Bulletin OEPP/EPPO Bulletin **26**, 577–585 (1996)

Current methods of desert locust forecasting at FAO[1]

by K. CRESSMAN

FAO, AGP Division, via delle Terme di Caracalla, 00100 Rome (Italy)

Desert locusts (*Schistocerca gregaria*) have been feared by farmers in Africa, the Near East and South-West Asia since antiquity. Given favourable environmental conditions, locusts can rapidly breed and form highly mobile swarms which may threaten agriculture in about 60 countries covering more than 20% of the total land surface of the earth. During this century, there have been eight major plagues, the last being in 1986/1989. Periods of recession broken by the occasional relatively minor outbreak of locusts occur in between plagues. For example, there has been an outbreak of locusts in Africa since 1992 which has not reached the proportions of a true plague. FAO operates a Desert Locust Information Service to provide early warning to affected countries of potential locust invasions and advice to the international donor community. Within this service, the locust situation and environmental conditions in affected countries are monitored on a daily basis using reports from national locust survey teams, remote-sensing imagery and meteorological data. Short and medium-term forecasts are prepared indicating potential locust migrations and areas of breeding. These forecasts form the basis of action plans in affected countries. This paper presents a brief introduction to desert locust biology, behaviour and population dynamics and a general overview of desert locust forecasting at FAO.

Introduction

Infestations of desert locust (*Schistocerca gregaria*) are generally restricted to the desert areas that extend from West Africa to South-West Asia covering about 16 million km^2. Breeding usually but not always occurs after rainfall. If a number of successive rains fall, locust numbers can rapidly increase as a result of breeding, and hopper bands and swarms may form that could lead to an outbreak. If this sequence continues, a full plague can develop and threaten a much larger invasion area of nearly 29 million km^2 in Africa and Asia. Outbreaks and plagues do not always originate from the same area, nor do they occur with regular frequency (Fig. 1). Adults are highly mobile and swarms can move large distances. For example, swarms migrated from West Africa to the Caribbean, a distance of 4500 km in 5 days during October and November 1988 (Thomas, 1988). As conditions become unfavourable, locusts move with the wind towards other areas where conditions are more suitable for survival and breeding. A summary of the main biological parameters of *S. gregaria* used in forecasting is presented in Tables 1 and 2.

Forecasts are primarily prepared at the international level and occasionally at the national or regional levels. Each level has different quantities and type of data available and has differing forecasting objectives. National plant protection organizations (NPPOs) will have detailed locust data for their own country supplemented by weather data from the national meteorological service. In most cases, data on locusts and the weather in other countries as well as satellite imagery will not be available. Regional organizations have similar limitations in that they do not have access to data outside the region. At both levels, locust organizations prepare forecasts that generally concentrate on potential developments in the coming days or weeks. Such forecasts are limited to the individual country or region and do not account for possible threats from outside the particular country or region.

At the international level, a greater variety of information, particularly national reports,

---

[1] Paper presented at the EPPO Conference on Forecasting in Plant Protection, Potsdam (DE), 1995 11 21/24.

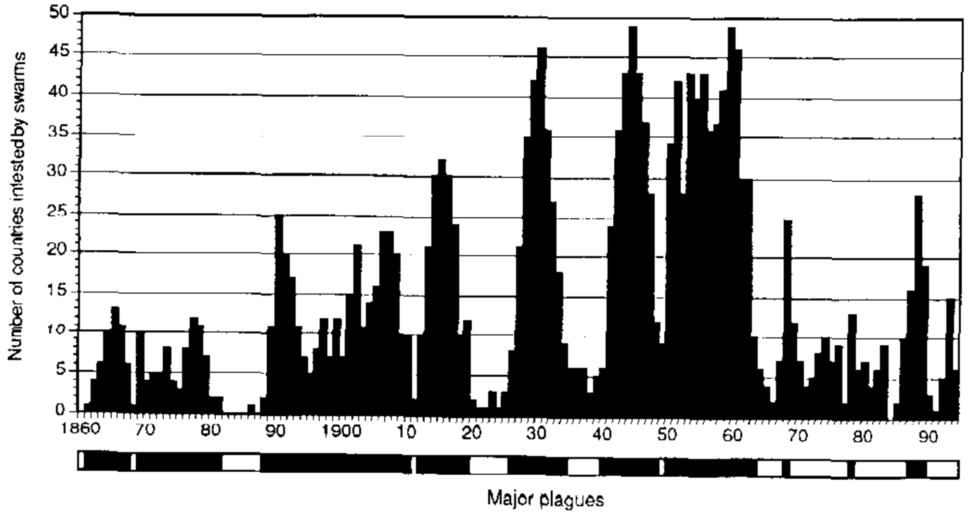

Fig. 1. The irregular nature of the outbreaks and plagues of *Schistocerca gregaria* from 1860 to 1995 (FAO, 1994).

meteorological data and satellite imagery, is available that covers the entire invasion area of *S. gregaria*. Access to such data is especially critical when forecasting a highly mobile pest capable of moving from one continent to another. Hence, the purpose of forecasting at this level is to provide all affected countries and the international donor community with information in order to prepare for locust invasions weeks or months in advance. Forecasts can aid decision makers in affected countries, such as directors of NPPOs, in planning the timing, location, type and scale of survey and control operations. Forecasts can also be used by donor organizations in determining emergency requirements for external assistance to support such operations as well as longer-term development assistance.

As part of its mandate, FAO operates a Desert Locust Information Service at its headquarters in Rome. Within this service, data on *S. gregaria* infestations, habitat conditions and meteorology are summarized and analysed in order to prepare short and medium-term forecasts distributed to affected countries and donor organizations.

Data used in forecasting

All data used in forecasting has until recently been manually collated. Starting in 1996, however, this data will be managed using a geographic information system known as SWARMS (Schistocerca WARning Management System) located within the Desert Locust Information Service. The system operates on an UNIX-based SunSparc workstation using ArcInfo and Ingres software. Within SWARMS, data is stored in several databases and can be displayed on maps consisting of numerous thematic overlays (Healey *et al.*, 1996).

About 18 countries maintain a regular survey programme for monitoring activity of *S. gregaria*. These countries keep FAO informed of the locust situation by transmitting survey and control results in a standardized format via fax and, increasingly, by electronic mail, at least once or twice a month (Table 3). During periods of increased locust activity, data is received on a weekly or even a daily basis. More than 40 other countries do not maintain a regular monitoring programme since locusts are only an occasional threat. However, these countries will generally inform FAO immediately when an invasion occurs.

Table 1. A summary of the main biological parameters of *Schistocerca gregaria* important in forecasting: breeding and development

	Value		
Parameter	solitary	gregarious	Reference
Breeding			
copulation temperature (min)	> 17°C		Popov (1954)
laying temperature (min)	> 17°C		Popov (1954)
soil moisture required	5–15 cm		Popov (1954)
rainfall required (1962)	15–20 mm		Popov (1954), Magor
eggs per pod (average)	95	80	Ashall & Ellis (1962), Roffey & Popov (1968)
laying times per female	3+	2–3	Popov (1958b), Papillion (1960)
number of larval moults	6	5	Pedgley (1981)
Development rates			
laying time	7–30 h		Popov (1958a)
laying interval	6–11 days		Popov (1958b)
egg incubation	10–65 days		Symmons *et al.* (1973, 1974)
1st instar (average)	6 days		Pedgley (1981)
2nd instar (average)	7 days		Pedgley (1981)
3rd instar (average)	6 days		Pedgley (1981)
4th instar (average)	7 days		Pedgley (1981)
5th instar (average)	10 days		Pedgley (1981)
hopper (total)	24–95 days (average = 36 days)		Pedgley (1981)
laying to fledgling (total)	40–50 days		Pedgley (1981)
adult maturation	2–4 months		Pedgley (1981)

In addition to habitat data collected during locust surveys in affected countries (Table 3), FAO receives NOAA satellite imagery that estimates green vegetation at 1-km^2 resolution. This data is currently available for West Africa and the Red Sea area where it is collected and processed by regional centres and transmitted to Rome by courier.

To supplement rainfall reported by affected countries (Table 3), FAO receives daily rainfall reports from national meteorological services through MeteoFrance (FR) by electronic mail. Synoptic maps indicating atmospheric pressure and winds at three different heights over the locust invasion area are received daily by fax. Additional meteorological data is downloaded via the Internet on a daily basis from MeteoConsult B.V. (NL) which is used to operate a Locust Migration Model. FAO also receives visible, infra-red, water-vapour and thermal imagery of clouds from the geo-stationery weather satellite Meteosat every 3 h and cumulative cold cloud imagery on a daily and 10-day basis. All locust and weather data is maintained in archives at FAO and the Natural Resources Institute (GB).

Forecasting methodology

All locust and rainfall reports are first registered and entered into SWARMS. Coordinates and location names are checked and corrected using databases and electronic gazetteers contained within the system. In some cases, NPPOs may be requested to provide additional clarification or details.

Table 2. A summary of the main biological parameters in *Schistocerca gregaria* important in forecasting: migration

	Value		
Parameter	individuals	swarms	Reference
air speed during flight	9–23 km h^{-1}		Rainey (1963)
ground speed during flight	–	1.5–16 km h^{-1}	Rainey (1963)
displacement	1–400 km/night	5–200+ km day^{-1}	Rainey (1963), Pedgley (1981)
displacement direction	within 10° downwind or 10–20° to right of surface wind		Rainey (1963)
flying height above ground	< 1800 m	15–1690 m	Rainey (1963), Schaefer (1976)
take-off time (warm)	20 min after sunset	2–3 h after sunrise	Roffey (1963), Waloff (1963), Schaefer (1976), Pedgley (1981)
take-off time (cool)	—	4–6 h after sunrise	Waloff (1972)
take-off temperature (sunny)	—	> 14.5°C	Rungs (1946)
take-off temperature (cloudy)	—	> 23–24°C	Pedgley (1981)
take-off wind speed (cloudy)	< 4–7 m s^{-1}	< 4–6 m s^{-1}	Waloff (1972), Pedgley (1981)
flight temperature (sustained)	25–35°C		Rainey (1963)
flight temperature (min)	—	23–24°C (immature) 26°C (mature)	Gunn *et al.* (1948), Waloff & Rainey (1951)
flight temperature (night)	> 20–24°C		Predtechenskii (1935), Rainey (1963)
flight temperature (day)	> 9–17°C < 40 + °C		Rainey (1963)
flight duration (min)	4 h	9–10 h	Pedgley (1981)
flight duration (max)	10 h	13–20 h	Pedgley (1981)
landing time	—	–2 h to +0.5 h after sunset	Pedgley (1981)

Data is then displayed using a variety of symbols on maps containing different backgrounds such as topography, borders, rivers, towns and roads. The next version of SWARMS will allow such data to be displayed on top of background layers derived from satellite imagery indicating clouds and vegetation.

Plotting locust and rainfall data allows the forecaster to visualize the spatial relationships between the various data points in order to have some idea of the distribution of particular infestations or rainfall over time and space. Prior to SWARMS, this was done manually on several maps of differing scales.

Depending on the stage of development of a local locust population, the forecaster typically examines the current situation by posing a series of questions (Fig. 2). These questions are based on the biology of the insect and their answers usually depend on the state of the habitat. For example if mature adults are present and laying eggs, the forecaster asks when these eggs are likely to hatch, when the hoppers would fledge (the final moult leading to a winged adult), and whether the new adults would stay in the area, mature, copulate and lay or move to another area; in both cases, when this is likely to occur and on what scale. In order to answer these questions, the forecaster will need to have information on the development rate of eggs and hoppers, previous rainfall and ecological conditions, air temperature, winds and an estimate of the scale of current infestations.

Table 3. Standardized data collected during field surveys for *Schistocerca gregaria* (modified from FAO, 1995a)

LOCATION		date name area (ha) topography latitude/longitude
LOCUSTS		presence/absence
	appearance:	solitary/transiens/gregarious
	behaviour:	copulating/laying/hatching/settled flying (direction & time passing overhead) flying (height and width)
	maturity:	instar/fledgling/immature/mature adult
	density:	hoppers per m^2 or bush/adults per transect or ha band and swarm density (low, medium, high)
	size:	band and swarm size (m^2 or km^2)
ECOLOGY	rainfall:	date and quantity (mm) of last rain
	vegetation:	condition (dry, greening, green, drying) density (low, medium, high)
	soil:	moisture (wet, dry)
CONTROL	pesticide:	name, formulation, application rate, quantity area treated (ha)
	method:	ground or aerial
	efficiency:	estimated % kill

Several models are used to assist the forecaster in answering these questions. One model estimates the development time of eggs and hoppers from the laying to fledging stages (Reus & Symmons, 1992). This model is based on the well established relationship between temperature and locust development (Pedgley, 1981). Long-term daily temperature means are used in combination with particular locust stages, and dates and locations of sightings which are entered by the user. A second model is used to estimate the displacement of adults forward or backward in time (MeteoConsult, 1995). The model uses 12-h meteorological data (temperature, winds and pressure at surface, 950, 850 and 700 mbar) with a resolution of 1.25 square degrees. This data is derived from actual field reports and a large weather model at the National Meteorological Center (USA). It also includes 72-h forecast data. The user can indicate the start or ending location of the migration, dates, take-off and landing times, time steps, speed, and temperature or height of flight.

The above procedures are used to gain a better understanding of the current situation and how it may develop over time. Quite often, even the current situation has to be estimated, especially in those areas where surveys cannot be carried out due to limited resources or insecurity, or over areas in which satellite imagery is not available.

The likelihood that the current situation may evolve in one particular way or another is further explored by comparing it with the past. Using SWARMS, current locust infestations are matched with historical data for the past 65 years in order to look for similar situations; in particular the scale, timeliness and spatial resolution are considered. If analogous occurrences are found, these are carefully examined since they can provide clues as to what may happen in the future. Many specific situations have been studied in detail and the results of these case studies can also help the forecaster. In a similar manner, rainfall and vegetation conditions are examined and compared using historical records, long-term averages and archived satellite imagery, but there is far less historical data.

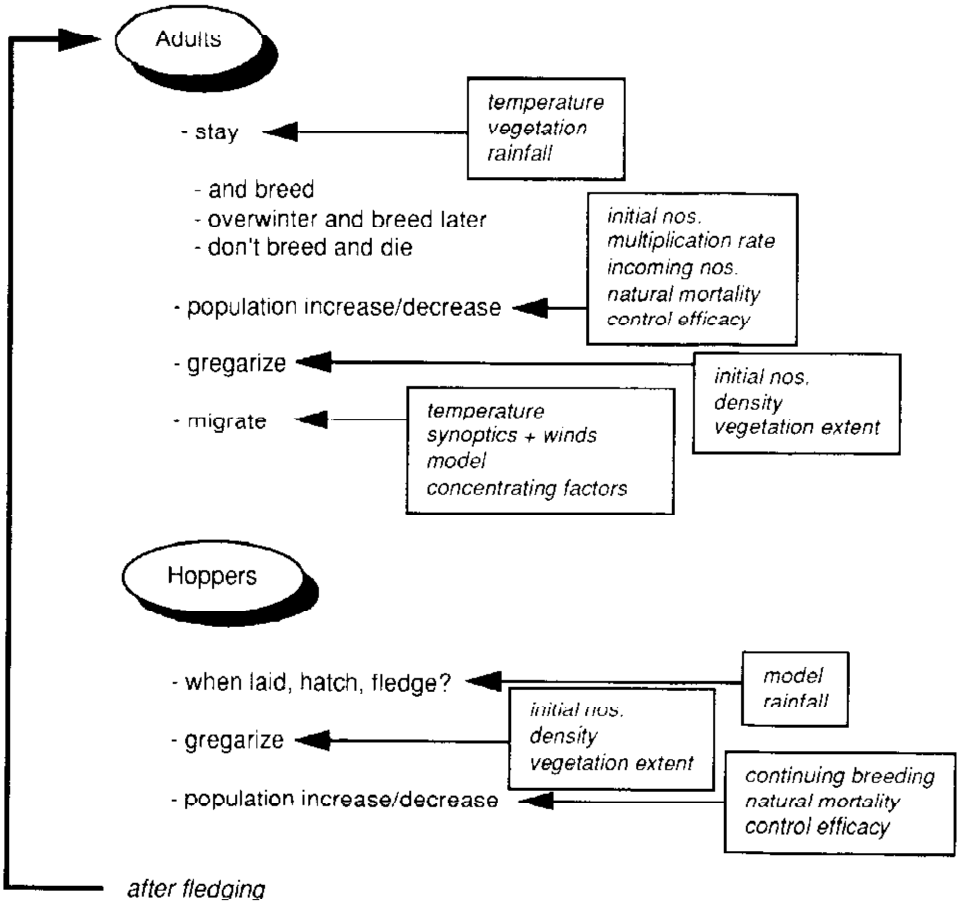

Fig. 2. Schematic presentation of the forecasting procedure for *Schistocerca gregaria* used at FAO.

Outputs

FAO prepares a Desert Locust Bulletin at the beginning of every month for affected countries, the donor community and other interested groups. This bulletin contains a summary of locust activity, weather and ecological conditions during the previous month. A 6-week detailed forecast is also prepared for each country. During periods of increased locust activity, an update is produced at mid-month or every 10 days. Furthermore, FAO prepares warnings for individual countries as the situation demands. All bulletins and updates are written in English, French and Arabic and sent by fax directly to NPPOs and the donor community. They are also sent to individuals and organizations who have electronic mail and copies are placed on FAO's World-Wide Web site on the Internet (www.FAO.ORG).

Validation

It is extremely difficult to validate the locust forecasts prepared by FAO, since forecasts are more qualitative than quantitative. The probability of a certain occurrence is not expressed as a numerical value due to the nature of the data and the time period of the forecasts; instead, forecasts are expressed in relative terms. One study found that the mean accuracy of forecasts for 24 countries over a four-month period was 55% (Cressman, 1989). This was before FAO had access to improved satellite imagery and prior to using a geographic information system to assist in the management and examination of the data. Additional studies are certainly required to gauge the effectiveness and improvements made in forecasting at FAO.

The Desert Locust Egg and Hopper Development model has been validated and results are usually accurate to within a few days of actual occurrence at temperatures of 20–40°C; below 20°C and during years of unusual temperatures, the model tends to be less accurate. On the other hand, the Locust Migration Model has not been validated and therefore it is used with extreme caution. Results of this model will probably not be incorporated into bulletins and warnings until forecasters gain more experience in using the model and increased confidence in its estimated trajectories.

Furthermore, satellite imagery requires validation before it can be used confidently for forecasting. One validation study was carried out in Niger (Cherlet & Di Gregorio, 1993) which resulted in several correction factors that could be applied to imagery for vegetation monitoring. However, it appears that these factors are only valid over a limited area. Consequently, another validation study is in progress in a different biotope on the Red Sea coast of Eritrea (FAO, 1995b). Further studies will be required in other areas.

Conclusion

The importance of forecasting has increased as the strategy of locust control has moved towards attempting preventive control with limited resources. Though improvements are being steadily made, the challenge of forecasting breeding and migration of *S. gregaria* accurately remains to be overcome. Meanwhile, forecasts continue to depend on data of variable quality collected during field surveys and are supplemented by meteorological, satellite-derived and historical data which is not always complete. Models are helping to fill in data gaps and to simulate various biological processes. The use of a geographical information system to better manage and examine this vast range of data in a variety of formats from different sources has great potential but is still in its infancy.

Méthodes de prévision utilisées par la FAO pour les criquets pèlerins

Les criquets pèlerins (*Schistocerca gregaria*) sont redoutés des agriculteurs en Afrique, au Proche-Orient et en Asie du sud-est depuis l'Antiquité. Dans des conditions environnementales favorables, les criquets peuvent se reproduire rapidement et former des essaims très mobiles susceptibles de menacer l'agriculture de quelque 60 pays couvrant plus de 20% des terres émergées du globe. Il y a eu 8 pullulations majeures au cours de ce siècle, la dernière en 1986/1989. Entre les pullulations ont lieu des périodes de récession, interrompues par des foyers occasionnels relativement mineurs. Un foyer de criquets est par exemple présent en Afrique depuis 1992, mais il n'a pas atteint les proportions d'une véritable pullulation. La FAO opère un service d'information sur le criquet pèlerin dans le but de fournir aux pays des avertissements précoces sur les invasions potentielles de criquets, et de conseiller la communauté internationale de donateurs. La situation des criquets et les conditions environnementales dans les pays touchés sont évaluées quotidiennement dans ce service à l'aide des rapports des équipes nationales de surveillance du criquet pèlerin, d'images satellites et de données météorologiques. Des prévisions à court et moyen terme sont préparées. Elles indiquent les migrations potentielles des criquets et les zones de reproduction. Ces prévisions forment la base de plans d'action dans les pays touchés. Cet article présente une brève introduction à la biologie, au comportement et à la dynamique des populations du criquet pèlerin, et une vue générale des prévisions effectuées par la FAO pour cette espèce.

Применяемые ФАО методы прогнозирования появления пустынной саранчи

Со времен античности саранча пустыни (*Schistocerca gregaria*) наводит страх на фермеров в Африке, на Ближнем Востоке и в Юго-Западной Азии. При благоприятных условиях окружающей среды саранча может быстро размножаться и образовывать характеризующиеся большой мобильностью стаи, которые могут угрожать сельскому хозяйству почти в 60 странах, охватывая более 20% всей возделываемой площади земного шара. На протяжении XX-го века было отмечено 8 крупных массовых размножений саранчи, последнее из который имело место в 1986/1989 гг. Периоды спада прерываются сравнительно небольшими случайными вспышками появления саранчи в период между массовыми размножениями. Так например, в Африке с 1992 г. была отмечена одна вспышка саранчи, однако она не достигла пропорций настоящего стихийного бедствия. В ФАО работает служба информации о пустынной саранче, которая дает заинтересованным странам раннее предупреждение о потенциальных инвазиях, а также предоставляет консультационные услуги международному сообществу стран-доноров. В рамках этой службы контролю на каждодневной основе подвергается ситуация с саранчой и условия окружающей среды в затронутых странах; при этом используются рапорты национальных команд наблюдения за саранчой, карты, составленные с помощью дистанционного зондирования, а также метеорологические данные. Готовятся краткосрочные и среднесрочные прогнозы с указанием потенциальных миграций саранчи и зон ее размножения. Эти прогнозы представляют собой основу для плана действий в конкретных странах. В докладе дается краткое введение в биологические проблемы саранчовых, поведенческие аспекты и динамику популяций, а также дается общий обзор прогнозирования пустынной саранчи, проводимого в ФАО.

References

Ashall, C. & Ellis, P.E. (1962) Studies on numbers and mortality in field populations of the Desert Locust (*Schistocerca gregaria*). *Anti-Locust Bulletin* **38**, 1–59.

Cherlet, M. & Di Gregorio, A. (1993) Calibration and integrated modelling of remote sensing data for Desert Locust habitat monitoring. *FAO Plant Protection Service, RSC Series* no. 64.

Cressman, K. (1989) Desert Locust forecasting report: forecast accuracy by country July to mid-November 1989. FAO, Rome (IT).

FAO (1994) *The Desert Locust Guidelines: I. Biology and Behaviour.* FAO, Rome (IT).

FAO (1995a) *Desert Locust Survey Form.* FAO, Rome (IT).

FAO (1995b) Improving the monitoring of Desert Locust habitats by remote sensing. EMPRES project GCP/INT/596/BEL. FAO, Rome (IT).

Gunn, D.L., Perry, F.C., Seymour, W.G., Telford, T.M., Wright, E.N. & Yeo, D. (1948) Behaviour of the Desert Locust (*Schistocerca gregaria*) in Kenya in relation to aircraft spraying. *Anti-Locust Bulletin* **3**, 1-70.

Healey, R.G., Robertson, S.G., Magor, J.I. Pender, J. & Cressman, K. (1996) A GIS for Desert Locust forecasting and monitoring. *International Journal on Geographic Information Systems* **10**, 117–136.

Magor, J.I. (1962) Rainfall as a factor in the geographical distribution of the Desert Locust breeding areas, with particular reference to summer breeding areas of India and Pakistan. *PhD Thesis*, University of Edinburgh (GB).

MeteoConsult (1995) *Desert Locust Migration Model: User Manual.* MeteoConsult B.V., Wageningen (NL).

Papillion, M. (1960) *Etude préliminaire de la répercussion du groupement des parents sur les larves nouveau-nées de Schistocerca gregaria. Bulletin Biologique de la France et de la Belgique* **93**, 203–263.

Pedgley, D.E. (ed.) (1981) *Desert Locust Forecasting Manual* (Vol. I). Centre for Overseas Pest Research, London (GB).

Popov, G. (1954) Investigations of suspected outbreak areas of the Desert Locust in Iran. *Anti-Locust Bulletin* **14**, 1–30.

Popov, G. (1958a) Ecological studies on oviposition by swarms of the Desert Locust (*Schistocerca gregaria*) in Eastern Africa. *Anti-Locust Bulletin* **31**, 1–70.

Popov, G. (1958b) Note on the frequency and rate of oviposition in swarms of the Desert Locust (*Schistocerca gregaria*). *Entomological Monthly Magazine* **94**, 167–180.

Predtechenskii, S.A. (1935) [Studies on the desert locust (*Schistocerca gregaria*) in Central Asia and Transcaucasus in 1929–30.]. *Trudy po Zashchite Rastenii* **11**, 1–92 (in Russian).

Rainey, R.C. (1963) *Meteorology and the Migration of Desert Locusts*. WMO, Geneva (CH).

Reus, J.A.W.A. & Symmons, P.M. (1992) A model to predict the incubation and nymphal development periods of the desert locust, *Schistocerca gregaria. Bulletin of Entomological Research* **82**, 517–520.

Roffey, J. (1963) Observations on night flight in the Desert Locust (*Schistocerca gregaria*). *Anti-Locust Bulletin* **39**, 1–32.

Roffey, J. & Popov, G. (1968) Enviromental and behavioural processes in a Desert Locust outbreak. *Nature* **219**, 446–450.

Rungs, C. (1946) Rapport sur les essais de lutte contre les adultes de *Schistocerca gregaria* au Maroc français, au printemps de 1945. *Bulletin Semestriel de l'Office National Anti-acridien* **2**, 41–87.

Schaefer, G.W. (1976) Radar observations of insect flight. In *Insect Flight. Symposium, Royal Entomological Society of London* 7, 157–197.

Symmons, P.M., Green, S., Robertson, R.A. & Wardhaugh, K.G. (1973) *Incubation and Hopper Development Periods of the Desert Locust*. Centre for Overseas Pest Research, London (GB).

Symmons, P.M., Green, S.M., Robertson, R.A. & Wardhaugh, K.G. (1974) The production of distribution maps of the incubation and hopper development periods of the Desert Locust *Schistocerca gregaria. Bulletin of Entomological Research* **64**, 443–451.

Thomas, I. (1988) The Desert Locust Atlantic migrations and invasions of the Cape Verde Islands, the Caribbean and the north coast of South America in the autumn of 1988. Natural Resources Institute, Chatham (UK).

Waloff, Z. (1963) Field studies on solitary and *transiens* Desert Locusts in the Red Sea area. *Anti-Locust Bulletin* **40**, 1–93.

Waloff, Z. (1972) Orientation of flying locust, *Schistocerca gregaria*, in migrating swarms. *Bulletin of Entomological Research* **62**, 1–72.

Waloff, Z. & Rainey, R.C. (1951) Field studies on factors affecting the displacements of Desert Locust swarms in eastern Africa. *Anti-Locust Bulletin* **9**, 1–50.