). The principal ones are Tug Bareris near Bio Fogo (10°19'N, 44°12'E), Tug Durdur at Saba Wanak (10° 32'N), Tug Osilih at Lukhaya (10°55N, 43°55'E) and Tug Silil (11°00'N, 43°30'E). Of these, the last two are the most important.

There are other, somewhat less important, breeding habitats on the coastal plain, some east of Berbera notably near Harshau (11°11'N, 47°26'E), Las Khoreh, and Durdureh and also others on the eastern coasts between Candala and Bargal. Others are known in some inland places and valleys of the subcoastal zone, notably at Boghan San (10°02'N, 44°20'E), Sanka Beriska (10°17'N, 45°36'E), Hagal (10°15'N, 45°44'E), Las Dureh (10°11'N, 45°59'E) and possibly a few others may exist in similar locations elsewhere. Their common characteristics are: sandy-silty alluvial soil; adequate drainage; and open, or lightly-wooded steppe vegetation. Although of similar appearance the specific species composition varies in response to edaphic conditions and frequently includes local endemics, such as *Iphiona rotundifolia*, which are known to be palatable to locusts.

Breeding of recession populations has occasionally been recorded at very low densities beyond the limits of the subcoastal plain in other vegetation zones. The southern limit of hoppers is 4°N, and 2°N for adults. Generally, maximum southward penetration follows exceptional build-up in the coastal areas during the preceding months and occurs during October and November analogous with swarming populations. The numbers that reach and then breed in these more remote habitats are generally very small, unless build-up and gregarisation had occurred previously.

During recessions the frequency of recorded breeding in Somalia is not high: the highest monthly frequency for any degree square within the country is only 3, recorded during April and June (Map 9b), as compared with a record of 15 for the Red Sea Coast of the Sudan. However, breeding can occur in any month of the year and in some years sequences of favourable rainfall during winter and spring through into the summer months have resulted in substantial build-up and gregarisation of initially solitary-living locusts. A particularly well-documented case is that of the 1956-1957 season when regular monitoring was conducted by Desert Locust Survey personnel. An initial estimated population of some 10^7 to 10^8 individuals was present in October and November. Extensive reconnaissances conducted from that date established that large scale breeding was taking place; the total population was rising rapidly to reach some 10^9 in late February but by May was estimated at 10^{10} individuals despite the application of intensive control measures in the later stages. Thus, an increase of 100 to 1000 times had taken place in the course of 6 months (J. Roffey, 1959, unpublished report).

Breeding on the north-west Somali coast, in a sequence not unlike the above, contributed in a dramatic manner to the 1977-1978 plague upsurge (Roffey, 1982). This resulted from an initial incursion, probably from Arabia, in late October 1977. Exceptionally favourable breeding conditions following abundant and widespread rains during November 1977 and continuing through to February 1978, permitted the occurrence of two successive generations resulting in the production of numerous bands and swarms. Later, in June 1978, there was a spectacular direct migration of a large number of swarms from the Horn of Africa to India.

Description of the Habitats

The main characteristics of the principal habitats of the coastal and subcostal zones, based on a classification by Hemming (1966) of the northern region of the Somali Republic are given in Habitat Table 5. Those in the other more southerly zones have not been studied in such detail but physiognomically they are similar to the habitats in the sub-coastal region.

The *Acacia bussei zone* consists of open shrub or open woodland but large areas of this open woodland contain dead standing trees, a result of overgrazing, lopping and possibly increasingly arid conditions (Dhanani, 1988). The other species found in association with *Acacia bussei* are *A. nilotica* and *A. mellifera* and the low shrubs, such as *Boscia, Grewia, Cadaba,* and with *Indigofera* and *Ipomoea* abundant in the heavily grazed areas; *Chrysopogon aucheri, Sporobolus* spp., *Andropogon kelleri* and *Dactyloctenium scindicum* are also found.

The *Acacia etbaica* zone ranges between 1250 and 1500 m in altitude, with an annual rainfall of 350 mm and 550 mm. The other main species found in this zone are *Balanites glabra, Cadaba farinosa, Maerua sessiliflora,* and *Grewia* spp. However, this zone is the most favourable for rain-fed agriculture and is being increasingly cleared and exploited, especially between Hargeisa and Borama.

The Evergreen scrub zone is situated immediately above the *Acacia etbaica* zone and consists of open shrub, characterised by *Buxus hildebrandtii, Dodonaea viscosa, Cadia purpurea, Terminalia brownii* and *Combretum trichanthum.* The *Juniperus excelsa* forest occurs on the highest mountains above an altitude of 1650 m. This forest has been badly damaged by human activities but pockets of forest can still be seen on the Libaaxley mountains in the west, on Mount Surud and on the Cal Madow range.

The Haud-type mixed bush lies to the south of the *Acacia bussei* zone and continues down the central region of Somalia covering much of the Ogaden and the Northern Province of Kenya. The vegetation is dominated by the same plant species as in the subcostal zone but with a higher species diversity. The vegetation is essentially woody with shrubs 1 to 5 m in height, the most important species being *Acacia* and *Commiphora.* The perennial grass *Chrysopogon aucheri* dominates lightly grassed areas but was probably once even more abundant (Hemming, 1966). Much of this zone is being altered by overgrazing and plants which are characteristic of heavily grazed areas, such as *Aerva javanica, Calotropis procera, Indigofera articulata, Iphiona rotundifolia* and *Ipomoea* spp., begin to assume importance.

The Gypseous zone is found in eastern and southern Somalia and the Nogal valley. The vegetation is very sparse and is dominated by numerous halophytes. The soil is frequently poorly drained and salts brought to the surface by evaporation are common. This zone is largely avoided by the Desert Locust during both plagues and recessions.

5.5.7 Saudi Arabia and Yemen

General characteristics

Rainfall

The highlands of south-west Arabia (with peaks rising to above 3000 m) receive more rain than any other part of the Arabian peninsula with a maximum of 700 to 1000 mm a year. Much of the rainfall drains off the highlands towards the coasts of the Red Sea, the Tihama and the Gulf of Aden or towards the vast plains of the interior. The coasts receive less rain than the highlands, in many parts only 100 mm a year. As a rule, north of the tropic of cancer most of the rain falls in winter and south of the tropic the rain occurs mostly in summer. However, as in Eastern Africa under the influence of the highlands the Red Sea and Gulf of Aden, the coasts can have an overlapping sequence of rainfall during winter, spring and summer.

Distribution of locust breeding (Maps 2c, 3c, 15)

There is a close correlation in the chronology and the frequency of Desert Locust breeding between the African and the Arabian coasts of the Red Sea and the Gulf of Aden. The frequency during plagues and recessions is one of the highest anywhere, while the overlapping rainfall regimes in favourable years permit prolonged breeding, although in a succession of habitats, that may span three successive generations, thus leading to a rapid build-up of locust populations. In southern Yemen (as in Somalia), breeding may occur in any month, but is more frequent during July to October, while on the Tihama of northern Yemen and Saudi Arabia, rain is more frequent during November to March, but may continue until June. Given these breeding opportunities, together with suitable habitats, this area has the highest record of Desert Locust outbreaks and plague upsurges.

Conversely, in the interior of Arabia, there is a considerable difference between plagues, when it is a high frequency spring breeding area, and recessions when there are few records of breeding. Most of the recession breeding in the interior is recorded in the lowlands of southern Hejaz and Yemen where breeding is more frequent in summer. No recession breeding has been recorded in the highlands and even during plagues breeding rarely occurs there.

Description of habitats (Maps 14a-d)

The coasts of the Red Sea and the Gulf of Aden show a similar zonation to that found on the African coast of the Red Sea.

(i) *Halophytic coastal communities.* Along the coast and immediately inland, the soils are saline. Much of this is a belt of mud flats or sabkhas which are largely devoid of vegetation although scattered salt bushes belonging principally to the genera; *Suaeda, Sevada, Halopeplis* and *Salicornia* may be found. Some of the coves and inlets bear a fringe of mangroves which are quite visible on LANDSAT imagery. Elsewhere, there are extensive formations of coastal sand dunes, sometimes with a sparse covering of *Odyssea* and *Halopyrum* tussock grasses. Other parts of the shore consist of raised coral beaches, where the characteristic plant is *Limonium* spp. sometimes accompanied by stunted *Acacias*. None of the halophytic communities constitutes a suitable Desert Locust habitat.

(ii) *The coastal plain (the khabt)*. Inland from the halophytic coastal belt, lies the coastal plain where the vegetation is largely non-halophytic. The plain extends to the foothills of the main Hejaz, Asir and the Yemen highlands; its width may exceed 50 km, but is often less and in places the hills and lava fields may reach the coast. Much of the coastal plain is flat or gently undulating rising gradually towards the hills. The substrate consists of sedimentary deposits of silts and sands. In places, especially towards the hills, the surface is gravelly and stony, bare or with scattered xerphytic bushes such as *Salsola* spp. or *Indigofera spinosa* and a few small *Acacia* spp. Much of the central plain, however, is sandy, flat or with rolling ridge dunes or in places, especially the mouths of wadis, the sands form chains of barkhan dunes. It is this sandy plain, known as the khabt with the numerous wadis that traverse it draining the highlands towards the Red Sea and the Gulf of Aden, that forms the principal locust habitat.

South-western Arabia has a very long history of human occupation and intensive land use, so locust habitats must be considered in the light of the impact of agriculture and pastoral practices of the region. Given the low rainfall of the coast, the principal agricultural areas are found in the major wadis, which can flood for several weeks, while the larger ones can, in the foothills, maintain a flow for most of the year. However, there are as yet few modern irrigation projects and much of the irrigation is by the long-established traditional method of earthen dams and dykes which prevent most of the flood waters from the highlands reaching the sea.

The principal crop grown on the regularly irrigated heavy silty soils is dura *(Sorghum* spp.*)* with some cotton, sesame, tobacco, fruit and vegetables. The marginal and lighter silts and sands are planted with dukhn (bulrush millet, *Pennisetum typhoideum)*. This crop is also grown on the khabt outside the wadis whenever rainfall is adequate. This may sometimes occur as a single heavy fall of rain and in this manner, even areas where the annual rainfall would be regarded as inadequate for dry farming, may at times be planted. However, there is little dry planting on the Tihama north of Lith or on the southern coast of south Yemen. On the other hand, wherever the water table is sufficiently high, irrigation from wells is attempted and is generally on the increase.

Land that is left unplanted, as well as the fallows, is turned to grazing and is colonised by pioneer and secondary plant communities, which include such food/shelter plants of the Desert Locust as *Heliotropium* spp., *Dipterygium glaucum, Chrozophora* spp., *Tribulus* spp., *Aerva javanica* and *Panicum turgidum.* These communities, together with the unweeded millet fields, constitute the major food/shelter habitats of the locust. As most of the pioneer plants are unpalatable to livestock, these communities are not favoured by grazing and so, in general terms, increasing pressure on land has not in fact affected the ecological potential for locusts.

On Maps 14(a-d) and Map 15 and in Habitat Table 6 the potential of locust habitats is shown in general terms without attempting precise individualisation as was done, for instance, in the case of the south Saharan habitats. This is because the variability and the instability of the environment, resulting from climatic and cultural changes from year to year are such that the pattern of distribution of breeding varies from one occasion to the next in response to the environmental changes as well as the dynamics of the locust populations.

The principal areas on the coastal plain of the Red Sea Gulf of Aden (RSGA) area of Arabia, where on historical evidence locust breeding and gregarisation has been recorded most frequently, are discussed below.

Chronologically breeding progresses from the southern Yemen Tihama to the northern, then to the Gizan Tihama of Saudi Arabia, then to Qunfidha Tihama, and later to northern Tihama to Jeddah and beyond.

The southern Yemen Tihama. This is predominantly a sandy plain of varying width. It is flat, undulating or buried under fixed or mobile dune formations. Other types of terrain, stony, gravelly or silty regs and saline sabkhas are of relatively limited extent, but there are large areas of lava flow.

Much of the sandy terrain is a khabt. To a great extent this is a hummocky steppe of tussock grasses, like *Panicum turgidum* and *Odyssea mucronata*, salt bushes like *Salsola tetrandra*, and herbs like *Aerva javanica*. Following rain there is an abundance of annuals and emphemerals. Trees, shrubs and larger bushes like *Acacia tortilis, A. eherenbergiana, Maerua crassifolia, Salvadora persica, Cadaba rotundifolia* may be locally common where the water table is higher, notably in wadis where such other trees and shrubs as *Ziziphus spina-christi* and *Calotropis procera* may also be found.

Following clearance of land for cultivation, the area becomes colonised by pioneer communities of herbs such as *Heliotropium ramosissimum, Dipterygium glaucum, Tribulus pentrandrus, Tephrosia apollinea, Cassia* spp. and others which constitute the favourite food/shelter habitats of Desert Locust hoppers. Such sites are often situated in and along wadis where soil moisture conditions allow prolonged oviposition and where consequently locusts tend to aggregate and multiply and sometimes eventually gregarise. Such gregarisation has been recorded in the Am Riga area, near Shuqra and Ahwar, and similar conditions conducive to gregarisation are likely to exist in a few other localities in south Yemen.

Locust breeding in major agricultural areas like Abyan and Dathina is less frequent. It seems that heavier tilled irrigated soils and sorghum crops do not provide suitable conditions for the Desert Locust, which, in such areas, tends to keep to marginal fallow areas and lighter soils bearing millet crops and pioneer communities of weeds.

The northern Yemen Tihama. The principal difference between the southern and the northern Yemen Tihamas, is in the markedly greater pressure on land use in the north as a result of a higher rainfall and watertable and, thus, of agricultural potential, a denser human population and greater material resources. Consequently during the last decade in particular, there has been rapid expansion of agriculture both through government-sponsored action such as the Tihama Development Authority (TDA) in Wadi Zabid and in the private sector. The latter finds expression principally in a proliferation of wells equipped with motor-driven rotary pumps collectively irrigating large areas of the Tihama, particularly nearer the mountains where soil is richer and the water table higher. Nevertheless large areas of unirrigated khabt remain, but here again the khabt comes under much greater pressure than its counterpart in southern Yemen. The frequency and the extent of millet rotation is such that very little of the khabt remains fallow long enough to regenerate to the stage of a *Panicum* steppe and even less to a higher succession represented by such elements as *Salvadora persica, Leptadenia pyrotechnica, Cadaba rotundifolia* or *Acacia ehrenbergiana* and *A. tortilis.* In several areas such as Haradh, Zohrah, Bajil, Wadi Rima, and Wadi Zabid, continued clearing of the khabt for planting has promoted wind erosion and led to the formation of considerable areas of shifting sands, certainly of greater extent in 1989 than in 1962 or 1971, when the same areas were seen by the author.

Yet all these changes have done little to diminish the ecological potential of the environment for locusts. Although the irrigated agricultural land on heavier soils seem to be largely avoided by locusts, large areas of the sandy khabt remain, and their frequent clearance leading to the development of pioneer communities, containing such favourite food-shelter plants as *Heliotropium ramosissimum, Dipterygium glaucum, Tribulus pentandrus* and *Aerva javanica* has, if anything, enhanced their value for locusts.

Historically breeding is most frequent in the northern part of the Tihama in a belt corresponding to the sandy khabt, extending from the Saudi border to Wadi Mawr with the highest frequency in the Haradh-Habil area. A second belt is situated further south, extending from Zeidiyah down to Bajil and Mansuriyah. Further south breeding is rare, and there is only one record of breeding south of Mocha. The reason for this is not obvious, since that area contains suitable habitats. Perhaps the explanation lies in the winds, which are particularly strong in the south-western corner of the peninsula and which tend to carry the locusts to more northerly habitats.

No breeding is recorded in the inland mountain valleys of the Tihama. However, potentially, survival and even multiplication is possible in fallows and wastelands associated with cultivations that exist in some of the larger wadis.

<u>The Saudi Arabian Tihama</u>. The frequency of breeding is higher on the Saudi than the Yemen Tihamas and is particularly high in Qunfidha Tihama. The likely reason is two-fold: (a) progressive increase of populations during their northward progression as a result of multiplication and continued influx, and (b) the particularly favourable habitat conditions on the Tihama in the sector between Wadi Shafqa in the south and Wadi Lith in the north.

The pressure on the environment arising from agricultural practices, is less intense than it is in northern Yemen. The greatest pressure on the Saudi Tihamas is from grazing exerted by large herds of local and imported sheep and goats, and not only on the coastal plain but everywhere where grazing is to be found. This affects both the quantity and the quality of the vegetation, but here again this process has not greatly diminished the value of the habitat for locusts. This is because many of its favourite food/shelter plants: *Heliotropium, Dipterygium, Tephrosia, Cassia, Aerva, Cleome,* are unpalatable to stock and thus the pressure of grazing if anything, favours the maintenance of locust habitats.

Most of the khabt is suitable for locusts, but particularly good are areas of drainage offering better soil and moisture conditions both for the development of locust food/shelter habitats and as oviposition sites, and also, incidentally, good conditions for planting of dukhn, which, being highly palatable, is very vulnerable to locust attack, and especially when left unweeded, forms a favoured habitat.

Since the better habitats are localised, they concentrate locusts; whenever concentrations reach critical densities, gregarisation occurs and, depending on the overall size of the population, greater or lesser outbreaks may result.

Practically all the wadis in the Qunfidha Tihama between Lith and Shafqa, and in the Jizan Tihama between Wadi Baysh and the Yemen border and again in the Shuqaiq area, as well as much of the surrounding khabt, provide such outbreak conditions in the event of adequate rainfall and flooding.

Northwards from Lith, the quantity of rainfall declines rapidly and locust habitats become confined to individual wadis like Tuwwal, Dhahban, Rabigh, Safra, Umm Lajj and others. The timing of breeding is later in spring and its frequency declines markedly.

(iii) *Subcoastal plains, hills and lava fields.* During both plagues and recessions, breeding sometimes occurs in the subcoastal plains and valleys situated in the foothills and behind the coastal hills and lava fields. Much of the land here is too stony and rocky to provide suitable habitats, although breeding occurs in areas where softer alluvial or aeolian deposits accumulate. Many of these areas are cultivated and support plant communities similar to those on the coastal plains; *Cassia italica, C. senna, Heliotropium pallens, Tephrosia apollinea* and *Aerva javanica* are the frequent dominant herbs.

(iv) *The mountains.* The mountains and the highlands of south western Arabia support a rich and varied flora that exhibits a marked zonation with altitude. Acacias dominate the lower slopes, but *Olea chrysophylla* (wild olive), *Tarconanthus comphoratus,* and aromatic labiates (Apiaceae) are characteristic of the upper slopes. However, as these do not constitute locust habitats no distinction is shown on the habitat map except to show the juniper woodlands that grow on the highest peaks along the main watershed and which are easily distinguishable on LANDSAT imagery.

While adult solitarious Desert Locusts occasionally reach the highlands, their importance is negligible, and probably few survive to breed there. There is only one unconfirmed record during a recession period: of hoppers near Dhammar in June 1970.

Once locusts gregarise and begin to fly actively by day, their appearance in the highlands becomes more likely and some breeding occasionally occurs. Again, the importance of this area during recessions is negligible.

(v) *The lowlands of the interior.* The inland slopes of the mountains of south west Arabia are in the rain shadow and thus direct rain is scanty, but flooding does occur and the main wadis support abundant vegetation such as *Acacia* spp., *Tamarix* spp., *Salvadora persica*, and *Calligonum comosum* trees and shrubs with a variety of bushes, tussock grasses and herbs, most of these are also common on the coastal plains and foothills. Many of the wadis (for example Tathlith, Dawasir, Najran, Jawf, Marib, Harib, Beihan, Hadhramaut) support important settlements and are extensively cultivated. Breeding occurs here during both plagues and recessions in habitats consisting principally of pioneer and annual plant communities associated with crop areas and pastures, some of the latter are well away from crop areas within the limits of the Rub al Khali.

The lowlands of the interior are an important breeding area, for although the annual rainfall is low, there are occasional heavy downpours coupled with flooding from the mountains. Moreover, such breeding as occurs is often complementary with that along the coasts and thus can make an important contribution towards the build-up of locust numbers. This area may also be reached by locust populations, from sources in the Eastern Region (India, Pakistan, southern Iran), and eastern Arabia (the United Arab Emirates and Oman) and from other parts of the Central Region (Somalia, Djibouti, the Tihama). On a number of occasions in the past, for instance in 1949, heavy breeding occurred here and in the absence of control it made an important contribution to the upsurge of the major plague in 1950, which then lasted until 1963. The highest frequency is during the Seif and Kharif seasons (April to October).

The physical characteristics of the habitats are fairly similar to those of the coastal areas and many of the plants are common to both. It is predominantly a steppe with *Panicum* and scattered *Acacia* dominant in many areas. Another very common plant is *Rhazya stricta*, which although unpalatable to locusts, is a useful shelter plant. The most widespread food/shelter plant of locusts is *Dipterygium* which grows everywhere where rain may fall, even in the heart of Rub of Khali. *Tribulus* sp. is another, while a profusion of annuals spring up after rains. The quality of these habitats is good and, being generally localised and of relatively limited extent, they tend to concentrate locusts, a process which favours gregarisation.

(vi) *Central Arabia.* During major upsurges and plagues the interior of Arabia is a moderately high frequency spring breeding area, but during recessions there are few records of breeding. However, there are many suitable habitats in the interior where locusts breed during plagues. Most of the sandy areas of the Hejaz interior, Nejd and the Eastern Province of Saudi Arabia together with the major wadis and sandy steppes in the Hail, Qasim, Tuwaiq and Al Kharj areas provide suitable breeding habitats.

Major agricultural development in the interior has increased the range of habitats for locusts. During the late 1988-early 1989 swarm invasion of Arabia, swarms were found in the crop areas of the Qasim, Al Hasa, Al Kharj and Dawasir when dry conditions prevailed elsewhere and although control measures were undertaken the survivors were found inside and along the margins of the crops where some matured and bred.

5.5.8 Oman and the United Arab Emirates

The frequency of breeding in Oman and the United Arab Emirates is not high, but it has been recorded in virtually every month of the year and the low frequencies could be due to scarcity of surveys; what is particularly important about this area, however, is the occurrence of infrequent but abundant rains brought by cyclones which develop over the Arabian Sea and then move inland, bringing widespread torrential rains along their path (Pedgley, 1969). Such abundant rainfall and flooding lead to the development of habitats which provide suitable conditions for multiplication of locusts and sometimes their gregarisation. Such events at times contribute to plague upsurges, as happened notably during the 1948-49, 1966-67 and probably 1977-78 upsurges. Yet again abundant rains during July 1986 and February 1990 in the Sharqiyah area of Oman, led to concentrated breeding and gregarisation, but on these last occasions timely control by the Plant Protection Service prevented major swarm migration.

Locust Habitats in Oman and the United Arab Emirates

Some of the principal habitats where breeding occurred during the 1967 upsurge, in the interior and the coastal areas of eastern Oman were visited by Popov in January-March 1968. A description of them is extracted from Popov (1988).

The locust habitats may be attributed to one of three main types: (a) the sands, (b) the wadis, and (c) the coastal and subcoastal plains.

(a) The sands. The sands of eastern Rub al Khali at Sahma are mountainous block- and chain-dunes, often reaching a height of 200 m. the upper crests are mobile and barren but for a few artha (*Calligonum comosum),* bushes and tufts of qseis (*Cyperus conglomeratus).* The lower slopes and hollows, however, bear a much more abundant vegetation, which after heavy rains of the summer of 1967 could be called luxuriant if rather meagre floristically. Among the dominants noted were *Cyperus* sp., birkan *(Limeum* sp.), rimram (*Heliotropium kotschyi*), harm (*Zygophyllum album* and *Z. coccineum*), alga (*Dipterygium glaucum),* nezza (*Crotalaria* sp.), Zahr (*Tribulus* sp.), *nussi (Aristida* spp.) and *Centropodia forskalii.* In the inter-dunes and surrounding plains the vegetation is patchy, comprising salt bushes, mainly *Zygophyllum* sp. and annuals such as halawa *(Fagonia* sp.) and nussi *(Aristida* spp.). The food and shelter value of habitats of this type must be rated high, but their laying potential is lower, for the coarse dune sand drains quickly and the moisture is soon beyond the reach of laying locusts.

(b) The wadis. Numerous wadis drain the mountains of Oman and Dhofar, some seawards, others towards the great lowlands of eastern Rub' al Khali, where they become lost in the sands or in salt marshes (sabkhas) like the Umm al Samim. The major wadis which spill into the sands are of particular interest, for it is in their deltas where the combined effect of water and wind erosion create a mosaic of different soils, which in turn lead to the development of a wide range of plant communities, including some which offer favourable habitats for the Desert Locust. Laying in these habitats may continue to be possible in some situation or another, for up to 5 months after rain. Thus in the delta of a wadi near Nafun soil moisture was found at 8 cm below the surface in late January, the last known rain having fallen the previous July or August at the latest.

In addition to the plant communities found in the sands, there are several others, in particular those dominated by tussock grasses; *Cymbopogon schoenanthus* and *Lasiurus hirsutus* in predominantly silty soils, and *Panicum turgidum* and *Pennisetum divisum* in predominantly sandy soils. The tussock grasses often grow in association with trees and shrubs, like *Acacia tortilis, A. ehrenbergiana,* or *Prosopis cineraria* and herbs such as *Tephrosia apollinea* and *Aerva javanica.*

In depressions between dunes liable to flooding, there are sometimes extensive developments of bushy *Calligonum comosum* and *Hammada elegans* and usually some ghaf *(Prosopis cineraria)* trees. Annual communities are richer and more varied than in the sands, the commonest herbs being *Aerva javanica, Tephrosia apollinea, Dipterygium glaucum, Farsetia ramosissima, Cleome* spp. and many others.

In the lower part of the delta water stagnation often occurs and salinity may become pronounced. Various halophytic communities dominated by such species as *Tamarix* sp. and *Zygophyllum* spp., *Sevada schimperi* and *Halopeplis perfoliata* become established. Eventually as in the Umm Samim salt flats, salinity becomes too great for any plant growth.

Locusts tend to be particularly common in sandy and silty areas bearing communities of tussock grasses (*Panicum turgidum, Pennisetum divisum, Lasiurus hirsutus)* and the sedge *Cyperus conglomeratus* and a variety of bushes and herbs especially the common Desert Locust food and shelter plants such as *Dipterygium glaucum, Heliotropium kotschyi, Tephrosia apollinea, Tribulus* sp. and *Aerva javanica.*

Some sand-loving halophytic elements such as harm *(Zygophyllum coccineum* and *Z. album)* and rimth *(Hammada elegans)* were frequent or even at times dominant members of such communities, but truly halophytic vegetation in salt marshes is generally avoided by locusts, as are sparsely vegetated stony and gravelly plains like the Jiddat al Harasis, where plant cover is insufficient to provide adequate shelter. Much of the interior of Oman consists of great expanses of such barren plains, consequently the localised habitats in the wadis, forming only a small fraction of the terrain tend to concentrate the locusts and this probably plays an important part in the development of outbreaks.

(c) The eastern coastal and sub-coastal plains. In general the ecological conditions found along the coastal and sub-coastal plains, notably such areas as Hawshi, Sirwan, Wadi Iswir, Al Wat and the Jazir coast are similar to those found along the wadis, the difference being more topographical than ecological. These areas are plains and valleys, enclosed on one or more sides by more or less prominent features, drained by water courses or sheet flooding. As in the case of wadis this creates diverse soil conditions; coarser soils in the higher and finer soils in the lower parts. Locust habitats are predominantly found along the lower slopes where accumulations of sand and silt occur. Here in such areas as Hawshi, Jawba and Iswir there develops extensive communities of *Panicum turgidum, Lasiurus hirsutus, Tephrosia apollinea, Dipterygium glaucum, Aerva javanica, Heliotropium kotschyi and Tribulus* spp. rivalling in luxuriance the better known locust habitats of the Tihama in western Arabia. Extensive and occasionally concentrated breeding occurred here during July-October 1967.

Apart from the habitats in the hinterland of Oman where outbreak conditions develop from time to time in the event of sporadically abundant rains, there are other habitats in the coastal areas of Oman and the United Arab Emirates, where breeding has been recorded more frequently during plagues and recessions. The area of highest recorded frequencies is the coastal plain of the United Arab Emirates, which receive fairly regular winter-spring Mediterranean type rains. The plain is a broad-based triangle lying between the Persian Gulf and the Hajar mountains; much of the surface is occupied by a northward projection of the high continental sands from the Rub al Khali, leaving a coastal, largely saline silty/sandy maritime plain and an inland, largely gravelly and stony plain, extending to the foothills of the Hajar range. Thus the maritime plain, the sands, the inland plain, the foothills and the wadis form the four major types of habitat in this area.

Much of the coastal flats (sabkhas) are too saline to support vegetation, but as land rises and becomes sandier salt-bushes which include *Salsola* sp., *Suaeda* sp., *Cornulaca monacantha* and *Zygophyllum album* appear. This is followed by a belt of white sands of coral and shell origin which bear more abundant vegetation comprising, in addition to the salt-bushes, such herbs as *Heliotropium* sp., *Moltkiopsis ciliata, Convolvlus* sp. and a variety of annuals like *Centaurea pallescens, Emex spinosus* and *Plantago cylindrica*. Locust breeding may occur here, but rather more in the deeper sands where tussock grasses, *Panicum turgidum* and *Pennisetum divisum* gradually replace the salt bushes. The high, red continental dunes further inland constitute habitats of somewhat higher potential in providing a wider range of food-shelter plains. The vegetation is composed of shrubby *Prosopis cinerarea, Calotropis procera* and also *Calligonum comusum* and *Lycium* shrubs, tussocks of *Panicum, Pennisetum* and *Cyperus conglomeratus* and the herb *Moltkiopsis ciliata, Tribulus* sp. and *Chrozophora oblongifolia,* all of which are favourite food-shelter plants, as well as a profusion of annuals belonging to the genera *Plantago, Centaurea, Limeum, Monsonia, Medicago, Lotus, Hippocrepis, Calendula* and *Silene*.

In depressions between the dunes and in the inland plain beyond the sands, the soil is compacted sand, often with a covering of gravel and stones. The principal community is *Acacia tortilis - Hammada elegans* with such associates as *Calligonum comosum, Prosopis cineraria* and numerous herbs and ephemerals such as *Cenchrus setigerus, Stipa capensis, Aristida adscensionis, Neurada procumbens, Asphodelus tenuifolius* with patches of *Malva parviflora, Emex spinosus* and *Zygophyllum simplex.*

The vegetation, particularly the perennials, grow more abundantly in the wadis where, in addition to the above, are also found such species as *Acacia ehrenbergiana, Ziziphus* sp., *Pteropyrum scoparium* and *Gaillonia aucheri* bushes, while *Cymbopogon schoenanthus* and *Lasiurus hirsutus* are prominent among tussock grasses. Plague and recession breeding occurs in the sandier parts of the plain and especially along the sandy wadis, where habitats are improved by run-off.

The plain and the sands extend southwards to the interior of Oman, where conditions become progressively more arid and the existence of habitats increasingly dependent on run-off and the occurrence of exceptional rains.

The Batinah coast of Oman is relatively well-watered by more frequent rainfall, but particularly by flooding from the mountains, which also maintains a high water-table. Although much of the ground is stony and gravelly, there is some cultivation of dates, citrus, tobacco, cereals and vegetables as well as areas of *Prosopis* and *Acacia* woodlands. The locust habitats are largely confined to rather limited sandy areas where steppe vegetation similar to that of United Arab Emirates coast develops. Among the bushes the dominants are *Calligonum comosum, Lycium persicum* and *Cornulaca monacantha;* among the tussock grasses *Panicum turgidum* and *Pennisetum divisum* and among the chamaeophytes and therophytes *Indigofera intricata, Aerva javanica, Dipterygium glaucum, Centaurea pallescens, Chrozophora oblongifolia, Tribulus* sp. and *Neurada procumbens.*

Such areas, sometimes developing into low rolling dunes, exist between Muscat and Seeb and in the Sohar-Shinas areas and locust breeding has occasionally been recorded in them.

5.5.9 Dynamics of seasonal and plague upsurges

5.5.9.1 The Red Sea - Gulf of Aden (RSGA) area

The coastal areas of the Red Sea and the Gulf of Aden may be regarded as a major reservoir within which locust populations survive and breed, producing two to three generations annually. Breeding occurs principally from July to March, but occasionally may last until April-June with production of an extra generation. This success is ensured by the relatively frequent, if low, rainfall enhanced by flooding down the numerous wadis draining the closely adjacent highlands. Breeding which occurs when conditions are suitable, may lead to gregarisation.

Gregarisation and seasonal upsurges in RSGA area occur frequently. For instance in the Sudan, preventive control during 1964-83 was conducted in most years. However, despite the favourable conditions and the high frequency of reproduction and minor gregarisation, all the better documented examples of major upsurges involving RSGA area at an early stage, appear to have been associated with an influx of large numbers from outside. The 1948-49 and 1967 plague upsurges point unambiguously to Oman as the initial source area (DLFM). The 1978 plague upsurge is also believed to have involved populations from outside - probably Oman (Roffey, 1982). The 1972-73 major outbreak on the Saudi Arabian Tihama was initiated by the appearance of large numbers of adults in October, whose origin can be traced to the preceding monsoon breeding during June-September in Oman, south-western Arabia and northern Somalia, leading to the appearance of numerous groups, bands and swarms.

Yet another example is that of the Tihama outbreak in January-March 1965 when the likely external source was the progeny of the preceding prolonged monsoon breeding in the Indian desert which led to the production of gregarious swarms. During November these apparently spread through Southern Arabia along a route frequently recorded in the past (DLFM Vol. II, Fig. 53F, p.39). Their spread to the Tihama in November-December would be a natural sequence.

This dependence on topping-up from outside before any major outbreak can develop in the Red Sea coastal breeding areas, has a likely explanation: the very excellence of ecological conditions and persistent presence of locusts, would be conducive to a parallel development of various specialised and unspecialised pathogens, parasitoids and predators. There are indeed numerous records of egg predation by larvae of *Trox procerus* (Coleoptera), *Stomorhina lunata* and *Systoechus* sp. (Diptera), of parasitisation of hoppers and adults by *Blaesoxipha filipjevi* and *Symmictus flavipilosus* (Diptera) and of predation by migrant and resident birds and a host of insects and other arthropods. All these plus further mortality due to climatic causes take a heavy toll of locust numbers with the result that the "normal resident" populations have a low rate of multiplication. Indeed the only two well-documented quantitative studies on locust numbers in a seasonal breeding area (both in Eritrea) actually show a reduction from the parent to the filial generation (Stower and Greathead, 1969; Roffey and Stower, 1983).

Thus initially low populations in the face of such losses will often have difficulty in realising the order of increase required for a major outbreak leading to a plague upsurge. Given the high reproductive potential, the speed of multiplication and the mobility of locusts, the prospects rapidly improve in the short term with an increase in their numbers. A sudden influx of large numbers would so dilute mortality agents as to realise much higher rates of multiplication and the likelihood of large-scale gregarisation and major outbreaks.

5.5.9.2 Areas outside the RSGA area

The records of recession breeding in the Central Region outside the RSGA area are very sporadic and infrequent. There are scarcely any records from the short rains breeding grounds in central Somalia and few from the monsoon belt in the interior of Sudan. However, some spring breeding occurs in the interior of Arabia. The fact that the years when breeding has been recorded in the interior are also those when it was heaviest in the RSGA area, suggests that the two are complementary. Indeed during plagues, the movement of swarms resulting from winter breeding on the Red Sea coast to spring breeding grounds in the interior of Arabia is the rule and this trend also occurred during the 1949, 1967 and 1978 plague upsurges. There are no direct observations on the spread of the progeny of spring breeding in the interior of Arabia, except that there is a general decline from July although some hoppers and particularly adults may persist through autumn and even winter in a few favourite localities. By analogy with events during plagues and upsurges, it may be expected that some of the spring-bred adults in the interior of Arabia and also United Arab Emirates and Oman would spread towards summer breeding grounds; those nearest (Oman and south-west Arabia), are most likely to be reached by solitarious populations, although those already gregarised are known to be capable of long-range migrations (e.g. spread of swarms in June 1968 from Arabia across the Red Sea to Sudan, Niger and Mali (Desert Locust Forecasting Manual)).

The adults resulting from the rare summer breeding in the interior of Sudan apparently move directly to the RSGA area. The best documented case is that of 1978 discussed by Roffey (1982).

Apart from the likely source area round the periphery of the RSGA area, there are also others in the Eastern and Western Regions. Those in the Eastern Region seem to be particularly important both as a major source of invasion of southern Arabia (e.g. 1949 plague upsurge and the 1965 breeding) and as a likely additional source of locusts for Oman, that important though infrequent source of recent plague upsurges.

5.6 The Eastern Region

5.6.1 General distribution of breeding during recessions and upsurges

As described in Section 4.3.2, in the Eastern Region there is a close similarity in the temporal and, to some extent, also the spatial occurrence and distribution of breeding during plagues and recessions (Maps 2d and 3d). The two main breeding seasons during winter-spring and summer, coincide, but the distribution of the recession populations during winter-spring is confined to the warmer lowlands of the winter-spring breeding belt, where swarm breeding occurs during plagues, and in summer to the central and more arid third of the summer breeding belt, which closely corresponds to the part where swarm breeding is most frequent during plagues. There is considerable evidence to indicate that seasonal exchange of populations, between the two breeding belts also occurs during recessions.

The description of the main breeding habitats given below is based principally on the studies conducted by the FAO/UNDP Ecological Survey (Popov *et al*, 1965) and on information from Rao (1960).

5.6.2 Description of the habitats (Maps 18, 19, 20)

5.6.2.1 The winter-spring breeding belt

5.6.2.1.1 Makran

The Iranian and the Pakistan Makran form a single geographical area extending from the shores of the Strait of Hormuz in the west to the Indus valley in the east. It is composed of a coastal plain which reaches a width of over 80 km at Dashtiari, but is usually narrower and is backed by a mountainous region. The mountains consist principally of synclinal ranges of sedimentary formations aligned east-west in the central part, changing to north-south at the western extremity. At the eastern end they terminate at the Khirthar range and the Suleiman mountains, which also have a north-south orientation.

Central Makran presents a landscape of utter desolation comprising a succession of grotesquely eroded silt and clay badlands and broken flat-topped sandstones and marls and alluvial terraces raised to varying levels. The drainage tends to insinuate itself between the hills along broad shallow valleys. The gradient is usually slight and there is much deposition of finer alluvium generated in large quantities from the redepositing of silts and clays. In view of the prevailing east-west trend, many watercourses or khors extend long distances before finding a breach through the coastal ranges leading to the sea, and some are trapped in closed inland basins. The largest of these closed basins are the Hamun i Jaz Munain and the Hamun i Mashkel.

The recent alluvial deposits which occur on the coast and in all the larger valleys often reach considerable depth. For the major part they are composed of packed silts and clays, frequently with a surface covering of gravel and stones, similar to the regs of Arabia. Stony plains are usually near the hills and towards the centre of the valleys silt and clay pan "pats" predominate. The pats are subject to seasonal flooding and their surface is frequently completely devoid of vegetation and is saline and of the "takyr" type.

In addition there are scattered deposits of wind-borne sand, usually in the form of dunes, talus slopes, or hillocks and hummocks of varying magnitude. Some of the sand is derived from the natural process of erosion and some of it is secondary and artificial, caused by the breaking-up of the soil during land utilisation, as is evidenced by local deposits of sand in the vicinity of some cultivated areas.

The silty soils are generally fairly fertile and at a few points, where adequate water supply and drainage permit this, agriculture is practised. Dates are the principal crops, but some irrigated wheat is also grown in winter, and sorghum in summer; a little rice is also grown on a very small scale. In addition to the regular cultivations, some snatch cropping is also practised by planting *Sorghum* and *Pennisetum* in lighter soils on marginal floods. The practice deserves special mention since it provides one of the important habitats of *Schistocerca*.

With the exception of small, localised areas of mountain woodlands in the highest parts and the riparian thickets and forests, the vegetation can be considered to belong to just one major type, wooded steppe of the more arid type. In this area of pronounced relief and varied soils, even a small amount of rainfall is sufficient to create locally fairly humid conditions in the beds of khors and in some sheltered depressions. The vegetation, therefore, has a markedly patchy character; while the exposed hillsides are almost completely bare, the valleys may, at times, bear abundant vegetation such as thickets of *Tamarix* or beds of rushes. This creates a rich variety of diverse plant communities, but only those of importance as habitats of the Desert Locust are considered in any detail.

The principal characteristics which all the important habitats appear to have in common are a light sandy or silty-sandy soil and an open steppe vegetation with a predominance of annuals, and tussock grasses and small bushes. The sands vary in quantity and character from dunes dominating the landscapes to small inconspicuous hummocks or deposits along minor runnels.

Firmer siltier soils and loess deposits of the type frequently used for the rain or flood cultivation of bulrush millet bajri (*Pennisetum typhoideum*) are also important. The heavier clay soils seem to be generally avoided, and the few cases of laying in them apparently occurred soon after rain, while the soil was still soft, and may be regarded as exceptional. Gravelly and stony soils and saline takyrs were as a rule free from laying.

In Makran the locust habitats belong to two geographically distinct areas, the coast and the valleys of the interior.

The coast of Makran

On the coast the principal deposits of sands occur in the form of dunes, which, locally known as the reks (rek in Baluchi or rig in Persian signifies sand), extend at intervals along the entire length of the coast from Sonmiani to Jask and beyond. In view of the considerable importance of the reks as habitats of the Desert Locust (cf. Rao, 1960), a short description of them is given below.

Starting at the eastern end, the coastal dunes show a considerable development in the Sonmiani area, a vast triangular enclave, whose base is formed by the Sonmiani Bay and the two sides by prominent mountain ranges which gradually converge and meet north of Bela (Map 18). Much of this vast plain is formed by the delta of the Porali river, and there are extensive deposits of fine alluvium, especially in the central part. Where not reduced by deforestation as a result of clearing for cultivation or cutting for firewood, the area still supports mixed woodlands of *Acacia nilotica, Prosopis cineraria, Capparis decidua, Salvadora persica* and *Tamarix articulata,* especially in the presence of additional drainage water. Such areas are rare, however, and outside the cultivations much of the vegetation is secondary, composed of a steppe of salt bushes belonging to the genera *Salsola* and *Suaeda* with a few scattered *Prosopis cineraria* trees.

The deposits of sand occur mainly along the periphery, especially along the eastern and the southern borders of the plain (the western was not visited but extensive sand deposits appear on the LANDSAT image). Much of the area is composed of rolling ridge sand dunes, fixed by a steppe of tussock grasses and woody herbs. The sand, although composed mainly of coarser particles, contains sufficient silt and clay fraction to be fairly firm and stable, a condition furthered by the binding action of the vegetation. Loose drifting sand is rare and found only on some of the higher crests. The inter-dunes are silty and some of the deeper ones, where the soil moisture conditions are higher, are seasonally planted with bajri (*Pennisetum typhoideum*), which is well defined on LANDSAT imagery.

Floristically the vegetation here shows transition from the tropical (monsoonal) to the Mediterranean. Thus *Euphorbia neriifolia*, a common element in the Sind-Rajasthan area, here reaches the western limit of its distribution, while Mazung, *Sphaerocoma aucheri,* one of the dominant plants in the sandy areas of Makran, is very rare east of this point. Apart from a number of such characteristic species, however, many of the dominants are widespread species common to both areas and indeed to much of the Sindo-Saharan zone. At Ambagh, for instance, the prominent species were found to be the tussock grasses, *Panicum turgidum* and *Pennisetum divisum*, a sedge *Cyperus arenarius* and small woody bushes and herbs such as *Sphaerocoma aucheri, Aerva javanica* and *Sericostoma pauciflorum*. Annual vegetation includes such common species as *Neurada procumbens, Plantago ovata, Tribulus terrestris, Launaea nudicaulis, Arnebia hispidissima* and *Dactyloctenium scindicum*.

The habitat in the dunes and also the bajri fields in the inter-dunes are known to be important sites where both swarming and non-swarming populations have been recorded. Continuous observations on locusts conducted in Ambagh during the major recession period of 1933 to 1939 established that locust populations were commonly present and in the event of rain, breeding was a usual occurrence. The highest concentrations were always recorded in the habitats described above (Rao, 1960).

While scattered populations exhibited considerable selectivity with regard to their habitats, swarms were apparently less selective and in addition to sharing the habitat of the solitarious locusts in the dunes, they also bred in a number of other sites. One such site was in the siltier part of the plain, along one of the numerous watercourses draining the hills on the eastern side. Another locust habitat was higher up the same watercourse within the hills flanking the eastern side of the Porali plain. According to local sources, it is usual for swarms to skirt the hills and so penetrate into the side valleys and breed there. The particular laying site was on the sandy talus slopes bearing a vegetation similar to but sparser than that of the reks, with an admixture of shrubs such as *Acacia senegal, Commiphora quadricincta, Lycium* sp., *Salvadora persica, Grewia tenax*. The lower stratum was composed of tussock grasses, notably *Panicum turgidum, Lasirius hirsutus and Cymbopogon schoenanthus* with some herbs such as *Aerva* and *Heliotropium rareflorum*. However, within the foothills sand accumulations were local and rare and outside them the ground was rocky and hard and generally unsuitable for laying.

The reks of Pasni, which may be regarded as typical of other rek areas elsewhere in Makran, are one of the classic habitats of the Desert Locust in its solitary phase (Map 19). They have been described by Rao in several of his publications, notably those of 1933, 1937, 1942 and 1960 and are thus probably the most and longest studied of any habitats of *Schistocerca gregaria*.

The Pasni reks cover an area of about 120 sq km and consist of chain dunes 5-25 m high of rather coarse reddish sand separated by sandy or silty inter-dunes of varying width. Except near Pasni, where trampling and overgrazing have had their loosening effect, the sands are fixed by a fairly abundant steppe vegetation. In general aspect they are not unlike those of Sonmiani, except that the tropical elements such as *Euphorbia nerifolia* or *Commiphora* are not in evidence. Once again the dominants were tussock grasses, small bushes and woody herbs; prominent amongst them were *Panicum turgidum, Pennisetum divisum, Dactyloctenium scindicum, Sphaerocoma aucheri, Heliotropium ramosissimum, Crotalaria* sp., *Cyperus arenarius* and *Eleusine* cf. *compressa*. There are also numerous annuals (Rao, 1960).

Towards the foot of the dunes and in the inter-dunes salinity becomes apparent and such halophytes such as *Atriplex crassifolia, Aeluropus villosus, Sporobolus* *indicus* and *Heleochloa dura* progressively replace the other plants. Among the latter *Heliotropium ramosissimum* persists for some time, exhibiting a degree of salt tolerance, its leaves becoming fleshier. *H. ramosissimum* is one of the principal food plants of *Schistocerca gregaria* and concentrations of locusts tend to occur where it is abundant. Colonies of *H. ramosissimum* were seen along the margins of the belt of mobile dunes surrounding Pasni. These mobile dunes are of further interest, in that wind by shifting the surfaces may at times create locally suitable soil moisture conditions for laying for prolonged periods after rain. (Rao, 1960).

West of Pasni the coast is predominantly silty, sometimes stony, rarely sandy, some of it flat, the remainder badly eroded. Physiological aridity is pronounced and the vegetation is chiefly halophytic. Frequently it is confined to watercourses crossing the plain, where, in addition to the halophytes, *Acacia* sp., *Lycium* sp. and tussock grasses find a foot-hold. The larger khors are to a small extent cultivated and there are some date palms and irrigated fields of millet dotted with shade trees, chiefly *Prosopis cineraria*. It seems probable that laying, when it occurs, is largely confined to such sandier wadis and to the vicinity of cultivations where softer silty soils are more common.

The rek dunes at Gwadar are similar to those of Pasni, except that the vegetation cover at Gwadar is both sparser, being only of the order of 10-15% as against the estimated 25-30% at Pasni, and poorer floristically, comprising only about half the number of species. (Table 1).

West of Gwadar lies the vast expanse of the flat silty plains forming the delta of the river Dasht and, beyond the Irano-Pakistan border, that of the Dashtiari. On reaching the plain the rivers tend to break up into numerous channels or chils, carving themselves deep narrow beds in the thick deposits of silt. These are lined with *Prosopis* trees and, where salinity is greater, with dwarf *Tamarix* and salt bushes (*Salsola* and *Suaeda*). Cultivation is practised on a very limited scale. Locust breeding is rare here and most of it is said to occur along the margins of the fields.

The coastal areas of Iranian Makran present a range of locust habitats very similar to those found in Pakistan. In the Chahbahar area for instance, the bay is fringed by a belt of rek dunes closely resembling those of Pasni and Gwadar not only in the general physiognomy, but also in the specific composition of the vegetation.

Table 1: Principal perennial plants recorded at Sonmiani, Pasni, Gwadar and Chahbahar

Locality	Sonmiani	Pasni (a)	Pasni (b)	Gwadar	Chahbahar
Sphaerocoma aucheri	4	1	3	3	3
*Panicum turgidum**	3	1	2	3	2
Eleusine compressa	(3)	2	1	1	+
Heliotropium ramosissimum	-	4	+	+	+
Aerva javanica	1	+	2	1	+
Cornulaca monacantha	-	+	+	2	1
Crotalaria albida	?	-	1	?	-
Dactyloctenium scindicum	+	+	2	?	+
Cyperus arenarius	1	+	1	1	1
Euphorbia neriifolia	1	-	-	-	-
Lycium sp.	+	-	+	+	+
Asparagus curillus	-	+	2	-	+
Calligonum comosum	-	-	-	-	1

(a) and (b) are two dune chains on the west and east sides of a wide interior-dune known as the Dhak.

Thus the most prevalent species of the reks are *Sphaerocoma aucheri* and the tussock grass *Panicum turgidum*, both present throughout in almost the same proportions; other elements are subject to much greater variation.

West of Chahbahar the coastal landscape is largely dominated by the flat plain, predominantly silty and frequently saline. It is often bare or sometimes with a covering of salt bushes, especially in the presence of drainage, where larger trees, notably *Prosopis* and *Tamarix*, occupy a relatively small proportion of the area. Potential locust habitats are associated with localised sandy areas which occur, including rek-like dunes, local accumulations of sand, chiefly along the larger khors and deposits of sand, often in the form of talus, in the foothills.

The reks occupy well defined areas and occur at intervals all the way to Jask and beyond it along the Biaban coast to Minab. The most extensive seen were in the Kahir area, some 50 km west of Chahbahar, in the Kashi-Sadaich area about half way to Jask, and at Jask. Along the Biaban coast the dunes continue almost without interruption to Kuhistak about 30 km south of Minab. They resemble the Pasni-Chahbahar reks in their general aspect and to some extent also in their floristic composition.

Outside the reks sand accumulations occur here and there on the plain, sometimes as sheet sand forming hummocks under vegetation. Such accumulations reach their greatest development along the larger watercourses, especially in their deltas. The wind-breaking and sand-binding action of the vegetation which is usually present in greater amount in the vicinity of the khors plays an important part in the

* including a small proportion of *Pennisetum divisum* which due to the prevailing drought could not always be assessed with certainty.

formation of such sand deposits. These form one of the most varied habitats for *Schistocerca* and are to be regarded as potentially one of the most important. They were seen at many points along the coast, and those of Bandini (25°23'N, 59°36'E), Rabch (25°37'N, 59°13'E) and Jagin (25°37'N 58°11'E) could be cited as examples but there are many variants created by the extremely diverse soil and moisture conditions (Popov *et al,* 1965).

Aeolian deposits of sand are found at many points along the coastal ranges. They are frequently in the form of a talus covering part of the hill slope. Those of Bandini are typical of many. The vegetation is generally very similar to that of the reks, but the lower slopes frequently benefit from the additional drainage water from the hills. At Bandini the principal plants recorded were *Calligonum comosum, Pennisetum divisum, Panicum turgidum, Sphaerocoma aucheri, Indigofera semitrijuga* and *Rhynchosia* sp. One notes the dominance of tussock grasses at the expense of *Sphaerocoma, Cornulaca* and *Heliotropium* which are dominant on the coast.

(b) The valleys of the interior (Map 19)

The mountains of Makran, composed of sedimentary tilted ranges of rock and solidified eroded silt and clay deposits, run roughly parallel to the coast. Between them lie a succession of valleys, which rise in progressive, though irregular steps. Those south of the watershed formed by the Bashagerd range and the line of the central Makran mountains, drain towards the sea; those north of it, into a series of land-locked basins of various sizes. Those with which we are principally concerned and which between them probably cover a representative range of locust habitats are: (i) the Kulanch valley, about 20-30 km north-west of Pasni; (ii) the extensive Dasht valley, including its major tributaries the Kech and the Nihing; (iii) the Panjgur valley and the Diz basin; and (iv) the Jaz Murian basin in Iran.

(i) The Kulanch valley is located about 30-40 km inland behind a multiple range of broken hills. It extends roughly east-west and is some 50 km long and less than 8 km wide. Reks are found at the two extremities and, as seen from Table 2, the specific composition of their vegetation is similar to that of the coastal ones. The reks grade down to a sandy plain studded with hummocks bearing tussock grasses and low woody herbs and the sandy plain leads down to the central portion of the valley which is silty. The plain bears patches of *Prosopis* woodlands and salt bushes and small fields of bajri (*Pennisetum)* and jiwari (*Sorghum*) watered by run-off from the adjoining hills.

Table 2: Common plants of sandy areas in the Kulanch valley

Site / Plant species	1	2	3	4
Panicum turgidum	4	3	1	4
Lasiurus hirsutus	1	2	2	-
Pennisetum divisum	-	+	-	2
Eleusine compressa	2	2	3	+
Heliotropium ramosissimum	2	-	1	1
Salsola sp.	+	+	1	-
Sphaerocoma aucheri	+	-	+	+
Aerva javanica	+	+	2	+
Cornulaca monacantha	+	+	1	+
Hammada elegans	+	+	+	1
Maerua crassifolia	+	1	1	-
Calligonum comosum	+	-	+	2
Erempogon foveolatus	+	-	+	-
Cenchrus ciliaris	1	+	-	1
Leptadenia pyrotechnica	-	+	-	1
Lycium sp.	+	-	2	1
Ephedra sp.	-	+	+	-
Periploca aphylla	-	2	+	-
Commiphora quadricincta	-	+	+	-
Acacia sp.	-	+	-	-
Crotalaria albida	-	1	+	+
Cymbopogon schoenanthus	-	2	-	-
Tephrosia sp.	-	1	-	+
Rhazya stricta	-	1	-	-
Ziziphus nummularis	-	+	-	-
Capparis decidua	-	1	-	+
Prosopis cineraria	-	1	-	-
Chrysopogon aucheri	-	+	-	-
Tribulus pentandrus	+	+		+

1. The rek formation at the south-eastern corner of the valley.
2. Nearby sandy watercourse.
3. Adjoining plain of hard sand.
4. Hummocky sandy plain in the southern central part of the valley.

Much of the valley provides excellent breeding grounds for locusts, alike in the reks, in the runnels, on the sandy plain and in the fields where a patchy system of planting and weeding create some of the best locust habitats. Indeed a small population of green hoppers in the first to third instars was present in May 1963 among the weeds growing within and especially along the margin of the cultivations. The hoppers were found to be confined to *Chrozophora gracilis*, a common weed throughout the area, and they occurred singly on individual plants. Other common plants in this habitat were *Eleusine compressa, Cynodon dactylon, Cenchrus ciliaris, Dichanthium annulatum, Taverniera nummularia, Centaurea* sp., *Asphodelus tenuifolius, Aristida adscensionis, Convolvulus* sp., *Tribulus pentandras, Astragalus* sp. and many others, all common members of pioneer communities with a widespread distribution throughout the Sindo-Saharan zone. The soil on which planting was done is a sandy silt, finer and more compact than that of the reks, but sufficiently soft for laying, especially when moist. Soils of this type are especially propitious for laying because of their ability to conserve moisture compared to pure sands.

Rao (1960) attaches considerable importance to such cultivations, considering that they have a special attraction for locusts. If a sufficiently large number of locusts are drawn together into these relatively limited areas, concentrated breeding may follow and the resultant hoppers congregate in the weeds and the crops and undergo phase transformation. These areas, therefore, play an important part in the formation of outbreaks.

(ii) The Dasht valley (Map 19) The Dasht river and its two branches, the Kech in the east and the Nihing in the west, drain a vast area lying south of the central Makran range. The two tributaries flow towards their point of confluence from the opposite ends of a broad valley which stretches due east-west in an almost straight line: from the Iran border through more than three degrees of longitude; below the junction, the Dasht river so formed, assumes a more sinuous course south-westwards through a series of broken sedimentary hills to the sea.

The floor of the valley is silty, often bare, occasionally saline, and formed of pats and takyrs. The sides are usually gravelly and stony, seamed by numerous watercourses, bearing mixed scrub composed largely of species such as *Pteropyrum* cf. *aucheri, Gaillonia hymenostephana, Calligonum* sp., *Lycium* sp., *Taverniera glabra, T. spartea, Grantia aucheri* and frequently dense stands of the dwarf palm, *Nanorrhops ritchieana.*

As Rao noted, the deposits of softer soil associated with locust breeding are few and localised, being largely confined to the deposits of sand along the sides of the valley at a number of localities; the following are outstanding examples.

Kolwa - An extensive silty flood plain at the upper end of the Kech valley, is the site where both swarm and solitary locust breeding have been recorded. The environment is varied and includes the following habitats: (a) rocky hills with their stony screes and gravelly aprons; (b) sandy talus slopes fixed by the spreading grass *Eleusine compressa* and a few tussock grasses and such shrubs as *Capparis* and *Calotropis;* (c) plains of sandy silt with a sparse orchard growth of *Capparis decidua*, and a carpet of such grasses as *Dichanthium annulatum* crossed by a number of small sandy runnels dotted with *Cymbopogon schoenanthus* and (d) at the western end of this area, several fields seasonally planted with *Pennisetum* and *Sorghum*. Laying has been reported in the fields, on the sandy talus and along the sandy runnels.

Shashtal area near Naserabad in the Nihing valley. This area, located near the confluence of the Nihing with the Ketch, a short distance west of Turbat, is one of the classic outbreak areas where incipient gregarisation occurred in the summer of 1935 (Rao, 1960). Ecologically it is even more complex than Kolwa. The following habitats can be recognised: (a) an interrupted chain of rocky hills with gravelly and stony slopes and fairly extensive aprons and flats stretching along the southern border of the area; (b) a river branch with local thickets of *Tamarix dioicea* in the lower parts; (c) the same with a mixture of various halophytic bushes such as *Suaeda fruticosa* and *Salsola baryosma;* (d) fallow fields with *Tamarix* seedlings and various salt bushes; (e) a belt of barkhan sands extending along the edge of the river and liberally dotted with *Prosopis, Calligonum, Tamarix*, and *Panicum* with a scanty ground cover of psammophilous annuals such as *Tribulus marcropterus, Heliotropium ramosissimum, Neurada procumbens* and *Gisekia pharnacioides;* (f) sorghum cultivations, limited to depressions along the edge of two dunes watered by marginal floods. Surrounding are the usual communities of pioneers such as *Tribulus pentandrus, Chrozophora gracilis, Gisekia pharnacioides* and *Limeum indicum*.

There are several other suitable locust habitats in the Dasht valley system, such as an extensive sandy area near Mand where there are more dunes and marginal cultivations, and still more are said to exist along the river Dasht itself. Rao (1960) provides a sketch indicating the location of some of the more important ones here and elsewhere in Makran.

(iii) The Panjgur area lies in the extensive Rakshan river valley, which, starting some 100 km east-north-east of Panjgur, later swings northwards to reach the Hamuni Mashkel. This valley lies at a greater altitude than the Dasht, the height of Panjgur being about 950m while Turbat is only 150m. Otherwise, there are many similarities between them. The Rakshan valley is also mainly stony and silty and here also sandy areas suitable for locust breeding are highly localised.

One such is the Sarwan area located along the southern side of the Rakshan valley about 15 km south-west of Panjgur. The centre of the valley is silty, dissected by numerous channels bearing larger shrubs which arrest sand to form barkhans and drifts (Table 3, column 1). Above this the plain becomes sandier, developing into a hummocky steppe of low woody herbs of a mixed floristic composition reflecting the diverse soil conditions (Table 3, column 2). Higher still the soil becomes coarser with patches of gravel. Some of this is cultivated, the fallows becoming colonised by *Hammada elegans* and *Peganum harmala* and the flood patches by *Eleusine compressa, Cynodon dactylon* and *Alhagi camelorum* (Table 3, column 3). Habitats such as these, and with some variations resulting from a greater development of sand deposits to reach dimensions of low dunes, were seen in other parts of the Rakshan valley and in the Diz depression about 50 km south-west of Panjgur.

Table 3: Dominant plants in three principal habitats at Sarwan near Panjgur

Habitat **Plant Species**	1	2	3
Taxarix	3	+	-
Calligonum comosum	2	2	1
Hammada elegans	2	2	3
Chenopodiaceae, Nb. 181	1	2	1
Pennisetum divisum	2	1	1
Eleusine compressa	1	3	3
Cynodon dactylon	3	-	1
Rhazya stricta	1	2	-
Indigofera sp.	1	2	
Alhagi camelorum	2	1	2
Atriplex sp.	1	+	1
• *Artemisia herba akba*	-	+	3
• *Hertia intermedia*	-	1	+
Fagonia sp.	+	1	3
Plantago sp.	+	3	+
Euphorbia granulata	+	+	+
Lotus sp.	+	+	+
Peganum harmala	-	-	1

(iv) Jaz Murian. This is an enclosed basin rather more than 400 km long and about 150 km across at the widest point, with an east-west alignment. The basin is bounded on the south side by the Bashagerd range and on the east by the broken mountains of Baluchistan; the mountains on the north side consist of the 3,300 m high dormant Bazman volcano in the east, followed westwards by a number of lower ranges then by the granite massif of Jamal Bariz with peaks rising to 4,000 m high; the mountains along the western border of the basin soon lose height southwards and at Kahnu the watershed falls down to 600 m.

The Jaz Murian basin is fed by waters from four main drainage systems. The north-west or Jiruft drainage rising in the high mountains of Jamal Bariz, Hazar and Lalezar, unites to form the Halil-rud which at first flows southwards, then eastwards. The eastern or Bampur drainage unites to form Rud-i-Bampur in the vicinity of Iranshahr, and from this point the river flows from east to west in an almost straight line. The two main rivers are largely perennial but may dry up completely during an exceptional drought year. After heavy and widespread rainfall their flood waters may reach and mingle in the central pan of Jaz Murian. The northern and southern drainage consists of numerous minor runnels, dry through most of the year, and only a very few of them may contain water in the dry season, or in the wet season flow on to join the Halil-rud or Bampur, or reach Jaz Murian.

• It is interesting to record the appearance of Artemisia and Hertia, elements normally associated with the cool region above 1,000 m altitude.

The hamun, or the pan, of the Jaz Murian is about 300 m above sea-level at its lowest point, with an imperceptible rise towards the borders, so that relatively little water is needed to flood an extensive area. It consists of vast alluvial deposits and considerable sections are saline. The centre of the pan is completely bare, except along the gullies (chils) where annual grasses and other ephemerals appear after the floods have receded sufficiently. The fringes of the flood plain support a thin growth of salt-bush (*Suaeda maritima, Salsola* sp., *Zygophyllum album,* etc.).

As the plain rises away from the centre towards the hills, it passes through the stages of lighter silts, sands, gravel and eventually rock. The upper part of the Jiruft Plain is mainly gravelly and stony and the silt first appears in quantity just north of Sabzevaran. The vegetation is sparse and mainly consists of scattered *Rhazya stricta, Calligonum comosum* and *Pteropyrum aucheri* bushes and a few annuals. Lower down there are woodlands of *Prosopis cineraria* and *Tamarix orientalis.* Where the trees are scanty, or absent, there is frequently a matted undergrowth of dwarf *Prosopis stephaniana* and occasionally the silty stretches may be completely devoid of all vegetation.

Along the northern borders of the Jaz Murian basin, the sands form a narrow belt which starts in southern Jiruft and continues intermittently eastwards to the vicinity of Dalgan. Northwards, sands gradually lose height and merge with the surrounding gravel plain, but their southern border is very sharply outlined by the dunes falling abruptly to the silty floor of the central pan. Few of the dunes forming this belt exceed 15 m in height, they are of a rolling nature, without clearly defined sheer slopes and crests, and are well fixed by a variety of scrub vegetation such as *Tamarix* sp., *Calligonum* sp., salt-bushes and tufts of *Pennisetum* sp., as well as other grasses and an undergrowth of annuals.

East of Dalgan, the dunes terminate, and are replaced by an extensive sandy plain overgrown with *Zygophyllum eurypterum, Haloxylon ammodendron, Calligonum* sp., *Heliotropium* sp., *Pennisetum divisum, Panicum turgidum* and other grasses which, together with *Salsola* and *Haloxylon* spp., form various plant communities, usually rather sparse, though where the drainage from the hills reaches the plain they may attain considerable luxuriance.

In the southern part of the basin the sands occupy a large area extending as a belt of dunes, 20 km wide in places, westwards from Iranshahr for a distance of over 200 km to the longitude of 58°30'E. For much of the distance the dunes lie as parallel ridges but at the western extremity they are mostly pyramidal in shape with well defined crests, and attain a height of up to 70 m above the floor of the plain. These sands are of a reddish hue, whilst the sands elsewhere in the basin are predominantly whitish or yellowish. The lower slopes and depressions are fixed with *Prosopis cineraria* usually found in groves, dwarf *Tamarix* scrub, *Zygophyllum coccineum, Salsola* sp., and other salt-bushes as well as straggling grasses like *Aelurophus* sp.; the higher slopes support *Calligonum* sp., *Leptadenia pyrotechnica, Haloxylon ammodendron, Indigofera* sp. and scrubby borages - *Moltkiopsis ciliata* and *Heliotropium* sp., whilst the crests are either bare or surmounted by *Cyperus* sp. The northern edge of this belt of sand is sinuous, forming sweeping bays and headlands with a general north-west to south-east trend and the high dunes fall abruptly to the main pan which here is highly saline and of a type known as kavir (sabkha).

West of longitude 58°30'E the sands gradually break up into isolated ridges and develop into a hummocky salt-bush steppe with intervening stretches of saline or fresh bare silt. In the presence of adequate irrigation water this is sometimes cultivated, the cultivations gradually becoming more frequent towards Jiruft.

On the Jiruft plain there is an uninterrupted belt of cultivation which is watered by the canals diverted from the Halil-rud and is thus largely independent of the rain. Along the western banks of the river, the belt of plantations is considerably narrower and less continuous. Similar large cultivations are to be found along the Bampur river in the Daman-Iranshahr-Bampur area, but elsewhere the cultivations are purely local, restricted to isolated settlements and dependent on rain, *qanats* or wells. In addition some cultivation is also done on the flooded silt at the mouth of the Halil-rud in the centre of the Jaz Murian pan by nomads, who graze their flocks in this area in spring. The main grain crops are wheat and barley raised in winter-spring and millet in summer. The millet plantations are more restricted and depend on the summer floods from melting snows. There are also some small vegetable plots and a number of the villages have date and fruit gardens.

Popov (1954b) regarded this area as of particular importance from the point of view of locust breeding and the place it may have in the formation of outbreaks. Subsequently there has been some support for this view since "in south-eastern Iran in late June 1964 two small immature swarms, one reported to be one-tenth of a square kilometre in size and a 'quantity of hoppers' were recorded in the Jiruft area" (DLIS Desert Locust Information Service Summary No. 76). This was at the time of an almost complete absence of any other swarming populations elsewhere in Iran and Pakistan.

The above are only some of the more important valleys in the interior of Makran and south-eastern Iran. There are certainly others which provide suitable locust habitats, and the ecological conditions found in them are probably on the whole similar to those described above.

5.6.2.1.2 <u>The coast of Iran West of Minab</u>

Compared with Makran, this region presents a very different aspect. West of Minab the horizontal or tilted sand stones and marls and the eroded silts and clays abruptly give way to the massive whaleback limestone ridges characteristic of the Zagros. These lie in parallel ranges separated by valleys, each lying a little higher than the preceding, as one moves away from the coast.

Between Minab and Lengeh, for much of its length, the coastal plain is narrow and steep, and the stony apron extends from the hills right across it to the coast. A succession of small seasonal watercourses scours its surface, each dotted with bushes of *Euphorbia larica, Pteropyrum scoparium, Gaillonia hymenostephana* and a few taller *Acacia tortilis*. Such areas offer little scope for the locusts but here and there the plain widens, the gradient becomes less steep and deposits of finer alluvium accumulate: it is these areas which provide suitable locust habitats. The more important of these are: the extensive plain lying between Bandar Abbas and Minab; the plain of Gachin, in the estuary of the river Shur, some 30 km west of Bandar Abbas; the plain of Mehran half-way between Bandar Abbas and Lengeh; and the enclosed plain of Mehrakan north of Lengeh. The following description of the principal vegetation zones is based on the plain of Gachin, but is representative of the others. The central part is subject to seasonal flooding and is silty and bare; the vegetation is higher up along the fringes. Parts are saline bearing a variety of salt-bushes such as *Halocnemum strobilaceum, Suaeda vermiculata* and *Tamarix* sp. along the chils; others where the salt is leached from the surface by drainage usually develop a good cover of principally annual vegetation of a rich and varied floristic composition including such species as *Cyperus fuscus, Asphodelus tenuifolius, Eremobium lineare, Schismus arabicus, Malva parviflora, Anastatica hierochuntica, Stipa capensis, Plantago ovata, P. amplexicaulis, Astragalus cruciatus* and *Hippocrepis* spp. Higher still the soil becomes sandier and perennial plants such as *Prosopis cineraria, Acacia tortilis, Salsola baryosma, Lycium* sp. and *Atriplex* sp. make an appearance. Cultivation of date palms and cereals (wheat and barley) is normally practised in this zone wherever soil conditions and availability of water permit; in Minab for instance, cultivations cover a large area. Above this lies the stony apron which descends from the hills. Deposits of surface sand are rare and localised; they occur in parts of the Gachin plain both in the foothills and along the beach and at the western end of Mehrakan plain. Locust breeding is largely associated with such sand deposits and with the zone of sandy silts, where it frequently involves cultivated areas (Popov, 1954a).

West of Lengeh the coast narrows still further and much of the way the mountains fall steeply down to the sea. Behind the coastal range, however, there lies a succession of valleys of varying dimensions, showing a zonation very similar to that of the coastal plain between Bandar Abbas and Lengeh. As far as the Mand river sand deposits are rare, and only at Maqam are there local dune formations. Locust breeding, therefore, would occur predominantly in the zone of sandy silts in habitats, which are to a considerable extent cultivated.

In the estuary of the Mand river, there are extensive accumulations of silts and sands in the form of dunes and barkhans and their general aspect suggests the probability of locust habitats perhaps similar to those of the Rabch area of Makran.

South-east of Bushehr lies an extensive plain with considerable accumulations of sand especially along its western border, where there are also eroded loess deposits. The margins are cultivated; the combination of sands, cultivations and the pioneer communities of weeds is certain to provide excellent breeding opportunities for swarms, a contention borne out by the local farmers who confirmed that this area was indeed preferred by laying swarms to others in the vicinity. Similar sandy areas also abound in the extensively cultivated plain of Shabankareh and beyond it further along the coast towards Behbahan. Gradually, however, the country gives way to barren heavily overgrazed hills and silt pans.

In the alluvial plain of Khuzistan the Desert Locust probably finds the best opportunity for breeding in the cultivations and the concomitant fallows, especially in the few areas where there are accumulations of wind-blown sand. Swarm breeding is fairly frequent during plagues in this area, but during recessions there have been only a few reports of adults and none of hoppers.

5.6.2.1.3 The highlands of Baluchistan and southern Iran

This is the area known as the cool region (the Sardsir), where the locust breeding habitats function as such at a later stage (on average about two months later) than in the warm region. However, some of the southern parts of the Iranian plateau, for instance the Sarhad of Kerman and Fars province, appear to have a swarm breeding frequency only slightly lower than that of their counterparts in the Garmsir region. According to Rao (1960) solitarious locusts also regularly reach parts of the highlands of Baluchistan, such as the Kharan valley in Pakistan and breed there.

The following general comparison between the locust habitats in the two major climatic regions is based on Popov (1953 and 1954) and Popov *et al*, (1965). A striking feature in a comparison of the habitats in the two regions is their similarities, especially with regard to the soil types and the physiognomy of the vegetation of locust habitats for in the Sardsir region also they are associated with sandy and sandy-silty soils and open steppe vegetation principally composed of ephemerals, woody herbs and bushes, and more rarely some shrubs or isolated trees. Although the specific composition may differ substantially, it generally includes familiar elements, among them some of the preferred food plants of the Desert Locust.

As an example, the area at Mastung where solitarious hoppers were found, was in a sandy plain covered by drifting dunes partly stabilised by planting reeds. Much loose sand, however, still remained and this was partly planted with Jiwari millet and partly left waste and colonised by a mixture of bushes and woody herbs such as *Hertia intermedia* (ghich) and *Calligonum* sp. and a variety of annuals, notably *Heliotropium serpentinicum, Tribulus* sp., *Chrozophora gracilis, Peganum harmala* and some others.

Among other habitats where swarm breeding has taken place in the past was one near Nushki, where laying was associated with cultivations. This was in an extensive plain of sandy silt, crossed by several watercourses (chils). Some of the chils were dammed, which resulted in the flooding of a considerable area which was afterwards ploughed and planted first with wheat and later with watermelons and melons. The margins and the uncultivated area below the dam has become populated by a shrub-steppe vegetation comprising such plants as dwarf *Tamarix* sp., *Lycium* sp., *Alhagi camelorum, Suaeda vermiculata, Peganum harmala* and a number of prostrate grasses and annual herbs. Oviposition is said to have taken place along the margins of the fields.

In the Sarhad area of Iran, south of Zahedan, breeding often takes place in sandy steppes along margins of the plain or the sand talus and dunes on the slopes of the adjoining hills. On the plain the vegetation is mainly an *Artemisia - Zygophyllum* steppe; in the dunes it is mainly *Haloxylon ammodendron - Calligonum* sp.

These types of habitat occur in many parts of the Iranian plateau and also over much of the lowlands of south-western Afghanistan. Other habitats are found along sandy watercourses lined with shrubs and bushes, but among the most important are man-made habitats associated with past and present cultivation. The conditions are in general not unlike those in the Campbellpur area of Pakistan.

5.6.2.2 <u>The summer (monsoon) breeding habitats</u>

An area of two degrees square (26-28°N/70-72°E) centred on Jaisalmer was chosen by the FAO/UNDP Desert Locust Ecological Survey to conduct a detailed study of breeding habitats of the Desert Locust. The choice was governed by the following considerations:

- this is a part of the summer breeding belt with the highest breeding frequency during both plagues and recessions;
- the network of rainfall observing stations though not very dense was sufficient to give a reasonable picture of rainfall characteristics;
- Jaisalmer district possesses a wide range of habitat types representative of Rajasthan as a whole;
- it was felt that the reports of Desert Locust described locust events during the 1960-62 three-year study period, with a comparable degree of accuracy.

Moreover, it was possible to identify many of the actual laying sites on the ground with a fair degree of reliability. Although the study was based on the sites of swarm breeding, the habitats are also used by recession populations.

The Jaisalmer area (Map 20)

Geomorphologically the district consists of three main sectors; the north-western bordering the Pakistan border, is a region of parallel dune ranges stretching regularly from east-north-east to west-south-west. The central sector is very heterogeneous; north of Jaisalmer lie tilted rocky plateaux of partly metamorphosed sandstones and marls, sometimes with a capping of numulitic limestones. These are drained by a series of wadis into alluvial basins and plains, the deeper of which form a series of ranns (seasonal marshes) lying a short distance north and east of Jaisalmer. Elsewhere there are plains of old alluvial deposits in the form of silt depressions, gravel regs, or covered by deposits of aeolian sand. Dunes cover a relatively small proportion of the area, probably not exceeding ten per cent. The southern sector is again sandy, consisting of ranges of high and frequently complex dunes overlying the old alluvial plains.

The annual rainfall ranges from about 100 mm in the north at the Pakistan border to about 250 mm in the south. Corresponding to this rainfall gradient, one notes a sequence of the main vegetation zones. Thus the north-western sector can be ascribed to the bush/shrub steppe zone and the remainder of the area to the tree steppe zone.

The distribution of human population also reflects the rainfall gradient. The drier north-western part is the least populated, there is relatively little pressure of grazing and practically no agriculture. Because of this one sometimes observes the paradox of a more developed vegetation (notably along the border) in areas of lower rainfall. With the increasing rainfall south-eastwards the population rises rapidly. It is mixed pastoral and agricultural and settled in numerous little villages scattered throughout the area. The principal crops are rainfed *Sorghum* and *Pennisetum.* A little wheat may also be raised.

Beginning with bare ground (a) the stages of succession are: (b) cultivated plants, all annual species such as wheat *(Triticum turgidum)*, millets (*Pennisetum typhoideum*, *Sorghum*, oilseed (*Sesamum indicum*) and watermelon (*Colocynthis citrullus*) and some others; (c) pioneer plants that invade the fields *en masse* in the first year after crop growing has ceased, but tend to diminish in subsequent years. These are, as a rule, annual species but in regions with more than one rainy season (the northern part of West Pakistan, Baluchistan) some of them may last for longer. This may also happen in years of exceptional rainfall. The species which tend to predominate throughout the area studied belong to the genera *Cenchrus* and *Aristida* for the grasses and *Crotalaria, Indigofera, Heliotropium, Boerhavia* and *Fagonia* for the herbs. In addition to this many more annual species may predominate locally; (d) creeping and stoloniferous species belonging to the genera *Eleusine, Dactyloctenium, Cynodon, Cyperus* and *Fimbristylis* which quickly colonise heavily overgrazed areas and bare ground; (e) late colonisers which become established amongst the early pioneers after several years of protection from ploughing and overgrazing. Typical amongst these are the tussock grasses belonging to the genera *Pennisetum, Panicum, Lasiurus* and *Cymbopogon* and shrubs and bushes such as *Euphorbia neriifolia, Hammada elegans* and *Salsola baryosma;* (f) species which tend to assume their optimal development in the climax stage of evolution. To judge from the rare vestiges of a more or less spontaneous vegetation, they consist especially of trees and shrubs.

Amongst the trees, the genera *Acacia, Prosopis, Tecomella, Ziziphus, Commiphora* and *Salvadora* are prominent and among the shrubs, *Capparis, Leptadenia, Calligonum, Lycium* and *Grewia*; (g) species particularly favoured by heavy overgrazing; these are, as a rule, unpalatable or toxic to livestock. Amongst them are the shrubs *Calotropis procera, Euphorbia neriifolia* and *Aerva javanica* and the herbs *Colocynthis vulgaris, Peganum harmala, Cousinia minuta, Tribulus terrestris, Euphorbia* spp. and *Cleome* spp.

Plant communities formed by a single group of colonisers are extremely rare. In most cases plants belonging to two or more of these groups will be found in close association. The predominance of one group or another should, however, permit to judge whether a plant community represents an early or an advanced stage of evolution. In other words it should be possible to judge whether a plant community is the result of recent ploughing or overgrazing, or not. The extremely widespread community with *Prosopis cineraria* and *Aristida adscensionis* may be cited as an example; in this community the strata of annual plants (pioneers) is combined with a tree strata of *Prosopis cineraria* and occasionally *Tecomella undulata* (final colonisers); often the intermediate strata of perennial grasses or bushes is completely lacking. This is due to heavy grazing and/or ploughing combined with protection of the trees whose branches are useful as food for cattle.

<u>Main types of habitats, their vegetation and the occurrence of laying within them</u>

While, on the geographical scale, the main vegetation zones are linked with the climatic and particularly the rainfall gradient on the meso-ecological scale, the plant communities show a close correlation with orographic and edaphic variations (especially with soil texture and hydrography). On this basis, ten major types of habitat were recognised. Each type is defined by a group of plant species characteristic of it, though individually the species may occur in more than one habitat type. However, physiognomically the succession of vegetation is rather similar in all types and parallel evolutionary series may be recognised for all of them.

(i) <u>Rocky hills and plateaux</u>

Outcrops of crystalline, sedimentary and metamorphic rocks are frequent within the high-frequency breeding grounds of the Desert Locust. Rock which is deprived of its detritus by erosion and so remains unaltered, is devoid of plant growth. On patchy decomposed rock, and on this deposits of soil in the hollows and crevices of the rocks, definite stages of evolution may be observed; for example, for metamorphic sandstone in the Sindo-Rajasthan region it is: small bushes - succulent shrubs - deciduous shrubs and dwarf trees.

(ii) <u>Gravelly terrain</u> (regs)

Gravelly regs are extremely widespread in the high frequency areas of the Desert Locust. Their common characteristic is the density of the soil, surface run-off and its corollary, the residual accumulation of gravel on the surface. Regs are hostile to plant growth and only a sparse vegetation might slowly colonise them. The following stages of evolution may be recognised: bare reg - creeping grass/sedge steppe - bush/shrub steppe.

(iii) Sandy plains and gentle slopes

These are second to gravel regs in their extent within the high frequency breeding areas. Here permeability and water storage are higher and surface run-off is strongly reduced. Plant growth, therefore, is less handicapped, much richer and a rapid succession of the complete set of physiognomic vegetation types recognised for the region may be found with the sole exception of woodland which is unlikely to become established here with a rainfall below 250 mm.

(iv) Dune slopes and sandy talus

Depending on their soil compaction, exposure to wind and run-off, sandy slopes and talus whose gradient exceeds 5 per cent become colonised by a varying proportion of communities belonging to the dune crests (v) and the sandy plain (iii). The complete set of physiognomic vegetation types recognised may be found with the exception of wood and parkland.

(v) Dune crests

Due to their exposure to wind action sandy crests are kept in continuous motion. However, the extreme penetrability of loose sand to water and plant roots also ensures an easy and rapid resettlement of vegetation. A quick and characteristic succession of evolutionary stages is as follows: shifting sands - invasion by creeping sedges - establishment of shrubs (*Calligonum*) and perennial grasses.

(vi) Fluvial sands

Fluvial sands are linked in the breeding areas with temporary watercourses (wadis). Here floods tend to alter the habitats and the mechanism of progressive evolution is therefore naturally interrupted and reversed at intervals. The following main stages of evolution may be recognised; bare fluvial sand - invasion of creeping grasses and sedges - establishment of tussock grasses and/or patches of dense woodland.

(vii) Inter-dune space

In the inter-dune areas sand tends to contain a fair amount of silt and to be much more compact than on the dunes. The greater compactness of the soil might hinder to some extent the establishment of vegetation, but additional shelter and the occasional influx of water from the dunes tend to favour plant growth. The stages of evolution recognised are very much the same as on the dunes, but the plant species are essentially different.

(viii) Shallow depressions

Shallow depressions are found scattered in many parts of the alluvial plains. What has been said about the inter-dune spaces largely applies to them also, but soil in depressions tends to be somewhat siltier and denser. The ultimate stage of evolution of the vegetation is, however, not a tree steppe but rather a fairly dense woodland.

(ix) Submersible depressions

Depressions receiving heavy influx of run-off water may be periodically submerged. Considerable silt and clay deposition usually leads to the build-up of fertile soils very suitable for cultivations. Naturally such depressions tend to be colonised by physiognomically the same stages of evolution as in (viii) but composed of more hygrophilous species.

(x) Saline depressions and flood plains

As a result of influx and evaporation of run-off and irrigation water, salt tends to accumulate at the surface over large areas. Cultivation may then be rendered impossible and bare silt pans, which are eventually covered with a salt crust, become established, mainly in the central part of the depression. Elsewhere in the depression one observes the succession of colonisation by creeping grasses and succulent shrubs. Under less saline conditions and especially on submersible plains a very open woodland tends to become established.

In line with the particular conditions at the 112 egg fields studied, the ten habitats were subsequently reduced to the following basic habitat types:

I. Rock
II. Gravel
III. Sand
  1. Plains and gentle slopes
  2. Hillocks
  3. Ridges and pre-dunes
  4. Dunes
  5. Fluvial sands
IV. Silty depressions

Thus the sandy habitat was expanded into five sections, while the silty depressions were condensed into one and the saline depressions, not represented at any of the egg-fields, were omitted altogether.

The distribution of laying in the 112 egg-fields in relation to the above habitats and the ten vegetation types found within these was analysed; the occurrence of laying within the habitat type is shown by a plus sign and its occurrence in an adjacent habitat is shown by a minus sign. A synopsis of the results is given in Table 4 where the soil types are shown along the abscissa and the vegetation types along the ordinate.

From the table it becomes evident that laying is concentrated within certain vegetation and habitat types. The bulk of laying occurred in the sands, where 97.5% of laying was recorded. The remaining 2.5% was within silty depressions. No laying at all was noted in the rocky and the gravelly habitats, although sometimes it occurred in their vicinity.

5.6.2.3 Conclusions

The studies in Jaisalmer area indicate that a marked correlation exists between rainfall pattern and the distribution of egg-laying by the Desert Locust. On the meso-scale (the habitat or plant community pattern), however, the pattern of rainfall alone did not account for the habitat preferences shown by the Desert Locust at the time of laying.

Table 4 Synopsis of the major habitat types, the physiognomic vegetation types and the occurrence of laying within them, based on the egg-fields studies in Rajasthan (Figures in brackets indicate number of occasions when laying occurred in patterns in the respective vegetation type)

Habitat type					Sands												
Vegetation type	i Rock		ii Gravel		iii Plains		iv Hillocks and ridges		iv + v Dunes		vi Wadis		vii - ix Silty depressions		Total		%
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	
a.Bare ground	0	4	0	26	0	2			0	7	1	1	0	0	1	40	0.5
b.Cultivations (fallow)					2	35			1 (1)	4 (0)			3	3	9 (1)	39 (0)	4.5 (0.5)
c Ephemeral sward			0	4	8	13			5	2			1	3	14	22	7
c_1 (fallow)					(7)	(11)							(1)	(3)	(8)	(14)	(4)
d.Creeping grass/sedge steppe			0	12	16	26			6	6	3	0	0	3	25	47	12.0
d_1 (fallow)					(5)	(11)							(0)	(3)	(5)	(14)	(2.5)
e.Tussock grass steppe					7	24	31	1	20	13	5	5	1	12	64	55	32.5
f.Bush/shrub steppe	0	5	0	8	9	33	15	2	55	7	1	0	0	3	80	58	41.0
g.Scrub thicket (fallow)	0	4			5 (0)	8 (2)									5 (0)	12 (2)	2.5
h.Parkland					cf. "c"								cf. "c"		cf. "c"		
i.Tree steppe													0	2	0	2	
j.Woodland	0	3									0	1	0	3	0	7	
Total	0	16	0	50	47 (12)	141 (24)	46	3	87 (1)	39 (0)	10	7	5 (1)	29 (6)	195	285	100
+ : -	0		0		1/3		15/1		2/1		3/2		1/6				
					<------------190		1/1		190---------->								
% +	0		0		24		23.5		44		5		2.5%				
					<------------		97.5%		---------->								

The analysis of data resulting from the examination of 112 egg-fields representing between them 132 individual cases of laying established clearly that on this scale the Desert Locust shows at the time of laying a marked preference for certain types of habitat and habitat complexes which are clearly brought into prominence by certain vegetation types and complexes of vegetation types as well as soil conditions, topography and drainage. Oviposition sites as a rule have pronounced physiognomic characteristics suggesting that their choice in the first place is probably visual.

In Jaisalmer non-saline sandy soils covered with an open patchy steppe vegetation comprising tussock grasses, bushes, shrubs and occasionally scattered trees was most frequently associated with laying, the association being highly significantly non-random. Evidence suggests that heterogeneous habitats are preferred to the homogeneous ones and of the 112 egg-fields only two were in completely uniform vegetation.

The genesis of the habitats where laying was recorded was examined and it was concluded that in many cases they owed their existence to biotic influences, notably all forms of land use, by cultivation, wood cutting, clearing and grazing.

As in Pakistan, it was established that in addition to the physiognomy of the habitat, which probably influences its selection in the first place, there are also other factors which are responsible for the final choice of the habitat and the distribution of laying within it. The more important of these are:

- exposure and slope, probably due to the effect of the micro-climate, especially temperatures;
- soil texture, soil moisture and penetrability which are closely linked with each other and soil salinity;
- vegetation structure, as evidenced by the proportion of life-form types (e.g. annuals, tussock grasses, bushes, etc.) and by the patchiness of the vegetation carpet.

It is considered that these conclusions are probably in general applicable to the major part of the distribution area of the Desert Locust, but it should be realised that the habitat preferences are not absolute and only relate to the range of conditions available in the areas to which the swarms are brought by the winds. Should the preferred habitat not be available, laying will occur in others, selected according to the above mentioned criteria, but not randomly. In extreme cases such as excessively dry, water-logged, saline or densely overgrown terrain, locusts do not lay and if alternative conditions are not found, laying fails altogether.

5.6.3 The pattern of upsurges in the Eastern Region

Rao (1936) in discussing the sequence of events leading to the 1935 incursion of locusts into North-West India emphasised the importance of two successive stages leading to this event: the first stage was a build-up of locust populations during two successive generations, the first generation during March-April 1935 in the warmer, coastal areas of Makran on abundant rains that fell there during November 1934 and again in January-February 1935, and the second generation in the valleys of the interior of Baluchistan, situated progressively inland:

- Shashtal in the Kech valley (24°N) (laying in mid April);
- Sehgazan and Gor in Panjgur (laying in early May);
- Mashuk in Kharan (26°30'N) (laying in May).

This displacement was reasoned on the grounds of the temporal and spatial changes in the locust numbers - their initial absence in the inland habitats at the time of breeding in the coastal areas, then their subsequent appearance and increase in the inland habitats, with a concomitant decline of the coastal populations.

The second important stage was the gregarisation of locusts during the second generation in inland habitats. These habitats consist of silt and sand accumulations on banks of rivers and sides of valleys, where millet crops (jiwari) are raised. The crops and fallow land, bearing weeds such as *Chrozophora* provided attractive habitats, where locusts concentrated, multiplied and eventually gregarised forming bands and swarms.

Rao (1936) quoted other examples of such outbreaks, notably in the Dasht Valley, in May 1923, when "millions (of locusts) extended from Zahrenbug to Gabd". Previously there were good rains on the coast in January. Following the double-generation winter-spring breeding, locusts migrated to their monsoon breeding grounds in the Indian desert.

In his later work Rao (1942) postulated that the continued build-up of a locust upsurge during the subsequent monsoon breeding in the Indian desert was particularly effective if preceded by a year of poor monsoon rains. This, he argued, would create localised areas of green vegetation at the beginning of the monsoon and concentrate the locusts still further.

Rao (*loc. cit.*) gave several examples of such a sequence (1868-69, 1899-1900, 1911-1912, and 1939-40) when outbreaks during years of abundant monsoon rains were preceded by drought in the previous year.

However, it was Gurdas Singh (1952) who, during the 1949 monsoon breeding in Rajasthan, observed the formation of gregarious hopper bands and swarms from an initially scattered parent population. The events were as follows.

The initial population till early May 1949 was very low, with a maximum of only 120 locusts/sq. mile; later in the month the population rapidly rose to 19200/sq. mile due to incursion from outside, the likely source areas were Makran and Oman, where breeding leading to partial gregarisation occurred during winter-spring. There were three principal areas - two in Bikaner and one in Jodhpur, where locusts concentrated and bred during the subsequent abundant monsoon rains. Ecologically the areas were very similar consisting of extensive gravel plains with ranges of dunes at irregular intervals separated by intervening hollows. The abundant rains produced a bumper crop of bajri millet raised in the hollows, while on the plains *Andropogon halepense, Cenchrus biflorus* and *Lasiurus hirsutus* developed into a dense solid cover. As a result, the locusts concentrated in the dunes as the only habitat containing suitable bare, sandy sites for oviposition.

Dense laying occurred here; the hoppers that emerged were initially typically solitarious. They aggregated on their favourite food-plants: *Gynandropsis, Cleome* sp., *Tribulus, Cenchrus, Aerva,* and later moved into millet crops, where further aggregation and gregarisation occurred, giving rise to hopper bands and subsequently swarms.

The role of the habitats in furthering concentration of locusts at the time of laying and subsequently the concentration and gregarisation of the hoppers seems fairly clear, what is less clear is the identity of the three areas - the two in Bikaner and the one in Jodhpur, where the parent adults became initially concentrated. Whether they are the outcome of the localisation of green vegetation under the influence of rainfall distribution as postulated by Rao, or the result of mesoscale convergence between the branches of monsoon current from the Arabian Sea and the Bay of Bengal or some other wind system as suggested by Popov *et al.* (1965), or in some way by both, is not clear at present. Further and more detailed studies of the phenomena should throw light on this problem and enable more timely identification of such potential areas of concentration and gregarisation.

Another and more recent major outbreak in the Eastern Region resulting in production of gregarious populations from initially solitary-living individuals, occurred yet again in the summer breeding area of India and Pakistan, this time between July and November, 1973 (DLFM, pp 27-30). The principal features of this outbreak were:

- small number of overwintering adults in Rajasthan and adjacent parts of Pakistan following monsoon breeding;
- larger number of immigrants from the west arriving during April and May, probably originating from the 1972-73 winter-spring breeding in RSGA of Arabia;
- further arrivals during July and August from Iran and Afghanistan;
- almost undetected breeding in the first generation in border areas difficult of access, resulting in production of sufficiently large numbers of adults to form some swarms on maturation;
- successive laying over two months by swarms and scattered adults following heavy rains in August resulted in the formation of some 3000 hopper bands within an infested area of about 20,000 km^2.

The main conclusions from the above regarding the pattern of outbreaks are as follows:

- a progressive build up of numbers often over two generations during winter-spring breeding, which can occur within the Region (Makran, Baluchistan) or outside it (Oman, RSGA, including Somalia), or both.
- Further build-up over two overlapping generations resulting in hopper band and swarm formation in the summer breeding grounds of India and Pakistan. Here the precise position of the breeding habitats is probably largely dependent on the pattern and distribution of the rainfall and is likely to vary to some extent on different occasions.

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ANNEX 1: HABITAT TABLES 1-8

EXPLANATORY NOTE TO THE HABITAT TABLES

Ecological potential is shown according to the 0-5 abundance scale for the following values:

S - survival
R - reproduction (breeding)
G - gregarisation (only applicable to recessions)
F - frequency of occurrence

NOTE that the major habitat types are described in greater detail in the text and some are illustrated in appropriate maps

1. Desert Locust habitats in Mauritania and Senegal.

1a. Habitat types in Khatt el Moinan recorded on 28 September 1979.

2. Desert Locust habitats in the southern Sahara (Timetrine-Adrar-Tamesna-Aïr).

3. Desert Locust habitats in Sudan and Egypt.

4. Desert Locust habitats in the coastal areas of northern Eritrea .

5. Desert Locust habitats in Northern Somalia.

6a. Desert Locust habitats in the Arabian peninsula (north and south of Jiddah).

6b. Desert Locust habitats in the Arabian Peninsula

7. Desert Locust habitats in Pakistan and Iran.

8. Desert Locust habitats in the Eastern Region.

HABITAT TABLE 1 - Desert Locust habitats in Mauritania and Senegal

Area/The Major Biotopes		Soil	Major Habitat Types	Vegetation	Ecological Potential						
					Recession				Plague		
					S	R	G	F	S	R	F
1.	SENEGAL RIVER VALLEY										
1.1	Flood plain	Mainly alluvial clays; deposits of sand on higher ground	1.1.1 Natural Riparian woodland savanna, rarely gallery forest	Acacia nilotica/Vetiveria nigritana community, abundance of trees variable giving way to Vetiveria/Echinochloa and Oryza grassland; other common elements: A. seyal; A. sieberiana, Piliostigma reticulata, Mitragyna inermis, Bauhinia rufescens.	1	0	0	1	4	2	2
			1.1.2 Crops	Rice, sorghum both rainfed and especially dry season on receding floods (sorgho de décrue), maize, millet, cotton, sugarcane.	1	-	-	1	2	0	1
1.2	Higher ground	Alluvial clays, silts and sands	1.2.1 Natural More or less wooded savanna prairie	The more xerophilous elements of above communities with more abundant ground vegetation, notably grasses belonging to genera Hyparrhenia, Panicum, Pennisetum, Dactyloctenium, Sporobolus, Chloris, Aristida, Eragrostis and particularly Cynodon dactylon. Forbs belong principally to Fabaceae, Malvaceae, Molluginaceae.	3	1	0	1	5	5	4
			1.2.2 Crops	Mainly rainfed sorghums and millets	3	1	0	1	5	5	4
2.	TALL GRASS SAVANNA (Sudanian Zone) (> 500 mm rainfall)										
2.1	Undisturbed	Arenosols	Savanna	Perennial tall grasses: Andropogon gayanus, Hyparrhenia dissoluta, Cymbopogon giganteus. Annuals: Aristida, Cenchrus, Cyperus, Eragrostis spp. Traces: Sclerocarya birrea, Prosopis africana, Combretum glutinosum, Sterculia setigera. Shrubs: Guiera senegalensis, Gymnosporia senegalensis.							
2.2	Grazed and Cultivated	Arenosols	2.2.1 More or less wooded prairie	Perennial grasses reduced to relics; annuals gain dominance. Trees reduced, small trees and shrubs especially Combretaceae gain ascendance.	-	-	-	1	4	0	0
			2.2.2 Crops	Principally millets and sorghums	4	3	0	1	4	4	3
3.	SAHELIAN ZONE (250-500 mm rainfall)										
3.1	Sandy plains	Arenosols fixed dunes and flat or rolling sandy plants	3.1.1 More or less wooded prairie	A more xerophilous version of 2.2. Perennial grasses replaced by annuals Cenchrus, Aristida, Eragrostis + Boerhavia, Gisekia, Limeum, Indigofera, Tribulus, Cleome. Trees: Balanites, Acacia spp., Commiphora gradually replace Combretaceae in the north.	5	4	0	3	5	4	4
			3.1.2 Crops	millets gain ascendance over sorghums							

Area/The Major Biotopes		Soil	Major Habitat Types	Vegetation	Ecological Potential						
					Recession				Plague		
3.2	Plateaux and Borderlands	Arenosols and lithosols, mosaic of rock pediment and alluvial & eolian soil deposits	3.2.1 Woodland/ scrubland & annual prairie mosaic	Trees and shrubs as above with some elements of 2.1 persisting as relics under higher moisture conditions in proximity to plateaux (Assaba, Affolé) locally colonies of Euphorbia balsamifera and Combretaceae, also Hyparrhenia and Andropogon.	5	4	0	2	5	5	5
			3.2.2 Crops	Millets gain ascendance over sorghums							
3.3	Regs and Flood Plains	Arenosols alluvial soil deposits	Woodland/annual grassland bare reg mosaic	Predominantly Acacia nilotica, A. seyal, Balanites, Panicum laetum, Aristida spp., Schoenefeldia.	3	2	-	1	4	3	3
4.	SAHELO-SAHARAN ZONE (50-250 mm rainfall)										
4.1	Deep sands, plains and dunes	Arenosols deep sands	Annual prairie tussock steppe ecotone - more or less wooded	From wetter condition in the south to drier in the north, the annual prairie (3.1) is gradually replaced by tussock grass steppe following the succession: Aristida pallida, Lasiurus hirsutus, Panicum turgidum, Stipagrostis pungens. Common trees are Balanites aegyptiaca, Commiphora africana, Acacia senegal, A. raddiana, A. ehrenbergiana, Maerua crassifolia the last 3 persist to the Saharan zone. Common shrubs: Leptadenia and Calligonum. Annual grasses Cenchrus biflorus, Aristida mutabilis, Latipes, Tragus, gradually replaced largely by herbs, Gisekia, Baerhavia, Tribulus, Mollugo, Heliotropium, Colocynthis.	5	4	2	3	5	4	3
4.2	Plateaux, hills and borderlands	Arenosols and lithosols mosaic of rock, hammada, reg and eolian and alluvial soil deposits	Mosaic of scrubland, more rarely woodland usually associated with higher moisture provided by drainage; more or less wooded steppe and prairie and reg and hammada with little or no vegetation	Wider range of habitat conditions provides better laying opportunities than 4.1. Predominantly same species as in 4.1 with locally some elements from 3 to even 2. Marked preference for sandy steppic vegetation containing preferred food/shelter plants.	5	5	3	4	5	5	4
4.3	Regs and flood plains (Graras and Sabkhas)	Arenosols, predominantly alluvial clays and silts, same eolian sands	4.3.1 Scrubland, more rarely woodland and annual prairie	Predominantly Acacia seyal, A. raddiana, A. ehrenbergiana, Boscia, Salvadora, Maerua; Capparus; Panicum, Lasiurus, Aerva, Psoralea and locally halophytic Nucularia, Salsola and Suaeda; annuals Aristida spp. Schouwia.	4	4	2	2	4	4	3
			4.3.2 Crops	Sorghum, locally in some flood plains, principal locust habitats on sandier soil, often in contact with 4.1.							

Area/The Major Biotopes		Soil	Major Habitat Types	Vegetation	Ecological Potential						
					Recession				Plague		
5.	SAHARAN ZONE (> 100mm rainfall)										
5.1	Deep sands	Arenosols, sand dunes and plains	Desert steppe on dunes/sandy plains	Stipagrostis acutiflora, S. pungens, Calligonum, A. ehrenbergiana (local), Cornulaca, Cyperus conglomeratus, Stipagrostis plumosa, Centropodia forskalii, Neurada, Monsonia.	21	1	1	2	2	1	<1
5.2	Wadis and depressions	Arenosols, alluvial gravel, sands and clay	More or less wooded desert steppe	Acacia raddiana/Panicum turgidum are the dominant species with associated chamaeophytes and therophytes (Mediterranean elements become progressively more common northwards).	5	4	2	2	5	4	2

HABITAT TABLE 1A - Habitat types in Khatt el Moinan recorded in September 1973

Ref	Environment	Soil	Origin and depth (cm) of Soil Moisture[1]		Vegetation[2]	Cover %[3]	Ecological Potential[4]		
							S	R	G
1	Dune crest	loose coarse sand	rain	10	Stipagrostis pungens 4 (4) Cyperus conglomeratus 5(6) Tribulus pentandrus 3(5) Indigofera argentea 1(5)	15	2	0	0
2	Dune slope	loose coarse sand + trace of silt	rain	17	S.pungens 3(4) C. conglomeratus 4(6) T.pentandrus 4(5) I. argentea 4(5) Limeum indicum +(5) Aerva javanica	25	3	2	0
3	Foot of dune	more silt than 2	rain	20	S. pungens 3(4) C.conglomeratus 3(7) I. argentea 4(6) Heliotropium ramosissimum 3(4) Giskia pharnacoides 2(6) Limeum indicum 2(3) Tribulus pentandrus 1 (6) Aerva javanica + (6)	20	3	1	0
4	ditto in presence of rock outcrops	ditto	rain + run off	38	Panicum turgidum 4(5) Heliotropium ramosissimum, Gisekia pharnacoides, Cyperus, Tribulus pentandrus 3(6-7) Aerva javanica Cenchrus biflorus and prieurii, Boerhavia repens 1(6-7), Chrozophora 1(3) Farsetia 1(6)	25	3	1	0
4a	as 4 + flood channels	mosaic of sands and silts	rain + flood	11	Calotropis, Maerua, Boscia, Acacia ehrenbergiana 1(4-5) Panicum 4(5) Cenchrus biflorus 3(5) Schouwia 4(3) Tribulus 3(5) Heliotropium 3(3-5) Aerva 1(5) Gisekia, A. adscensionis Pennisetum mollis + (1-5) other species 1(4-5)	variable up to 80	4	3	1
5	flood plain in Khatt valley	mosaic of clays, silts & sands	rain but mostly flood	9	Schouwia 4(3) Boerhavia 5(5) Schoenefeldia 4(5) Amaranthus 1(5) Portulaca sp.2(5) Sesbania sp 2(3) Zalea pentandra 1(4) Capparis, Maerua, Acacia, Boscia	50	4	2	0
6	5 scoured by drainage	as 5 but different pattern	as 5	bottom of runnel 8 side of runnel 5	Schouwia 4(4-6) Tribulus 3(5) Heliotropium 2(5) Boerhavia 3(5) Cenchrus biflorus 2(6) Schoenefeldia 2(6) Aristida adscensionis 3(6) Indigofera spp., Zalea, Amaranthus, Colocynthis, Sesbania, Cleome gynandra, Capparis	variable up to 80	5	3	1
7	bottom of the flood plain	as 5 but silts and clays predominate	rain and surface flooding	17	Sesbania 4(3) Echinochloa colonum 2(6) Panicum laxtum 2(6) Eragrostis sp. 2(6) Schouwia 3(3) Boerhavia 3(5) Heliotropium, Amaranthus, Schoenefeldia, Zalea (5-8)	60	4	2	0

1. Soil moistuire - In its origin whether rain or rain + run off and flooding; depth of discernable moist soil is measured from the surface in centimeters.

2. Vegetation - The dominant species are noted according to their dominance using (1-5) abundance scale and given as the first figure following the name of the plant or group of plants; the second figure (in brackets) gives the degree of growth and development (1-5); the higher figures (6-8) indicate degree of wilting and dessiction.

3. Cover - The total cover of the vegetation.

4. Ecological potential - The potential of the habitat for survival(S), reproduction(R), and gregarisation(G) of locusts using a 1-5 abundance scale.

HABITAT TABLE 2 - Desert Locust habitats in the Southern Sahara (Timetrine Adrar Tamesna Air)

Area/The Major Biotopes		Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
					Recession				Plague		
					S	R	G	F	S	R	F
1.	TIMETRINE (50-80 mm rainfall)										
1.1	Plateaux	Lithosols, eroded metamorphosed sandstones	Low, broken, plateaux of metamorphosed sandstones, numerous small and medium stony and sandy wadis	Sparse shrubs: Acacia raddiana, Maerua, Grewia, Combretum aculeatum, tussocks: Panicum, Chrysopogon. Vegetation largely confined to drainage channels; gravelly regs, bare or with some A. ehrenbergiana, Stipagrostis plumosa in hollows.	3	2	1	3	3	2	2
1.2	Sand plains/dunes	Aeolian and fluvial sands	Sand plains and dunes; weak drainage	Chiefly Panicum steppe with Stipagrostis acutiflora, S. plumosa, Aristida sieberiana, Cymbopogon shoenanthus, scattered Acacia raddiana, A. ehrenbergiana and Maerua crassifolia. Annual grasses Schoenefeltia, Cenchrus biflorens rare; herbs are more common; Gisekia, Mollugo, Boerhavia, Tribulus, Calocynthis, Limeum indicum, Cyperus conglameratus, Polygala.	4	4	2	3	4	4	2
1.3	Wadis	Ditto	Larger sandy and silty wadis and flood plains	Larger trees, Acacia raddiana, Balanites, Maerua; shrubs Leptadania, Combretum aculeatum, flood plains with Schouwia and Tribulus mollis chiefly along the eastern border and south-east of Tinkar.	5	5	3	3	4	4	2
2.	ADRAR DES IFORAS (20-100 mm rainfall)										
2.1	Hills	Lithosols (mainly crystalline & igneous rocks)	Gravel and stone plains, scattered hills, weak-medium drainage	Very sparse Aristida meccana, Chrysopogon aucheri, Stipagrostis plumosa, Centropodia, a few Acacia ehrenbergiana and Grewia sp.	2	1	0	2	2	1	2
2.2	Plains (regs)	Alluvial soils, stones, gravels sands and clays	Gravelly & silty regs weak drainage;	Vegetation in depressions, chiefly Acacia ehrenbergiana, Stipagrostis plumosa, Fagonia spp., Aristida meccana, Aerva javanica more rarely Lasiurus hirsutus.	3	2	0	2	3	2	2
			sandy plains	Sandy plants and minor wadis as for Timetrine. Principally Acacia raddiana/Panicum community.	4	4	2	3	4	4	4
2.3	Wadis & flood plains	Alluvial soils, stones, gravels sands and clays	Major wadis and valleys, relics of a former more extensive drainage system	Major wadis e.g. Tadelock, Tarlit, Eloudj, Ibdekene, Edjerer; main channels lined with Acacia nilotica, A. raddiana, Balanites, Maerua, Calotropis, Boscia senegalensis with communities of annual herbs dominated by grasses: Aristida spp., Eragrostis spp., herbs: Cassia obtusifolia, Zalea pentandra, Boerhavia, Pulicaria, Psoralea, Tribulus, Schouwia, Colocynthis and in places, colonies of Sorghum aethiopicum and Sprobolus helvolus. The valleys are broader and shallower than in Aïr and the development of favourable locust habitats dominated by Schouwia and Tribulus is more extensive	5	5	4	5	5	4	4

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
				Recession				Plague		
3. TAMESNA										
3.1 Saharan Zone (<-70 mm rainfall)										
Northern Tamesna	Alluvial arenosols: gravelly & sandy regs, fossil drainage network of broad shallow valleys with hydromorphic clays, their cracks filled by aeolian sand	Desert steppe and prairies largely confined to wadis and depressions	Trees are scarce and confined to localised groves of chiefly Acacia ehrenbergiana and A. tortilis or Maerua crassifolia in the deeper valleys. Elsewhere there is a sparse steppe of tussock grasses, Panicum turgidum and Lasiurus hirsutus associated with Aerva javanica. Further north under more arid conditions these species gradually become replaced by Stipagrostis acutiflora, S. plumosa and S. pungens and Cornulaca monacantha, Asteriscus (Bubonium) graveolens is locally common. Vast expanses are bare through most of the year but become populated for some time after rains by Fagonia spp., Neurada procumbens, Monsonia nivea, Centropodia forskalii and Stipagrostis acutiflora but chiefly by Tribulus pentandrus, T. mollis and Schouwia thebaica sometimes associated with Boerhavia repens and Colocynthis vulgaris. In good years Tribulus "Igles" may remain green until December while Schouwia "Alouat" can last until late March. The vegetation, even the annual component, is very largely confined to the fossil valleys, where development is ensured by run-off and the special soil conditions.	5	5	4	5	4	4	4
3.2 Saharan Zone (70-125 mm rainfall)										
Southern Tamesna	Alluvial arenosols	Wooded desert steppe and annual prairie mosaic	In Southern Tamesna with increasing rainfall vegetation becomes more abundant southwards. Trees and shrubs are more common, though still confined to wadis. Acacia ehrenbergiana and A. tortilis remain dominant, but Maerua crassifolia, Leptadenia pyrotechnica, Salvadora persica, Calotropis procera and Boscia senegalensis become common, and later Commiphora africana makes an appearance. Silty and clayey areas bear communities of Lasiurus hirsutus, Aerva javanica and Cymbopogon schoenanthus while Panicum turgidum steppe develops on sandier soils. The dominant annuals are grasses, collectively known among the Touareg as "Alemmoz" (straw) and comprise such species as Schoenefeldia gracilis, Eragrostis pilosa, E. diplachnoides, Chloris virgata, Dactyloctenium aegyptium and a number of Aristidas such as meccana, adscensionis, other non-gramineous plants like Boerhavia repens, Tribulus terrestris, Pulicaria sp., Farsetia ramosissima, Astragalus sp., Geigeria alata, Psoralea plicata are important elements, particularly because many remain green for some time after the grasses have died out. Some of these, and others like Ipomoea verticillata, Cyperus rotundus and Sorghum aethiopicum, and Pennisetum violaceum form extensive colonies in the flood plains of the Ighazer and are valuable grazing because of their salt content.	4	3	1	2	5	5	4
3.3 Sahelo Saharan Zone (125-200 mm rainfall)										
Southern Tamesna	Deep sands	More diffuse desert steppe and prairie	Southward flood plains become largely replaced by sandy areas which form a vast belt of fixed ridge dunes extending ENE to WSW. The vegetation here is at first a tussock-grass steppe, with a predominance of Panicum turgidum, Stipagrostis acutiflora and Aristida pallida with a ground cover of annuals such as Cenchrus biflorus, Aristida mutabilis, A. meccana and Limeum indicum. The trees and shrubs, such as Acacia spp., Commiphora africana and Leptadenia pyrotechnica are at first confined to depressions, but progressively southwards under higher rainfall conditions become more widespread and the subdesert tussock-grass steppe gives way to the wooded steppe and prairie.	4	3	0	1	5	5	4

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value: Recession				Plague		
4. AIR (50-150 mm rainfall)										
Sahelo-Saharan and Saharan	Mosaic of rock, rock debris and alluvial soils with local aeolian deposits	Mountainous terrain, vegetation principally a wooded steppe or scrubland largely confined to wadis	The vegetation of Aïr is typically subdesert (Sahelo-saharan), and predominantly riparian. Hill slopes are barren, or with a faint flush of hardy annual grasses such as Stipagrostis obtusa or Aristida meccana. The first vegetation appears along the minor runnels, where tufts of Chrysopogon aucheri, Stipagrostis papposa, S. hirtigluma, Helianthemum lippii, Heliotropium strigosum, Cassia obtusifolia and a few others find a foothold. Soon shrubs such as Acacia ehrenbergiana, A. laeta, A. tortilis, locally Gossypium somalense and later Maerua crassifolia and Ziziphus sp. appear as the wadi reaches the foothills where the gradient becomes less steep and soil begins to accumulate along the banks. Mixed formations locally reaching the density of woodlands develop in some of the sheltered larger wadis, particularly in southern Aïr, including elements such as Hyphaene thebaica, Acacia nilotica, A. raddiana a few Faidherbia albida, Balanites aegyptiaca, dense formations of Salvadora persica, Boscia senegalensis, Ziziphus sp., and Calotropis procera. The undergrowth consists chiefly of tussocky grasses: as the soil becomes sandy Panicum replaces Chrysopogon, to be replaced in turn by Cymbopogon as it becomes silty, the more humid sites usually become populated by Sporobolus helvolus or even the hygrophilous Rottboellia exaltata. Out of the plain, away from the hills, the vegetation soon begins to resemble that of souther Tamesna with its Alemmoz communities, except that it is always more luxuriant nearer the hills. Thus the Acacia-Panicum steppe with its associated elements persists to the northern extremity of Aïr, beyond latitude 20°N, while in Tamesna the last vestiges of it disappear south of latitude 19°N.	S	R	G	F	S	R	F
				Minor Wadis						
				3	2	1	2	3	2	2
				Medium Wadis						
				4	3	1	2	4	3	3
				Major Wadis						
				4	4	2	3	4	4	4
5. TERMIT AND THE DILLIA (50-120 mm rainfall)										
Sahelo-Saharan and Saharan										
5.1 The Massif	Lithosols, metamorphosed sandstones and marls; pockets of alluvial silts and aeolian sands	Eroded largely barren plateau	Much of the surface of the plateau is an expanse of broken sandstone with a rare Cymbopogon, Maerua or Grewia tenax and a thin stubble of Aristida and some Schoenefeldia gracilis in the hollows.	2	1	0	<1	2	1	1
		Around the plateau a wooded desert steppe	Along the foot of the plateau, thanks to drainage. The plants found on the plain, especially herbs such as Melhania denhami, Chascanum marrubifolium, Polygala irregularis, Indigofera argentea, Tephrosia purpurea and T. vicioides, Cenchrus, biflorus and Aristida adsensionis grow abundantly and form suitable locust habitats.	4	3	1	3	5	4	4

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
				Recession				Plague		
5.2 The Plain	Vast plain of deep continental sands often in dune formation	Desert steppe	The plain is a tussock grass steppe dominated by Stipagrostis acutiflora, Centropodia forskalii and more rarely Stipagrostis pungens forming associations on the softer sand of dune crests, while Aristida pallida and Panicum turgidum occur on firmer sand of lower slopes and depressions between the dunes. Stipagrostis papposa forms local colonies but is more common in the south. Cyperus conglomeratus occurs on patches of white sand with Moltkiopsis and Heliotropium sp. Apart from some Leptadenia pyrotechnica, shrubs and trees are scarce outside the Dillia valley. Annual vegetation is patchy, grasses such as Aristida adscensionis are relatively scarce, the common herbs include Indigofera argentea, Tephrosia purpurea, Monsonia nivea, Neurada procumbens, Boerhavia repens and Tribulus pentandrus.	3	3	0	3	5	4	4
5.3 The Dillia Valley (100-150 mm rainfall)										
Fossil drainage, relic of the Tafassasset (traceable from Termit to Lake Chad)	Well-defined valley; some old beds of silt, but generally sandy	Wooded steppe	The vegetation is denser and shrubs appear. There are extensive patches of Leptadenia, while the main floor of the valley supports stands of Acacia raddiana, Salvadora persica, Maerua crassifolia and Balanites aegyptiaca, with tussocks of Panicum turgidum, Cenchrus ciliaris and herbs such as Boerhavia, Chascanum marrubifolium, Cassia sp., Aerva javanica and Melhania denhami.	3	3	0	3	5	4	4

HABITAT TABLE 3 - Desert Locust habitats in Sudan and Egypt

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
				Recession				Plague		
				S	R	G	F	S	R	F
THE COAST										
1.1 CORALLINE FORMATIONS	More or less decomposed coralline and marine soils	Sparse halophitic bushland	Limonium axillare, Zygophyllum spp.	0	0	0	0	0	0	0
	As above with sand mantle, less saline	As above, locally denses	As above, plants less halophytic: Salsola spp., Suaeda spp., Eleusine compressa, Panicum turgidum, Zygophyllum simplex.	3	2	0	2	3	2	1
1.2. SALT FLATS (SABKHAS)	Solonchaks; surface salinity variable	Mud flats with or without halophytic steppe	Often a marked succession of halophytic communities ranging from the more halophytic Halopeplis perfoliata and Arthrocenum glaucum nearer the sea, to the less halophytic Suaeda and Salsola spp. inland.	1	0	0	0	0	0	0
	As above with surface sand/gravel	Halophytic steppe	Presence of fluvial and aeolian sand, e.g. at mouths of wadis, promotes better development of notably the Suaeda monoica "adleeb" steppes which cover large areas of the coast especially in the mouths of larger wadis where on less saline soils, develop such associates as Panicum turgidum, Dipterygium glaucum, Zygophyllum simplex, Eleusine compressa, Heliotropium sp., Aerva javanica, Solanum spp.	3	2	0	2	3	2	2
3. COASTAL PLAINS										
3.1 Regs	Haplic xerosols and yermosols, more or less saline silts often with covering of gravels or marine debris	Patchy woodland and scrubland	Large areas completely bare, and much of the vegetation is confined to wadis; the dominant community is Acacia tortilis, Salsola forskalii, with such associates as Capparis decidua, Maerua crassifolia, Commiphora spp., Lycium spp., Gymnosporia senegalensis, Euphorbia cuneana, Panicum turgidum, Aerva javanica, Dipterygium glaucum, Zygophyllum simplex, Aristida spp.	3	2	0	2	3	2	2
3.2 Sand plains	As above but with deeper sand deposits, sometimes as dunes	Steppe, sometimes wooded	Panicum turgidum - Acacia tortilis community; common associates are Lasiurus hirsutus, Maerua crassifolia, Calotropis procera, Salsola forskalii, Jatropha villosa, Indigofera spinosa, Dipterygium glaucum, Heliotropium ramosissimum, Aerva javanica, Aristida spp.	5	3	2	4	5	3	4
		Crops	Millet is planted whenever rainfall is sufficient; this habitat is an extension of 2.4 in Eritrea and is similar to 4.2.2 in the Saudi Arabian Tihama, but anthropogenic pressure is lower in the Sudan. Fallows are colonised by the therophytes and chamaeophytes which commonly occur in the plain and also by some cosmopolitan weeds (see under Tokar delta 4.1.2 below).							

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
				Recession				Plague		
				S	R	G	F	S	R	F
4. WADIS										
4.1 Tokar delta										
4.1.1 Principal flood area	Eutric fluvisols; complex mosaics ranging from coarse sands and stones to silts and clays; salinity increases seawards	Complex anthropogenic landscape under intensive cultivation; a mosaic which varies in response to changes in flooding and rainfall patterns and cropping activities	The major communities:							
			1. Croplands: cotton, sorghum, maize, millet and associated fallows.	5	2	2	4	5	3	4
			2. Lower more saline delta; extensive scrubland of Mesquite (Prosopis glandulosa/juliflora) and halophytic bushland of Adleeb (Suaeda monoica). This is followed by sabkha proper along the sea shore (2.1 and 2.2 above).	3	1	0	3	4	2	3
			3. The upper, less halophytic delta; diverse communities including - Tamarix nilotica woodland along main course of Khor Baraka - Capparis decidua on silty flood plains - Calotropis procera and Hyphaene thebaica on lighter silts and sands with associated lower ground vegetation.	4	2	2	3	4	2	3
4.1.2 Marginal flood area	Lighter silts and sands; local formation of barkhans	Forming an outer fringe to 1-3 above	4. Crops millet, locally sorghum, weeded or with: 5. Colonisers: Calotropis, Hyphaene and pioneer communities of therophytes, which are also weeds of 1 and especially 4 above. The principal species: Solanum dubium; S. incanum, Datura spp., Dipterygium glaucum, Heliotropium spp., Boerhavia repens, Echinochloa colona, Cyperus sp., Tribulus spp., Zygophyllum simplex, Aristida spp. (Unweeded crops have a higher ecological value).	5	4	4	5	5	4	4
4.1.3 Adjacent hills and slopes	Haplic xerosoils & yermosols	Wooded steppe	As in 3.1 Regs and 3.2 Sand plains above.	5	3	2	4	5	3	4
4.2 Other major wadis	Eutric fluvisols and haplic yermosols	Crops, riparian woodland and scrubland	All major wadis are more or less brought under cultivation, chiefly of millet and sorghum but anthropogenic changes are less marked than in Tokar; Riverine thickets comprise the following species, most of which can be locally dominant: Tamarix nilotica, Salvadora persica, Calotropis procera, Acacia tortilis, A. ehrenbergiana, Ziziphus spp., and the smaller Leptadenia pyrotechnica and, in the deltas, Suaeda monoica. The crops and associated pioneer communities are similar to the marginal flood areas in Tokar (4 & 5 above).	5	4	4	4	5	4	4
4.3 Wadis north of Port Sudan	As above	As above	With decreasing rainfall the plant cover and the range of species decline; Acacia spp., especially A. tortilis and A. ehrenbergiana assume dominance; Panicum, Cymbopogon, and Salsola are the common tussock grasses and bushes. Frequency of breeding declines.	4	3	2	3	4	3	3

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
				Recession				Plague		
				S	R	G	F	S	R	F
5. INLAND PLAINS AND VALLEYS	Eutric regosols and yermosols	Localised scrubland and steppe	Landscape and vegetation similar to coastal wadis but often better preserved: halophytic elements less common. Among the trees Acacias, Commiphora, Balanites, Capparis decidua, Ziziphus spp. and, in larger wadis, Hyphaene palms predominate; the shrubs include Calligunum comosum, Salvadora, Indigofera oblongifolia, and Calotropis procera, together with tussock grasses Panicum turgidum and Cymbopogon schoenanthus and numerous herbs including Aerva, Tribulus, Aristida, Boerhavia, Gisekia and locally Schouwia thebaica.	4	2	(1)	(2)	4	3	3
6. SUMMER BREEDING BELT IN THE INTERIOR OF SUDAN	Note: The range of habitats is analogous to that in Western Africa, (Habitat Table 1). This area is seldom reached by recession populations and then, usually following major breeding and gregarisation on the coast; but the swarm breeding frequency in the Sudan is higher than in the analogous habitats in the Western Region. Maps 10a and 10b show the distribution of breeding in relation to the main vegetation types			4	3	(?)	1	5	4	5

HABITAT TABLE 4 - Desert Locust habitats in the coastal areas of northern Eritrea (after Hemming 1961)

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value (Recession and Plague values are similar)			
				S	R	G	F
1. LITTORAL AREA							
1.1 Coralline area							
1.1.1 Coral shelves	Coral cliffs, saline	Sparse dwarf halophytic bushes	Limonium axillare, Zygophyllum coccineum.	0	0	0	0
1.1.2 Raised beaches	Decomposed coralline soils						
1.1.3 The above + sand mantle	1.1.1/1.1.2 with quartz sand (less saline)	Mixed dwarf bush steppe	As above with Cyperus conglomeratus, Eleusine compressa, Panicum turgidum, Salsola forskalii, Heliotropium ramosisslmum, Trianthema crystallina.	3	2	0	2
1.1.4 Sand dunes	Coralline and marine dunes (saline)	Sparse halophytic steppe	Zygophyllum spp., Cornulaca ehrenbergii.	0	0	0	0
1.1.5 Wadi deltas	Alluvium over coralline sands, reduced salinity	Alluvium with seasonal crops	Pennisetum typhoideum millet, cotton and associated weeds as in 1.1.3 and Suaeda monoica scrub.	4	2	0	2
		Salt flats (impeded drainage)	Aeluropus lagopoides, Sporobolus spicatus, Eleusine compressa, Tavernieria lappacea.	2	0	0	1
1.1.6 Mangrove swamps		Mangroves	Avicennia marina, Rhizophora mucronata, Bruguiera gymnorhiza.	0	0	0	0
1.2 Coastal sand area withwind accumulated marine sands	Marine, more or less saline, sands	Steppe	Halopyrum mucronatum/Cyperus conglomeratus.	1	0	0	1
1.3 Salt flats	Saline soils	Salt bush steppe	Halopeplis perfoliata, Arthrocnemum glaucum.	0	0	0	0
with sand mantle	with wind-blown sand	Mixed steppe	Suaeda, Panicum turgidum, Aerva javanica, Dipterygium glaucum, Heliotropium pterocarpum.	4	3	2	3
2. COASTAL PLAINS							
2.1 Silt plains (Zula area)	Alluvial lava, fine sandy silt soils	Crops	Intensive cultivation of sorghum, millet, maize, watermelon; weeds Aerva, Echinochloa colona, Datura spp., Heliotropium ramosissimum.	3	2	1	2
2.2 Short grass plains (Arkiko & Wangabo plains)	Grey-brown loamy sand	Short grasslands	Cenchrus ciliaris/Cenchrus setigerus, Dactyloctenium scindicum, also Panicum turgidum and Acacia tortilis.	3	2	2	1
2.3 Compact sand plains 2.3.1 Inland marine sand plains	Coarse sands	Scattered Acacia bush	Acacia tortilis/Salsola forskalii community with Dipterygium/ Heliotropium, Zygophyllum simplex, Euphorbia aegyptiaca, Tribulus pentandrus, Aerva, Aristida spp., with Panicum on deeper sand.	4	2	1	3
	Finer sand & higher salinity due to drainage	Suaeda subtype	Dominance of Suaeda monoica and Dipterygium glaucum.	3	2	1	3

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value (Recession and Plague values are similar)			
				S	R	G	F
2.3.2 Sand plains with fresh water shells	Compacted sands with loose sand mantle	Sparse dwarf bush steppe	Arnebia hispidissima, Indigofera semitrijuga community.	2	1	0	2
2.4 Sandy plains and dunes	Deep sands; plains and dunes	Steppe	Panicum turgidum/Acacia tortilis community with Heliotropium, occasional Capparis decidua, Salsola forskalii, Jatropha villosa, Lasiurus hirsutus and Cadaba glandulosa on harder and Farsetia longistyla on siltier sands.	4	3	2	4
2.5 Consolidated sands (Karora type) (Wadi Falcat-Sudan border)	Compacted sands with variable aeolian sand deposits	Low steppe	Grasses: Cenchrus ciliaris, Latipes, Aristida, Panicum, Heliotropium, Tribulus, Indigofera spinosa, Pavonia, Tephrosia and Dipterygium.	5	4	4	5
2.6 Wadis 2.6.1 Smaller wadis	Fine sandy silty alluvium	Scrubland	Lined with Acacia tortilis and Leptadenia pyrotechnica.	4	3	2	4
2.6.2 Larger wadis	Non-saline	Woodland and crops	Lined with Tamarix orientalis, Ziziphus spinachristi, Salvadora and Acacia tortilis. Crops: sorghum, millet, locally maize and cotton; associated weeds: Echinochloa colona, Solanum, Datura, Aerva and Heliotropium ramosissimum in the outwash plain.				
	Slightly saline		Suaeda monoica, Abutilon asiaticum, Acacia ehrenbergiana, Digera alternifolia.	4	3	2	4
3. SUBCOASTAL PLAINS (along foot of escarpment 30-40 km from the coast							
	Generally sandy soils with stones/silts	Steppes, varialy wooded	Scattered Acacia tortilis, A. ehrenbergiana, Balanites aegyptiaca, Cenchrus ciliaris, Dactyloctenium aegyptium, Indigofera spinosa, Cadaba rotundifolia, Salvadora persica and crops.	3	2	1	3
4. LAVA AREAS							
	Lava boulders, ash and decomposed lava rock	Sparse scrubland	Scattered Acacia, mellifera, Aerva, Dactyloctenium, Trianthema, Zygophyllum simplex; Cenchrus ciliaris in depressions	3	2	0	2?
5. BASEMENT HILLS							
5.1 Slopes	basement rocks		Eleusine compressa, Blepharis persica, Melanocenchris, Stipagrostis hirtigluma, S. obtusa.	1	0	0	<1
5.2 Valleys	ditto		Commiphora spp., Cadaba rotundifolia, Acacia tortilis, Dobera glabra, Salvadora persica, Cissus quadrangularis, Eleusine compressa, Indigofera spinosa, Cassia senna and Aerva javanica.	2	1	0	1

HABITAT TABLE 5 - Desert Locust habitats in Northern Somalia

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
				Recession				Plague		
				S	R	G	F	S	R	F
1. THE COASTAL ZONE										
1.1 Halophytic littoral communities										
1.1.1 Beach dunes	Loose, coarse sand	Tussock grassland	Halopyrum mucronatum, Odyssea mucronata, Suaeda monoica, Arthrocnemum glaucum.	1	0	0	1	1	0	1
1.1.2 Salt Flats	Fine alluvium	Bare flats, sparse steppe	Limonium spp., Salsola spp., Suaeda spp.	0	0	0	0	0	0	0
1.1.3 Raised beaches	Coral beds and pockets of alluvium and gravel locally	Scattered shrubs, bushes and colonies of annuals	Acacia tortilis, Balanites orbicularis, Zizyphus hamur, Panicum turgidum, Cyperus spp., Fagonia spp., Salsola spp., Urochondra spp.	2	1	0	2	2	1	2
1.1.4 Flood pans	Fine alluvium and aeolian sand	Salt bush and grass	Suaeda monoica, Limonium axillare, Panicum turgidum, and annuals (as those below) along margins	3	2	0	2	3	2	2
1.1.5 Sandy shore	Coarse marine and coralline sand and aeolian non-saline sand	Herbaceous steppe	as for beach dunes with Sporobolus spicatus, Eleusine compressa, Panicum turgidum, Dipterygium spp., Aerva spp.	3-4	2-3	1	2	3-4	2-3	2
1.1.6 Estuaries	Fine alluvium	Mangrove thickets and salt bush scrub	Avicennia marina, Tamarix nilotica, Suaeda monoica, Aeluropus lagopoides	1	0	0	2	1	0	2
1.2 Non-halophytic coastal communities 1.2.1 The Plains (principally west of 46°E)	Alluvial sands, silts and gravels; calcareous concretions	Wooded steppe	Lasiurus hirsutus, Panicum turgidum, Balanites orbicularis, Acacia tortilis, Boscia, Dobera spp., Cadaba spp., Maerua spp., Commiphora spp., Aristida spp., Eragrostis spp., Latipes spp., Tragus spp., Indigofera spp., I. spinosa, Aerva persica, Dipterygium spp., Heliotropium spp., Cleome spp., Euphorbia spp., Blepharis spp., distinct communities depending on soil and drainage	4	4	3	3	4	4	3
1.2.2 The Tugs (seasonal watercourses)	Alluvial soils with marked zonation in response to fluvial and aeolian influences	Tree-and shrub-lined watercourses, extensive scrubland in mouths of some larger tugs, elsewhere wooded steppe	Tamarix nilotica (larger tugs), Conocarpus lancifolius (Mait-Bosaso sector), Calotropis procera, Leptadenia pyrotechnica, Datura spp., Withania spp., Cassia spp., Cenchrus ciliaris, Sporobolus helvolus. Flood plains and minor channels have well-developed communities of herbs and bushes as for above, millet and sorghum sometimes planted in major tugs.	5	5	4	3	5	5	3

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Estimated potential ecological value						
				Recession				Plague		
				S	R	G	F	S	R	F
2. THE SUBCOASTAL ZONE										
2.1 Inland Plains	Eroded gravel and alluvial deposits, locally aeolian deposits of sands	Scattered low shrubby trees	_Acacia tortilis_, A. _edgworthii_, A. _somalensis_, _Commiphora_ spp., _Salvadora_ spp., _Dobera_ spp., _Rhigozum_ spp., _Jatropha_ spp., _Croton_ spp., _Indigofera spinosa_, _Iphiona_ spp., _Salsola forskalii_ and annual communities, similar to the plains and tugs above, developing on sand and near drainage.	3	2	1	3	3	2	3
Locally at Boghan San				4	3	2	(3)	4	3	3

HABITAT TABLE 6a - Desert Locust habitats in the Arabian Peninsula (north and south of Jiddah)

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	North of Jiddah (Hijaz)				South of Jiddah (Asir)			
				S	R	G	F	S	R	G	F
			The Coasts								
1. CORALLINE FORMATIONS	Coral cliffs and more or less decomposed coralline soils	Sparse halophytic steppe	Limonium axillare, Zygophyllum spp.	Recession & Plague							
				0	0	0	0	0	0	0	0
	As above with sand mantle; (less saline)	As above, but locally denser	As above but with presence of less halophytic elements such as Salsola spp., Trianthema sp., Eleusine compressa, Panicum turgidum.	Recession & Plague							
				2	1	0	2	1	1	0	2
2. SALT FLATS (SABKHAS)	Solonchaks; surface salinity generally declining inland	Often completely barren mud flats with surface sand, gravel, or salt crust	Inland there is often a marked succession of communities of predominantly small to medium-sized bushes ranging from the more salt-tolerant Halopeplis, Arthrocuenmum and Salicornia.	Recession & Plague							
				0	0	0	0	0	0	0	0
	As above surface sand		Less halophytic Suaeda and Salsola spp. often with presence of Panicum, Aerva and Dipterygium.	Recession & Plague							
				3	2	0	2	3	2	0	2
3. COASTAL PLAINS	Marine, more or less saline sands	Predominantly beach dunes	Bare or with halophytic bushes and tussock grasses - Halopyrum, Odyssea, and (near mouths of wadis) Suaeda monoica, Aeluropus and Tamarix spp.	Recession & Plague							
				1	0	0	1	1	0	0	1
4. COASTAL PLAINS 4.1 Regs											
4.1.1 Rainfall >100 mm (Asir & Yemen)	Compact silt and sand with variable covering of gravel, stones and drift sand	Often bare, or a sparse steppe, or scrubland (denser along wadis, q.v)	Acacia tortilis, Salsola forskalii, Indigofera spinosa, Panicum turgidum, Lasiurus irsutus, Aerva javanica; among annuals Zygophyllum simplex, Dipterygium and Aristida spp. predominate.	Recession & Plague							
								4	2	0	3
4.1.2 Rainfall <100 mm (Hijaz, Oman, southern and eastern Arabia)	Often gradual transition from 2 to 4.1	Desert vegetation	Vegetation confined to wadis (q.v.) but more xerophilous - typically halophytic elements predominate.	Recession							
				4	2	0	2				
				Plague							
				4	3	0	3				
4.2 Sandy plains (Khabt) 4.2.1 Rainfall <75 mm (Hijaz, Oman, southern and eastern Arabia)	More or less deep sands, locally dunes	Desert vegetation	Vegetation largely confined to wadis, often barren outside or with sparse sprinkling of bushes and shrubs, colonies of annuals (Dipterygium, Heliotropium, Monsonia, Crotalaria, Tribulus, Aristida and Cyperus spp. develop after the rare, but occasionally heavy rains in eastern Arabia, this habitat extends far inland.	Recession							
				4	2	0	2				
				Plague							
				4	2	0	2				
4.2.2 Rainfall 75-150 mm (Asir & parts of ex Yemen AR and PDR Yemen)	As above	Open or lightly wooded steppe & rainfed crops	The characteristic community is a Panicum turgidum, Acacia tortilis lightly wooded steppe, with such associates as A. ehrenbergiana, Maerua crassifolia, Cadaba spp. and annuals, belonging chiefly to genera Heliotropium, Indigofera, Cleome, Farsetia, Tephrosia, Aerva, Dipterygium, Aristida and Evagrostis. Whenever rainfall permits, the Khabt is cleared and planted with millet (more rarely sorghum on heavier soils). As a result at any time there is a wide spectrum from the steppe to crops through a succession of pioneer communities. The ensemble is a particularly favourable desert locust habitat.	Recession							
								5	5	4	5
				Plague							
								5	5	-	5
4.2.3 Rainfall >150mm (N Yemen & part of Fizan Tihama, Batinah coast of Oman)	Deep sands, locally bookhans	Degraded largely cultivated Khabt	The habitat is largely anthropogenic, dominated by well irrigated and rainfed crops. Uncultivated Khabt is in the nature of fallow land. There are areas of largely uncultivable barkhan dunes resulting from soil erosion. Millet is the main crop but also sorghum, maize cotton and vegetables.	Recession							
								5	3	2	4
				Plague							
								5	4	-	4

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Phase	North of Jiddah (Hijaz) S	R	G	F	South of Jiddah (Asir) S	R	G	F
5. WADIS												
5.1 Small to medium	Alluvial soils ranging from stones and gravels to sands and more rarely clays	Wooded steppe to scrubland	Acacia tortilis Panicum turgidum is the predominant community over much of Arabia, also the species listed under 4.2 are generally more abundant here than on the plains. In places A. ehrenbergiana may form dense thickets. The more open, sandy parts with steppe vegetation provide good SGR habitats. Watermelons and, in more humid areas, millets might be raised following adequate rains.	Recession	5	3	2	3	5	5	5	5
				Plague	5	4	-	3	5	4	-	4
5.2 Large wadis 5.2.1 non saline	Alluvial soils; finer elements more abundant than in 5.1	Usually anthropic rarely riparian woodland	Most larger wadis are cultivated, those in Asir and the Yemens extensively so. The main crops are sorghum and locally cotton on the heavier and millet on lighter soils. SGR habitats are associated with the latter, especially in the mouths of wadis in pioneer communities (as under 4.2.2). Suaeda monoica and Salvadora persica are common associates.	Recession	4	3	1	2	5	4	2	4
				Plague	5	3	-	2	5	4	-	4
5.2.2 Brackish	As above, somewhat saline and/or alkaline	Halophytic steppe sometimes wooded	Frequently a hummocky salt-bush steppe with Nitraria, Salsola and Suaeda spp. and especially Hammada elegans. Tamarix and Acacia spp. and often Calotropis procena are common associates and A. chrenbergiana and Suaeda monoica with Sporobodeus and Aceluruopus grasses in areas subject to flooding.	Recession	4	3	2	3	4	3	1	3
				Plague	4	3	-	3	4	3	-	3
6. SUBCOASTAL PLAINS												
6.1 Hejaz, Asir and ex Yemen AR wadi valleys in foothills and base of escarpment which separates them from the interior	Deposits of alluvial soils, locally fine silts in valleys mid rock formations	Scrubland and riparian woodland more abundant than in 5.2.1	More abundant and varied vegetation than on the coastal plan; locally groves of Acacia spp., Hyphaene thebaica and Tamarix orientalis still survive; arable land, the valleys and many hillsides in Yemen are terraced and cultivated, mainly for sorghum. Locust habitats occur mainly in fallow land.	Recession	4	2	1	3	4	2	1	3
				Plague	4	3	-	3	4	2	-	3
6.2 Ex PDR Yemen, Oman, and eastern Arabia. The lower watershed permits access to valleys and plains often interior	More extensive alluvial deposits in larger valleys. Locally aeolian sand deposits	Scrublands, desert grasslands and steppes, often halophytic	Scrubland dominated by Acacia spp., Commiphora spp., Cadaba rotundifolia, Salvadora persica, Calotropis procera, Prosopis cineraria; among bushes Euphorbia spp., Aloe, Cissus sp., Jatropha, Gaillonia spp., Panicum, Cymbopogon, Chrysopogon and many therophytes. Locust habitats are in sandier areas.	Recession								
				Plague								
7. LAVAS	Basalt with pockets of alluvium	Sparse scrubland	A. mellifera, Grewia tenax, Aerva javanica and Zygophyllum simplex are characteristic. Locust habitats, along margins, mainly in Asir.	Recession	3	1	0	2	4	2	0	3
				Plague	3	1	-	2	3	1	-	2
The Interior												
Note: Recession populations only reach the interior following major build up outside it. The habitats are generally similar to 5.2.2 and 6.2				Average estimate for all areas (see frequency Map 3C and Text 5.5.7)								
Wadi valleys in the Interior	Alluvial deposits locally aeolian sand deposits	Steppe	Predominantly tussock grasses, Panicum, Lasiurus and bushes and herbs including Hammada elegans, Artemisia spp., Centaurea, Anvillea, Alhagi, Zilla.	Recession					4	3	1	2
				Plague					5	4	-	4

HABITAT TABLE 6b - Desert Locust habitats in the Arabian Peninsula (Yemen, Oman, United Arab Emirates and east coast of Saudi Arabia)

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Condition	N. Yemen				S. Yemen				Oman, UA Emirates and East Coast			
					S	R	G	F	S	R	G	F	S	R	G	F
			The Coasts													
1. CORALLINE FORMATIONS	Coral cliffs and more or less decomposed coralline soils	Sparse halophytic steppe	Limonium axillare, Zygophyllum spp.	Recession & Plague	0	0	0	0	0	0	0	0	0	0	0	0
	As above with sand mantle; (less saline)	As above, but locally denser	As above but with presence of less halophytic elements such as Salsola spp., Trianthema sp., Eleusine compressa, Panicum turgidum.	Recession & Plague	0	0	0	1	0	0	0	1	0	0	0	1
2. SALT FLATS (SABKHAS)	Solonchaks; surface salinity generally declining inland	Often completely barren mud flats with surface sand, gravel, or salt crust	Inland there is often a marked succession of communities of predominantly small to medium-sized bushes ranging from the more salt-tolerant Halopeplis, Arthrocuenmum and Salicornia.	Recession & Plague	0	0	0	0	0	0	0	1	0	0	0	0
	As above with surface sand		Less halophytic Suaeda and Salsola spp. often with presence of Panicum, Aerva and Dipterygium.	Recession & Plague	3	2	0	2	3	2	0	2	2	1	0	1
3. COASTAL PLAINS	Marine, more or less saline sands	Predominantly beach dunes	Bare or with halophytic bushes and tussock grasses - Halopyrum, Odyssea, and (near mouths of wadis) Suaeda monoica, Aeluropus and Tamarix spp.	Recession & Plague	1	0	0	1	1	0	0	2	1	0	0	2
4. COASTAL PLAINS 4.1 Regs																
4.1.1 Rainfall >100 mm (Asir & Yemen)	Compact silt and sand with variable covering of gravel, stones and drift sand	Often bare, or a sparse steppe, or scrubland (denser along wadis, q.v)	Acacia tortilis, Salsola forskalii, Indigofera spinosa, Panicum turgidum, Lasiurus irsutus, Aerva javanica; among annuals Zygophyllum simplex, Dipterygium and Aristida spp. predominate.	Recession & Plague	4	2	0	3	4	2	0	3				
4.1.2 Rainfall <100 mm (Hijaz, Oman, southern and eastern Arabia)	Often gradual transition from 2 to 4.1	Desert vegetation	Vegetation confined to wadis (q.v.) but more xerophilous - typically halophytic elements predominate.	Recession					4	2	0	3	4	2	0	3
				Plague					4	3	-	3	4	3	-	3
4.2 Sandy plains (Khabt) 4.2.1 Rainfall <75 mm (Hijaz, Oman, southern and eastern Arabia)	More or less deep sands, locally dunes	Desert vegetation	Vegetation largely confined to wadis, often barren outside or with sparse sprinkling of bushes and shrubs, colonies of annuals (Dipterygium, Heliotropium, Monsonia, Crotalaria, Tribulus, Aristida and Cyperus spp. develop after the rare, but occasionally heavy rains in eastern Arabia, this habitat extends far inland).	Recession					4	2	0	3	4	2	0	3
				Plague					4	3	-	3	4	3	0	3
4.2.2 Rainfall 75-150 mm (Asir & parts of North and South Yemens)	As above	Open or lightly wooded steppe & rainfed crops	The characteristic community is a Panicum turgidum, Acacia tortilis lightly wooded steppe, with such associates as A. ehrenbergiana, Maerua crassifolia, Cadaba spp. and annuals, belonging chiefly to genera Heliotropium, Indigofera, Cleome, Farsetia, Tephrosia, Aerva, Dipterygium, Aristida and Eragrostis. Whenever rainfall permits, the Khabt is cleared and planted with millet (more rarely sorghum on heavier soils). As a result at any time there is a wide spectrum from the steppe to crops through a succession of pioneer communities. The ensemble is a particularly favourable desert locust habitat.	Recession	5	4	3	3	5	5	4	4				
				Plague	5	4	-	4	5	5	-	4				
4.2.3 Rainfall >150mm (N Yemen & part of Jizan Tihama, S. Yemen & Batinah coast of Oman)	Deep sands, locally bookhans	Degraded largely cultivated Khabt	The habitat is largely anthropogenic dominated by well irrigated and rainfed crops. Uncultivated Khabt is in the nature of fallow land. There are areas of largely uncultivable barkhan dunes resulting from soil erosion. Millet is the main crop but also sorghum, maize cotton and vegetables.	Recession	5	4	3	4	4	2	1	2	5	2	1	3
				Plague	5	4	-	4	4	3	-	2	5	3	-	3

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Population	N. Yemen S	N. Yemen R	N. Yemen G	N. Yemen F	S. Yemen S	S. Yemen R	S. Yemen G	S. Yemen F	Oman, UA Emirates and East Coast S	Oman, UA Emirates and East Coast R	Oman, UA Emirates and East Coast G	Oman, UA Emirates and East Coast F
5. WADIS																
5.1 Small to medium	Alluvial soils ranging from stones and gravels to sands and more rarely clays	Wooded steppe to scrubland	Acacia tortilis - Panicum turgidum is the predominant community over much of Arabia, also the species listed under 4.2 are generally more abundant here than on the plains. In places A. chrenbergiana may form dense thickets. The more open, sandy parts with steppe vegetation provide good SGR habitats. Watermelons and in more humid areas, millets might be raised following adequate rains.	Recession	5	4	2	3	5	4	3	4	5	3	2	3
				Plague	5	4	-	3	5	4	-	4	5	4	-	3
5.2 Large wadis 5.2.1 non saline	Alluvial soils; finer elements more abundant than in 5.1	Usually anthropomorphic rarely riparian woodland	Most larger wadis are cultivated, those in Asir and the Yemens extensively so. The main crops are sorghum and locally cotton on the heavier and millet on lighter soils. SGR habitats are associated with the latter, especially in the months of wadis in pioneer communities (as under 4.2.2). Suaeda monoica and Salvadora persica are common associates.	Recession	5	4	2	3	5	4	1	3	4	3	1	2
				Plague	5	4	-	3	5	4	-	3	4	3	-	3
5.2.2 Brackish	As above, somewhat saline and/or alkaline	Halophytic steppe sometimes wooded	Frequently a hummocky salt-bush steppe with Nitraria, Salsola and Suaeda spp. and especially Hammada elegans, Tamarix and Acacia spp. and often Calotropis procena are common associates and A. chrenbergiana and Suaeda monoica with Sporobodus and Aceluruopus grasses in areas subject to flooding.	Recession					4	3	1	3	4	3	1	3
				Plague					4	3	-	3	4	3	-	3
6. SUBCOASTAL PLAINS																
6.1 Hejaz, Asir and N. Yemen wadi valleys in foothills and base of escarpment which separates them from the interior	Deposits of alluvial soils, locally fine silts in valleys mid rock formations	Scrubland and riparian woodland more abundant than in 5.2.1	More abundant and varied vegetation than on the coastal plain; locally groves of Acacia spp., Hyphaene thebaica & Tamarix orientalis still survive; arable land, the valleys and many hillsides in Yemen are terraced and cultivated, mainly for sorghum. Locust habitats occur mainly in fallow land.	Recession	4	2	0	1								
				Plague	4	2	-	2								
6.2 S. Yemen, Oman, and eastern Arabia. The lower watershed permits access to valleys and plains of the interior	More extensive alluvial deposits in larger valleys. Locally aeolian sand deposits	Scrublands, desert grasslands and steppes, often halophytic	Scrubland dominated by Acacia spp., Commiphora spp., Cadaba rotundifolia, Salvadora persica, Calotropis procera, Prosopis cineraria; among bushes Euphorbia spp., Aloe, Cissus sp., Jatropha, Gaillonia spp., Panicum, Cymbopogon, Chrysopogon and many therophytes. Locust habitats in sandier areas.	Recession					4	3	2	3	3	2	2	2
				Plague					4	3	-	3	3	2	-	1
7. LAVAS	Basalt with pockets of alluvium	Sparse scrubland	A. mellifera, Grewia tenax, Aerva javanica and Zygophyllum simplex are characteristic. Locust habitats, along margins, mainly in Asir.	Recession	4	2	0	1	3	1	0	2				
				Plague	3	1	-	1	3	1	-	1				
The Interior																
Note: Recession populations only reach the interior following major build up outside it. The habitats are generally similar to 5.2.2 and 6.2				Average estimate for all areas (see frequency Map 3C and Text 5.5.7)												
Wadi valleys in the Interior	Alluvial deposits locally aeolian sand deposits	Steppe	Predominantly tussock grasses, Panicum, Lasiurus and bushes and herbs including Hammada elegans, Artemisia spp., Centaurea, Anvillea, Alhagi, Zilla.	Recession												
				Plague												

HABITAT TABLE 7 - Desert Locust habitats in Pakistan and Iran

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Ecological potential							
				Pakistan				Iran			
				S	R	G	F	S	R	G	F
I. MAKRAN (Pakistan and Iran) (habitats generally below 1000m)											
1. The Coasts											
1.1 Mud Flats	Yermosols, alluvial soils, largely saline	Salt bush steppe	Frequently bare, or with halophytic communities, usually sparse, predominantly Salsola and Suaeda Anabasis and Atriplex spp.	Recession							
				3	1	0	1	3	1	0	1
				Plague							
				3	1	-	1	3	1	-	1
1.2 Silt & gravel plains	Alluvial soils, less saline, often with covering of gravel and/or wind blown sand	Barren or steppes and pseudo steppes. These cover large areas of the coastal plain and also inland valleys	Patchy, largely confined to khors and depressions, some trees - Acacia spp., Capparis decidua, Prosopis cineraria, Tamarix spp., Salvadora persica and the smaller bushes and tussocks of Calligonum comosum, Hammada elegans, Lycium sp., Panicum turgidum, Pennisetum divisum, Rhaza stricta, Pteropyrum aucheri, Spaerocoma aucheri, Eleusine compressa and smaller chamaeophytes and eremophytes, Eleusine compressa, Cyperus spp., Heliotropium sp., Zygophyllum spp.	Recession							
				4	2	1	2	3	2	1	2
				Plague							
				4	2	-	3	3	2	-	3
1.3 Sands (Rek - Rig) 1.4 Khors (see 2.2.1 below)	Marine and alluvial sands and finer silty sands (arenosols)	Steppes and pseudo-steppes	Rek dunes occur intermittently along the Makran coast from Sonmiani Bay to Jask and beyond. The dominants are woody bushes and herbs and tussock grasses, among them Spaerocoma aucheri, Heliotropium ramosissimum, Aerva javanica, Cornulaca monacantha, Panicum turgidum, Eleusine compressa, Dactyloctenium scindicum, Cyperus arenarius. In depressions halophytic elements, e.g. Aeluropus, Atriplex, Sporobolus and Salsola spp. appear. In some areas, e.g. Sonmiani Bay, bajri and jowar millets are planted locally, both in the interdunes on the coast and inland.	Recession							
				4	3	2	4	3	2	1	3
				Plague							
				4	3	-	3	3	2	-	2
2. Inland Valleys											
2.1 Rock formations	Sedimentary rocks; calcaric regosols	Barren plateaux and hillsides	The little vegetation which may develop in a few favoured depressions here and there, could perhaps provide a brief survival habitat but breeding is unlikely.	Recession & Plague							
				1	0	0	1	1	0	0	1

Area/The Major Biotopes	Soil	Major Habitat Type	Vegetation	Ecological potential	Pakistan S	Pakistan R	Pakistan G	Pakistan F	Iran S	Iran R	Iran G	Iran F
2.2 Valley floor												
2.2.1 Drainage systems	Calcic yermosols (silt/clays)	Riverine formations woodlands, scrublands and grasslands	The higher woodland strata consist principally of Prosopis cineraria, Acacia sp., Capparis decidua, the lower of Tamarix sp., Ziziphus nummalaris, Leptadenia pyrotechnica, Lycium sp., Salvadora persica, Calligonum comosum, Calotropis procera with the undergrowth of tussock grasses, Panicum turgidum and Pennisetum divisum and herbs like Aerva, Crotalaria and Tephrosia. Riverine formations of grasses, rushes and reeds are localised and largely confined to the major basins.	Recession	3	1	0	1	3	1	0	1
				Plague	4	3	-	3	3	2	-	3
2.2.2 Plains	Cambic arenosols silts/clays	Steppes, open, occasionally wooded	As on the coast the silt plains are often completely bare with the aspect of a reg or takyr, but where sandy, as often along the sides of the valleys, pseudosteppe formations composed of the lower strata elements cited for 2.1 above, develop. Particularly important are the communities of herbs and tussock grasses which include Heliotropium, Aerva, Tephrosia, Crotalaria, Gisekia, Panicum which constitute the principal locust breeding habitats, where gregarisation can occur.	Recession	5	4	3	4	5	3	2	3
				Plague	5	4	-	4	5	3	-	4
2.2.3 Plains	sand	croplands, (notably cereal crops)	Much of the arable land is cleared and planted with jowar and bajri sorghums, millets and maize, and these, especially the associated pioneer communities in fallows, also provide good habitats for locusts, in many areas they provide the best opportunities.	Recession	5	4	3	4	5	3	2	3
				Plague	5	4	-	4	5	3	-	4
II. BALUCHISTAN & SOUTHERN AFGHANISTAN (habitats generally above 1000m)												
Note: Habitats show a range similar to that of 1.2 above; the vegetation has a similar physiognomy although species composition may differ somewhat correspondingly, lower temperatures in II are a partial barrier to solitarious, less so to gregarious populations												
1. Drainage systems (often closed, feeding inland basins)		Riverine formation, scrubland & grassland	Among trees Populus euphratica and shrubs and bushes Hammada elegans, Artemisia sp. & Hertia intermedia, Alhagi sp. and Peganum harmala appear.	Recession	3	1	1	1	3	1	0	1
				Plague	4	3	-	3	3	2	-	3
2. Plains	silt and clay	Steppes, partly halophytic	On silty plains halophytic elements and Artemisia, and in sandy areas Calligonum comosum, Hammada, Pennisetum divisum and Hertia are more common.	Recession	3	2	1	2	3	2	1	1
3. Plains	sand	Steppes, crops	Wheat and barley are common winter crops and millet and sorghum main summer crops.	Plague	5	4	-	4	5	3	-	4

HABITAT TABLE 8 - Desert Locust habitats in the Eastern Region

(Distribution of laying in relation to habitats at 112 eggfields surveyed in the Jaisalmer area Rajasthan, India)

(Modified from Popov et al 1965 Table VII-2.1)

	Total				Estimated ecological potential value						
					Recessions				Plagues		
	+	(*)	-	(*)	S	R	G	F	S	R	F
I. Rock (hills and plateaux)											
a. Bare rock	0		4								
f. Bush/Shrub steppe	0		5								
g. Scrub	0		4								
j. Woodland (dwarf)	0		3								
	0		16		0	0	0	0	2	0	2
II. Regs											
a. Bare reg	0		26								
c. Ephemeral sward	0		4								
d. Creeping grass/sedge sward	0		12								
f. Bush/shrub steppe	0		8								
	0		50		2	0	0	2	3	0	3
III. Sands											
1. Plains and gentle slopes											
a. Shifting sands	0		2								
b. Cultivations	2		35								
c. Ephemeral sward with or without trees	8	(7)	13	(11)							
d. Creeping grass/sedge sward	16	(5)	26	(11)							
e. Tussock grass steppe	7		24								
f. Bush/shrub steppe	9		33								
g. Scrub thicket	5		8	(2)							
i. Tree steppe											
	47	(12)	141	(24)	4	3	1	4	4	3	4

	Total				Estimated ecological potential value						
					Recessions				Plagues		
	+	(*)	-	(*)	S	R	G	F	S	R	F
2. **Hillocks**	15		2								
3. **Ridges and predunes**	31		1								
4. **Dunes**	0		0								
	46		3		4	3	1	3	4	2	3
a. Bare crests	0		7								
b. Cultivations	1	(1)	4								
c. Ephemeral sward	5		2								
d. Creeping grass/sedge sward	6		6								
e. Tussock grass steppe	20		13								
f. Bush/shrub steppe	55		7								
	87	(1)	39		5	4	3	5	5	4	5
5. **Fluvial sands**											
a. Bare fluvial sands	1		1								
b. Cultivations											
d. Creeping grass/sedge sward	3		0								
e. Tussock grass steppe	5		5								
f. Bush/shrub steppe	1		0								
j. Woodland	0		1								
	10		7		4	2	1	3	4	2	3
IV. **Silty Depressions**											
a. Bare silt pan (takyr)	0		0								
b. Cultivations	3		3								
c. Ephemeral sward with and without trees	1	(1)	3	(3)							
d. Creeping grass/sedge sward	0		3	(3)							
e. Tussock grass steppe	1		12								

	Total				Estimated ecological potential value						
					Recessions				Plagues		
	+	(*)	-	(*)	S	R	G	F	S	R	F
f. Bush/shrub steppe	0		3								
g. Scrub thicket											
i. Tree steppe	0		2								
j. Woodland	0		3								
	5	(1)	29	(6)	3	2	0	2	4	2	3
	195	(14)	285	(30)							

Key

+ Laying recorded in the habitat

- Laying recorded outside the habitat in its vicinity

2,3 etc Laying recorded at the same habitat on more than one occasion as indicated

* Fallows