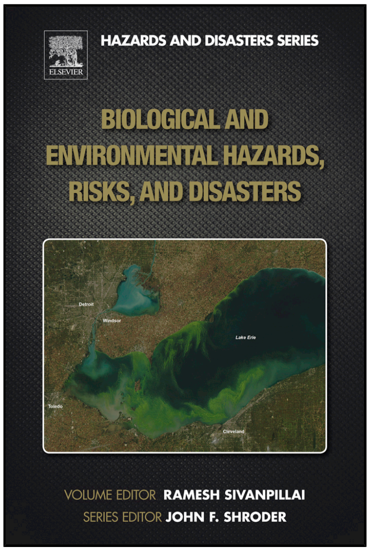

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Chapter 4.2

Desert Locust

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ABSTRACT
The desert locust is considered to be the most dangerous of all migratory pest species in the world due to its ability to reproduce rapidly, migrate long distances, and devastate crops. In order to minimize the frequency, severity, and duration of plagues, the Food and Agriculture Organization (FAO) of the United Nations operates a global early warning system based on the latest technological advances that have led to dramatic improvements in data management, analysis, and forecasting. The system can be a model for other early warning systems about migratory pests.

The desert locust (*Schistocerca gregaria*, Forskål) has the ability to change its behavior and physiology, in particular its appearance, in response to environmental conditions, and transform itself from a harmless solitarious individual to part of a collective mass of insects that form a cohesive swarm (Figure 4.2.1), which can cross continents and seas, and quickly devour a farmer's field and his entire livelihood in a single morning (Figure 4.2.2). For this reason, the desert locust is often considered as the most important and dangerous of all migratory pests in the world (Steedman, 1990).

For years the desert locust was thought to be two different insects. In the 1920s, a Russian scientist, Boris Uvarov, confirmed that it was a single species that had evolved a unique strategy for surviving in some of the harshest

FIGURE 4.2.1 A typical desert locust swarm (May 14, 2014, Addis Ababa, Ethiopia).

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FIGURE 4.2.2 In February 2014, locusts were present and causing damage to pearl millet (left) on the Red Sea coast in Eritrea that was due to be harvested shortly. Millet heads are extremely vulnerable and are at high risk to desert locust damage at this stage.

environments on Earth. Under normal conditions, solitarious locusts are found in low numbers scattered throughout the deserts of North Africa, the Middle East, and Southwest Asia, trying to survive in isolation by seeking shelter on sparse annual vegetation and laying eggs in moist sandy soil after intermittent rains. This arid and hyperarid area is some 16 million square kilometers in size, nearly twice as big as the United States of America, and includes about 30 countries. It is referred to as the **recession area** and the calm period without widespread and heavy infestations is called a **recession** (Figure 4.2.3).

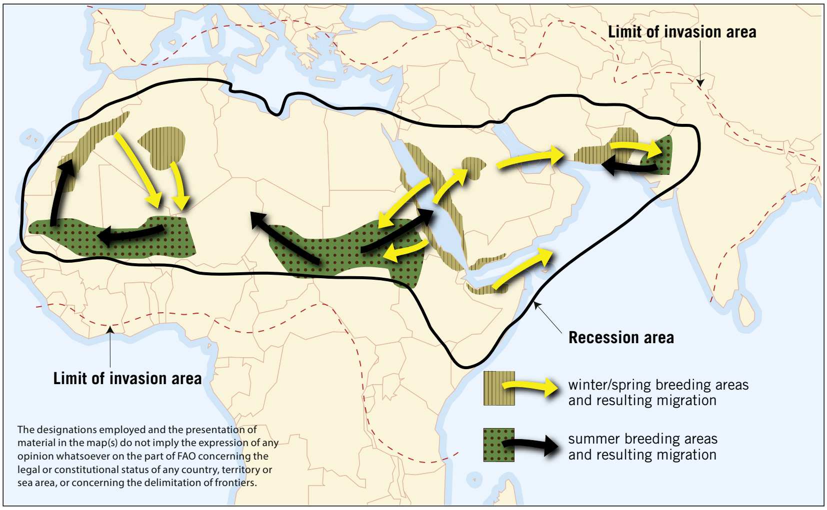

FIGURE 4.2.3 The recession and plague areas of the desert locust.

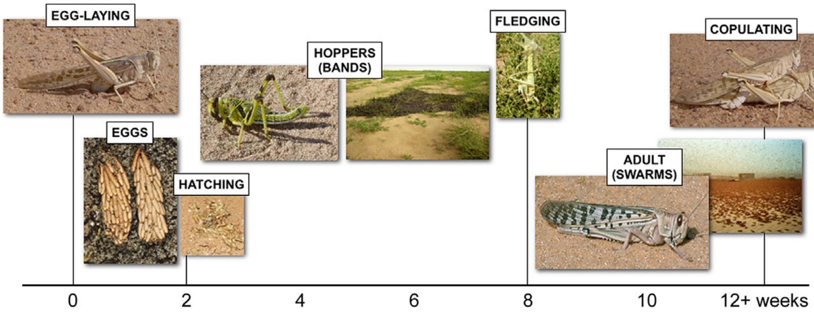

FIGURE 4.2.4 The life cycle of the desert locust.

When unusually heavy rains fall somewhere in the recession area, locusts take advantage of these rare events and multiple rapidly to increase in number. Under optimal conditions, locusts increase some 16–20 times every 3 months after a new generation of breeding (Figure 4.2.4). Once the desert habitat starts to dry out, large numbers of locusts are forced into the remaining patches of green vegetation, concentrate, come into physical contact with one another and start to behave as a single cohesive mass. They become increasingly more gregarious, initially forming small groups of hoppers (wingless nymphs) and adults that eventually fuse and form dense bands of hoppers and swarms of adults (Figure 4.2.5). This process is known as **gregarization** and the intermediate phase between **solitarious** and **gregarious**, that is, when locusts are grouping is referred to as **transiens**. Due to the sporadic nature of rainfall in the desert, fixed gregarization areas do not exist within the vast recession area. Gregarization takes place only in those parts of the recession area, where two generations of breeding can occur in rapid succession (Symmons and Cressman, 2001).

The marked increase in locust numbers on a local scale due to concentration, multiplication, and gregarization, which unless checked, can lead to the formation of hopper bands and swarms (Roffey and Popov, 1968). This is called an **outbreak**. If further rains fall, a very large increase in locust numbers and contemporaneous outbreaks can occur, followed by the production of two or more successive generations of transient-to-gregarious breeding in complimentary seasonal breeding areas. This is referred to an **upsurge**. A period of one or more years of widespread and heavy infestations, the majority of which occur as bands or swarms is called a **plague**. A major plague exists when two or more regions area affected simultaneously. During upsurges and plagues, locust swarms tend to migrate beyond the recession area, and invade an area of some 32 million square kilometers in size, equivalent to about 20% of the Earth's land surface (Figure 4.2.3). This is known as the **invasion area**.

An outbreak may develop in a relatively small area of only a few 100 square kilometers within part of a single country (Roffey et al., 1970). No fixed outbreak areas occur; instead, the location of an outbreak is a function of

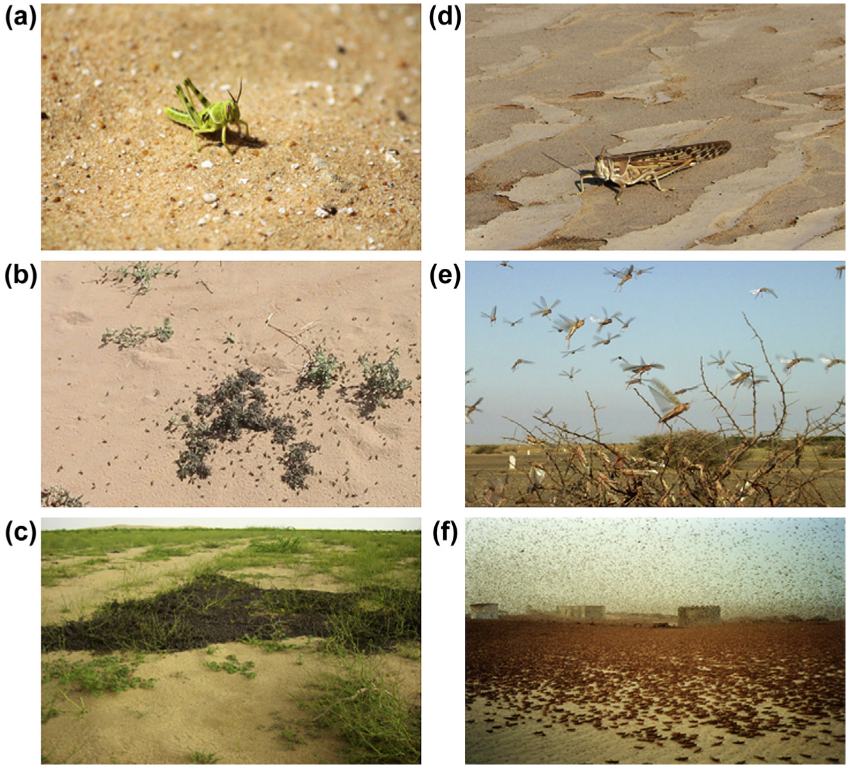

FIGURE 4.2.5 The gregarization process in desert locust occurs as locusts increase in number and concentrate, consisting of: (a) solitarious hopper, (b) a small group of *transiens* hoppers, (c) a fully gregarious hopper band, (d) solitarious adult, (e) a group of *transiens* adults, and (f) a fully gregarious immature adult swarm.

the sporadic spatial and temporal nature of rainfall in the desert, subsequent vegetation development, temperature, and locust populations. An upsurge, on the other hand, can affect numerous countries or an entire region, whereas plagues usually affect a continent or more. For example, good rains fell over a widespread area of the Northern Sahel between Mauritania and Sudan during the summer of 2003. The rains also fell some 100 km further north than usual. Although locusts bred during August and September, only low densities of scattered adults were seen in the field by survey teams. Once the rains stopped and as vegetation dried out in October, tens of millions of scattered individual locusts concentrated in the few small areas, where vegetation remained green. The locusts became increasingly gregarious, and formed hopper bands and adult swarms, giving rise to four separate nonrelated outbreaks in Mauritania, Mali, Niger, and Sudan (Figure 4.2.6). The outbreaks were not controlled because they developed suddenly and occurred in remote areas so they were

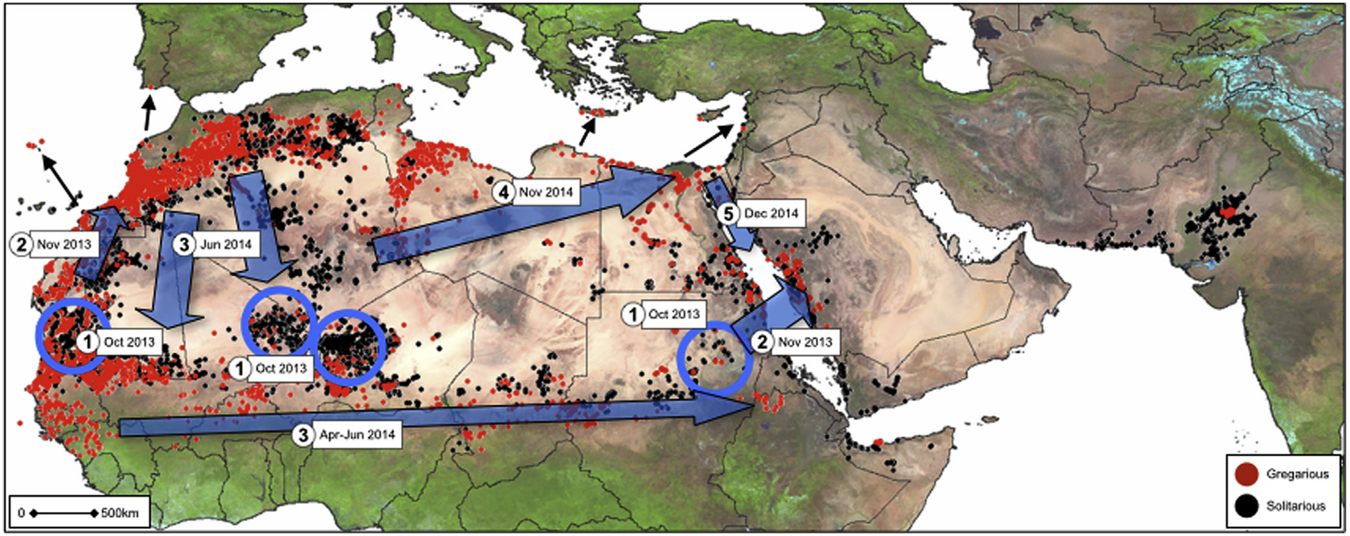

FIGURE 4.2.6 Good breeding during the summer of 2003 caused four desert locust outbreaks to occur simultaneously that were not controlled. Unusually heavy and widespread rains in late October led to an upsurge, which later spread and developed into a regional plague. By summer 2005, the plague had declined due to substantial control efforts and adverse weather.

not detected in time. Insufficient preparedness and a lack of available resources occurred in each country at that time. On 21–22 October, unusually heavy rains fell over a widespread area of West Africa extending from Dakar to the Atlas Mountains in Morocco. Some areas in Western Sahara received more rain in one day than what normally falls in an entire year. As a result, ecological conditions remained favorable for more than 6 months. Swarms that formed and were not controlled in the outbreaks in Mauritania, Mali, and Niger migrated to these areas, where 2–3 generations of breeding occurred from winter 2003 to spring 2004, giving rise to large numbers of locusts and causing an upsurge to develop. The upsurge, which in this case could be considered a regional plague, spread to 23 countries in Africa and the Middle East. It took nearly 2 years to bring it to an end, after spending more than $500 million and spraying 13 million hectares (Brader et al., 2006).

Locust plagues generally take several years to develop after a series of events in which locust numbers increase steadily (Roffey and Magor, 2001). This starts with the normally calm period of recession, followed by localized outbreaks and regional upsurges that can lead to a plague, which eventually declines, returning to a recession (Figure 4.2.7). A plague declines usually within 6 months, which is much quicker than it takes to develop. For example, it took more than 3 years for the last plague to develop but it declined within 6 months after reaching its peak. In 1985, good rains led to desert locust outbreaks in Northern Africa and around the Red Sea. Breeding continued along the Red Sea coasts, causing more swarms to form and by late 1986 an upsurge had developed in the region. Many of the swarms migrated to West Africa, where unusually heavy and widespread rain fell in late September 1987 in Northern Mauritania and Western Sahara. At least two generations of breeding occurred during the winter/spring of 1987/1988. During the following summer, swarms invaded the Sahelian countries in West Africa and

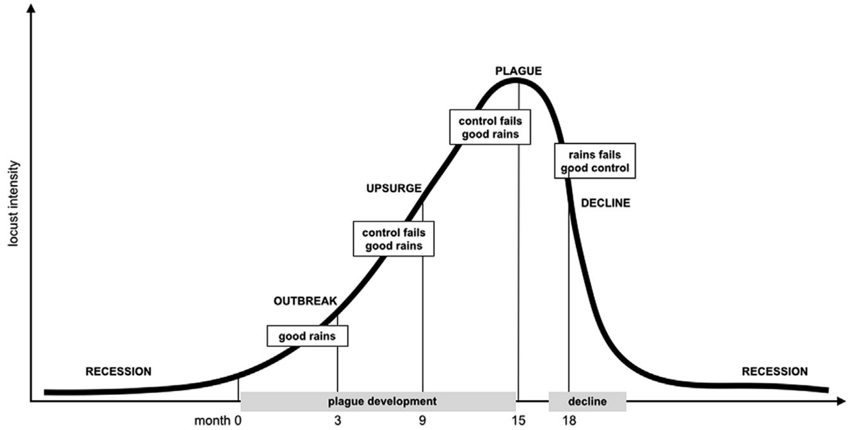

FIGURE 4.2.7 The evolution of desert locust plagues.

spread to Northeast Africa and the Arabian Peninsula, resulting in a plague that eventually declined by 1990 due to intensive control operations and poor rains.

Not all outbreaks turn into upsurges and, similarly not all upsurges become plagues. For example, an upsurge developed in 1993 after several generations of successful breeding along the Red Sea coast in the winter of 1992 (Figure 4.2.8). The resulting swarms moved to the interior of the Arabian Peninsula and bred again during spring 1993. Some of the new swarms that formed at the end of the spring moved east to India and Pakistan, while others moved west to Sudan and continued to West Africa, reaching Mauritania at the beginning of the rainy season when they bred, producing more swarms at the end of the summer that moved to Northwest Africa. Control operations brought the upsurge to an end in Southwest Asia by 1994 but it took several more years before the situation returned to normal in West Africa. Nevertheless, a plague did not develop.

Adult locusts are passive fliers and are carried by the wind. Solitarious adults fly in the early evening while swarms fly during daylight hours, starting early in the morning once the adults have warmed up and continuing until just before sunset. Swarms can fly up to 100–150 km in a single day at heights up to 2,000 m. While migrating over water, swarms can fly continuously for 20 or more hours. Locusts migrate between seasonal breeding areas. For example, summer-bred swarms often migrate from the Sahel of West Africa and Sudan to Northwest Africa, or from Sudan to the Red Sea coast; winter-bred swarms migrate from the Red Sea coastal plains to the interior of Saudi Arabia or Sudan, and spring-bred swarms can migrate from the interior of Arabia to Sudan and West Africa, or from the Horn of Africa to the Indo–Pakistan border (Pedgley, 1981). Given this terrific potential to migrate, it is not surprising that long-distance migrations have occurred in the past during upsurges and plagues, for example, from West Africa to the UK in the 1950s, and from Senegal across the Atlantic Ocean to the Caribbean in 1988.

The first records of desert locust plagues date from Pharaonic Egypt and have been documented throughout history. During the first 60 years in the twentieth century, 5 major plagues occurred, lasting up to 14 years. Plagues were present in nearly 4 out of every 5 years (Figure 4.2.9). Since 1963 a dramatic decline has occurred in the frequency and duration of plagues, and now plagues occur perhaps only once in every 10–15 years and rarely last more than 3 years. Consequently, the control strategy adopted and implemented by countries has shifted from curative to preventive. The cost of preventive control, which can be considered as an investment in food security, is substantially less than controlling a plague. For example, $500 million was spent to stop the 2003–2005 upsurge or regional plague, which is equivalent to 170 years of preventive control in West Africa.

The decline in desert locust plagues in the past 50 years can be attributed to a number of factors such as the introduction of chemical pesticides, improved

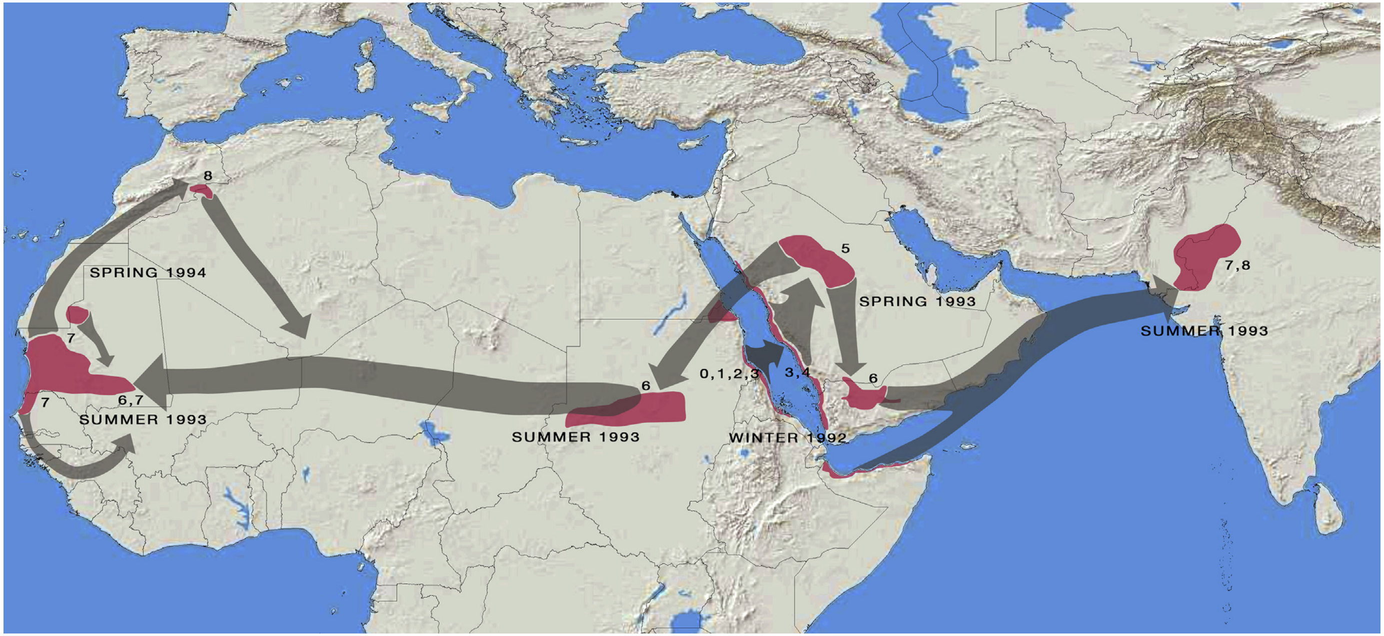

FIGURE 4.2.8 The development and spread of the 1992–1994 upsurge in which eight generations of breeding occurred, affecting Northern Africa, the Middle East, and Southwest Asia.

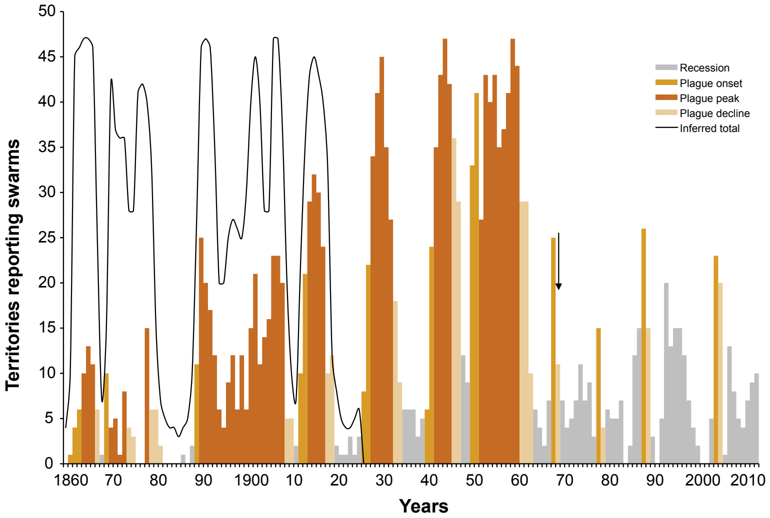

FIGURE 4.2.9 Plague and recession periods of the desert locust, 1860–2014.

transportation and infrastructure, and advances in technologies related to precision spraying, communications, geopositioning, spatial analysis, remote sensing, and early warning (Magor et al., 2007).

4.2.1 MONITORING AND FORECASTING

The early warning system for desert locust is based on more than 75 years of collaboration. It dates back to the early twentieth century and is perhaps one of the oldest systematic, pest-monitoring systems in the world. At that time, field teams and local scouts scoured the desert on camels, looking for locusts and recording their observations in notebooks. This information eventually found its way to the capital cities in the affected countries. In 1930, the Anti-Locust Research Centre (ALRC, London, UK) started to collect, map, analyze, and archive locust data from affected countries. A centralized information unit, the Desert Locust Information Service (DLIS), was established for the regular collection, exchange, and analysis of locust, weather, and ecological data. The systematic collection and mapping of the data showed that breeding of the desert locust coincided with rainfall, both seasonal and sporadic, and migration was associated with downwind movements. The importance of high-quality data on locust infestations, ecological conditions, and weather for predicting the scale, timing, and location of breeding and migration emerged. Countries agreed on a standard set of data to be collected on locust infestations, habitats, and weather to be transmitted to DLIS. This collaboration between locust-affected countries and DLIS formed the basis of the early warning system and continues to this day.

In 1943, DLIS began to issue alerts, monthly bulletins, and forecasts used for planning and undertaking control campaigns based on the analysis of information received from the field. In August 1978, the largest specialized agency of the United Nations, the Food and Agriculture Organization (FAO), assumed responsibility for global monitoring, data analysis, and monthly bulletins, and DLIS operations shifted to FAO's headquarters in Rome, Italy.

4.2.2 TECHNOLOGICAL ADVANCES

From the late 1980s onward, substantial improvements to the locust early warning system were achieved with the introduction and adoption of new technologies in a number of different fields (Figure 4.2.10).

Telecommunications. The first observations made by teams in the field were written down in a narrative style and hand carried or sent through the postal system as letters, often arriving weeks or months later. Telegrams and telex were used to transmit information from capital cities in the affected countries. Although there was a flow of information from affected countries, it was irregular, usually arriving too late and the data were often incomplete or vague. During the last major plague of 1987−1989, FAO installed facsimile machines in the key desert locust countries that were used for transmitting information and reports to DLIS. In turn, DLIS transmitted its monthly bulletins via fax rather than telex, reducing the time spent in preparation and distribution. Additional information could also be faxed relatively easily, such as daily synoptic charts, rainfall graphs, and maps of survey itineraries, locust

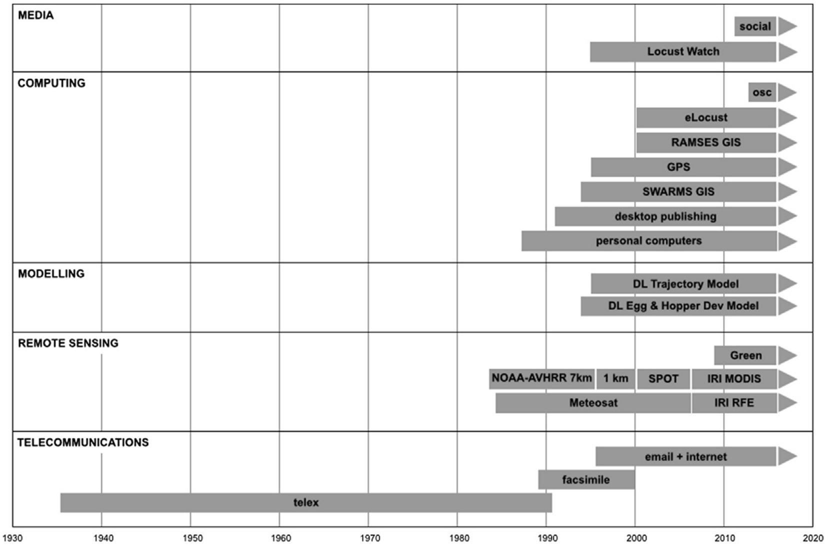

FIGURE 4.2.10 Technological developments related to locust early warning, 1935 to present.

infestations, and forecasts that previously were not possible by telex. This information helped to strengthen analysis of the locust situation and habitat conditions, and improve early warning.

Computing. Further improvements in telecommunications coincided with the widespread introduction and use of the personal computer in the late 1980s. Prior to this, typewriters and telex machines were used. The personal computer opened up nearly endless possibilities for managing, analyzing, and summarizing data, and preparing reports and bulletins. Initially, this was accomplished by using relatively simple database, word processing, and spreadsheet programs. In the early 1990s, desktop publishing was introduced, suddenly making it possible to prepare professional-level bulletins that seamlessly integrated images, maps, graphics, and text.

Geospatial data. Similar improvements occurred regarding the collection and analysis of geospatial data. The first handheld global positioning systems (GPS) appeared on the market in the late 1980s. Initial models were large and bulky, expensive, slow, and not very accurate because the system was intentionally degraded for civilian use. As handheld units became increasingly smaller and more affordable, it allowed for their gradual introduction and eventual adoption by national locust programs, so that by the late 1990s teams were using GPS units to determine the latitude and longitude coordinates of survey and control operations. In this way, precise locations of surveys, locust infestations, and control could be pinpointed on a map. In 2000, the selective availability was turned off, and GPS accuracy improved to within about 10 m or less.

In the early 1990s, with the prevalence of personal computing, geographic information systems (GIS) were introduced in response to an increasing interest in maps and mapping. A typical GIS consists of two components, a database and a mapping application. In order for the data to be displayed accurately on maps, it must be georeferenced, containing a latitude and longitude reference. In 1994, DLIS commissioned the Natural Resources Institute (NRI) and the Geography Department at the University of Edinburgh, both in the UK, to develop a GIS for operational locust monitoring and early warning. By 1996, *Schistocerca* **War**ning and **M**anagement **S**ystem (SWARMS) was being used by DLIS on a daily basis to manage and analyze environmental and locust data. It was one of the first GIS used for operational monitoring rather than map production purposes (Healey et al., 1996). SWARMS is a custom GIS consisting of an Oracle database that hosts all survey and control data received from locust-affected countries since the early 1990s, historical records dating from the 1930s, meteorological data and remote sensing imagery, and ESRI's ArcGIS software for querying, display and spatial analysis. SWARMS is a server-based system that supports several PC-based workstations, allowing users to access the same data set and work simultaneously. The system allows the forecaster to rapidly access large volumes of data in different formats and display them together in order to analyze the current weather, ecological conditions, and locust situation, and estimate future developments. Prior to GPS and GIS technology, location coordinates had to be determined from a paper map and infestations were plotted by hand on large transparent overlays using colored pencils. This was extremely labor intensive and time-consuming, especially during periods of increased locust activity when a large team of plotters was required to manage the sizable volume of data.

Difficulties in managing large volumes of data were not only a problem in DLIS but also in locust-affected countries. FAO addressed this issue by developing a smaller, less-complicated GIS that could be used by nationally designated locust information officers in the key frontline countries. **R**econnaissance **A**nd **M**anagement **S**ystem of the **E**nvironment of *Schistocerca* (RAMSES) was introduced in 2000, operating on a personal computer using Microsoft Access database and ESRI's ArcView software. In 2014, an open-source platform-independent version was developed using OpenJump GIS and Postgres spatial database that takes advantage of the last advances in spatial analysis and open-source software.

Internet. In 1996, e-mail and Internet services were introduced at FAO, and DLIS was one of the first users. Within a very short period of time, e-mail replaced facsimile as the mode of sending and receiving data and bulletins between countries and DLIS. This greatly enhanced the ability to easily and widely disseminate information in a timely manner. By 2000, all locust-affected countries had Internet services and were using e-mail every day to share data and information. The Internet also provided sudden access to a great wealth of information and knowledge that could be applied to locust early warning.

eLocust. Despite the numerous technological advances and associated advantages to locust early warning, one major obstacle persisted in the timely flow of high-quality data. Standardized forms had been developed and adopted for use by all countries in order to improve data quality. Locust officers were well trained in completing the forms in the field. National locust information officers were trained on how to enter the data from the forms into RAMSES. Completed forms and RAMSES data export files were transmitted to DLIS by e-mail. A strong, reliable information network had become established and was operating reliably on a daily basis between locust-affected countries and DLIS. But the weak link in the early warning chain remained the transmission of data in near-real time from the field to the national locust center in each affected country.

In 2000, a prototype data logger was developed for national field officers as a proof of concept to demonstrate that survey and control data could be enter digitally into a database in the field by the locust officer. The system, eLocust, consisted of a handheld Psion 5mx palmtop computer and a custom database linked to a mapping application. It was connected to a handheld GPS. Alkaline batteries powered both devices. But the system lacked transmission capabilities; data were only saved to the internal memory of the Psion. Five years later, an all-in-one system, eLocust2, was developed in collaboration with Novacom Services (France) that consisted of a rugged, data logger that was touch screen and handheld, with custom software in English and French, and an antenna that connected to the GPS network of satellites for determining the coordinates of the position of the survey or control position in the field and to the Inmarsat satellite for date transmission in near-real time. More than 400 units were distributed to frontline countries in 2006 for use by survey and control teams. The national locust information officer receives eLocust2 data via e-mail and the Internet, downloads it to the PC, and imports it into the RAMSES GIS. The data, as well as the position of the field teams, can also be accessed through a secure Webpage on the Internet. For the first time in more than 75 years of monitoring locusts, field observations and survey and control results became instantly available to decision-makers and forecasters (Figure 4.2.11). This revolutionized early warning and preventive control of the desert locust.

In 2014, eLocust2 was replaced with an updated version, eLocust3, that takes advantage of the latest technological developments. It consists of an Android-based 10.1-inch rugged Panasonic FZ-A1 ToughPad tablet with custom applications for data entry and viewing Landsat imagery and the latest dynamic greenness map and rainfall estimates in the field without requiring Internet access, a camera and video, a low-profile wireless (Bluetooth) antenna for data transmission, and a digital library of references that includes technical guidelines, standard operating procedures, field guides, and user manuals for survey and control equipment. The system checks the integrity of the data prior to transmission to ensure that mandatory data have been collected and entered correctly. This helps to ensure that the data are complete and of high quality. The updated maps on eLocust3 can be used to help guide the survey teams to places, where green vegetation and locusts may be present, thus reducing the large areas of empty desert that must be checked.

Remote sensing. Although satellites available for civilian use cannot detect locust infestations, remote sensing is used to help estimate where it has rained and where ecological conditions may be favorable for breeding. Since the early 1980s, DLIS analyzed visible and infrared Meteosat imagery to determine clouds that might produce sufficient rainfall for locust survival and breeding in Africa. It remained difficult to know where it had rained in the Middle East and Southwest Asia as equivalent imagery for those regions was not available. The FAO Remote Sensing Centre produced decadal maps of cold-cloud duration that estimated rainfall from cold clouds. This technique was acceptable during the summer over the Sahel of Northern Africa but did not detect rainfall reliably from low-level warmer clouds in winter breeding areas along the Red Sea coasts. Satellite sensors, meteorological numerical models, and rainfall algorithms have improved in the past 15 years, and new products have been developed to estimate rainfall on a

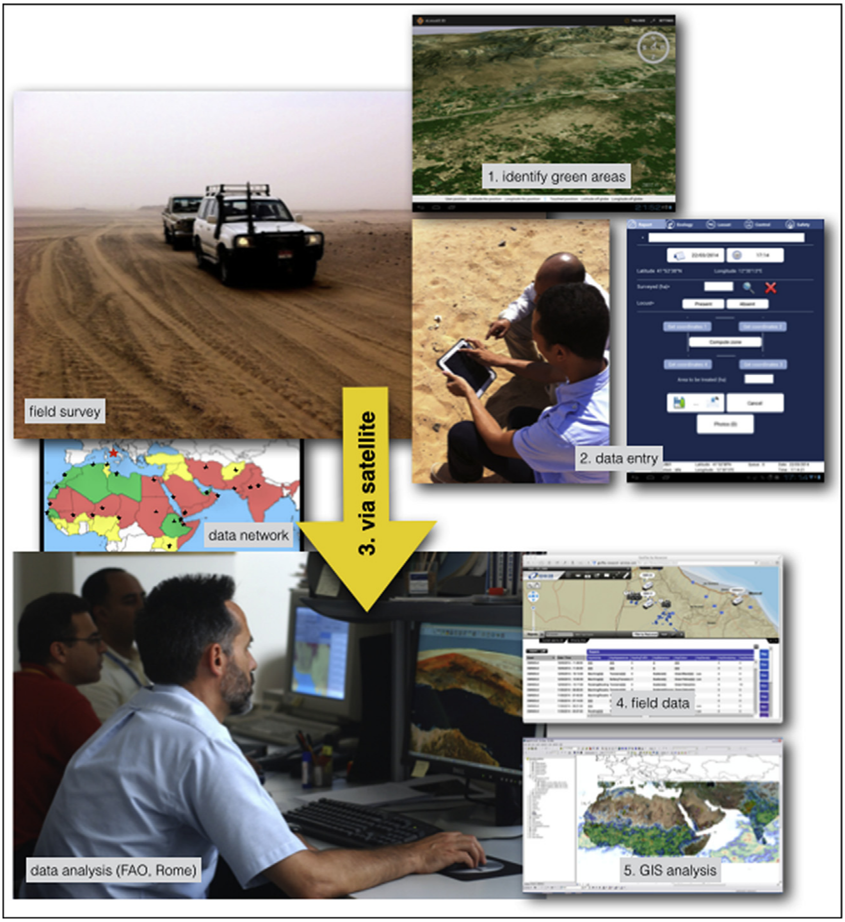

FIGURE 4.2.11 The flow of data used for desert locust early warning in which data are collected during field surveys, immediately entered into eLocust3 and transmitted by satellite in real time to national locust centers and the FAO Desert Locust Information Service in Rome where analyses are undertaken using a custom geographic information system (GIS) in order to provide assessments, forecasts, and early warning.

local, regional, or global level. Satellite-based, rather than model-based, products are used, because the former are better at estimating the spatial distribution of rainfall. DLIS has been using rainfall estimates since 2006 as an enhanced means of estimating rainfall in breeding areas of the desert locust, rather than relying on data from the relatively few national meteorological stations.

A significant evolution also occurred during the past three decades in remote sensing imagery for detecting green vegetation, shifting from 7-km resolution NOAA-AVHRR normalized difference vegetation index imagery in the mid-1980s, to 1-km resolution imagery 10 years later. In 2000, 1-km resolution SPOT imagery replaced NOAA-AVHRR, taking advantage of the SPOT sensor that was specifically designed for vegetation monitoring. In 2006, SPOT imagery was superseded by higher resolution 250-m MODIS imagery. Despite the dramatic improvements in spatial resolution, remotely sensed vegetation imagery continues to suffer from two limitations: accuracy and dissemination. Although resolution has increased nearly 800-fold, it is still not sufficient to detect the thin green vegetation that hosts desert locust (Dinku et al., 2010). In other words, imagery commonly indicates that an area is dry when in reality it is green, the so-called false negatives. With increased resolution, comes increased file size for each image and difficulties in data management. This makes it challenging to distribute high-resolution imagery such as MODIS to affected countries by Internet, e-mail, or FTP because many countries have very slow and erratic connections.

New, higher-resolution products from the latest generation of satellites, such as the European Space Agency's PROBA-V and Sentinel 3 with resolutions up to 100 and 30 m respectively, offer significant improvements in the detection of green vegetation in desert locust habitats within the next few years.

Modeling. In the mid-1990s, DLIS began using two, custom-developed models to estimate the development rates of eggs and hoppers and to estimate the migration routes of swarms. The Desert Locust Egg and Hopper Development Model relies on the well-known relationship of air and soil temperature on the development of eggs and hoppers, using long-term temperature means from the nearest meteorological station (Reus and Symmons, 1992). The Desert Locust Trajectory Model estimates the displacement of locust swarms forward and backward in time using 6-h meteorological and forecast data for up to 10 days from the European Centre for Medium-range Weather Forecasts (ECMWF), consisting of temperature, pressure, wind direction, and speed at several atmospheric levels between the surface and 500 hPa with a resolution of 0.25−1.0 degree square.

4.2.3 EARLY WARNING

New advances in technologies have led to a paradigm shift in locust early warning from that of collecting information for interpreting and forecasting breeding and migration to predicting habitat development and the development of outbreaks, upsurges, and plagues. In the past three decades, the system has shifted from camels to four-wheel drive vehicles, from telex to e-mail, from map reading to GPS, from narratives to handheld data loggers, from manual plotting to GIS, and from weather station reports to satellite-based rainfall estimates and greenness maps. GPS, RAMSES and SWARMS GIS, and Internet and eLocust3 have replaced the traditional tools of paper, colored pencils, maps, and telephone.

The current early warning system consists of a variety of integrated elements that all must function smoothly and reliably in order to provide accurate and timely information and alerts on a regular basis to a large international audience. The first step is the collection, recording, and transmission of survey and control data from the field by national teams using eLocust3. The data are received by e-mail at the National Locust Control Centre (NLCC) in each country. The National Locust Information Officer (NLIO) processes the data by importing it into RAMSESv4 where it is checked for completeness and accuracy before it is inserted into a standard database. The data are then exported and summarized, and both items are sent by e-mail to DLIS in Rome within a few days of the survey or control operations. In Rome, the data are checked and corrected prior to importing into the SWARMS GIS.

The NLIO at the NLCC and the Senior Locust Forecasting Officer in DLIS use RAMSESv4 and SWARMS GIS, respectively, to analyze the data in conjunction with rainfall estimate imagery, greenness maps, previous survey, and control results, and historical locust, ecology, and weather data. The objective of the analysis is to understand the current situation and estimate potential developments. The results of the NLCC analysis are used for planning field operations such as the timing, location, and extent of survey and control operations; whereas, the DLIS analysis focuses on the timing, location and scale of current, and future breeding and migration in order to provide advice and early warning to countries. As DLIS maintains locust, ecology, and weather data that cover the entire recession area, its analyses are global and regional in nature, whereas the NLCC analyses are restricted to the national level.

DLIS also prepares detailed case studies of particular situations, especially outbreaks and upsurges, in order to better understand locust population and plague dynamics. DLIS distributes a variety of products by e-mail, the Internet, and social media such as situation updates, bulletins, warnings, alerts, case studies, reference, and training material.[1]

4.2.4 CHALLENGES

In the past decade, a new challenge is facing the locust early warning system. Political unrest and instability, national border disputes and sensitivities, kidnappings, mines, and conflict have led to insecurity in many parts of the recession area. It is becoming increasingly difficult for survey and control teams to access many important areas, where desert locust may be present and breeding. These areas can only be accessed when accompanied by a military escort or are simply closed because they are deemed too unsafe. For example, an outbreak occurred along the Algerian/Libyan border in early 2012 that

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[1] Locust Watch (www.fao.org/ag/locusts), Facebook (www.facebook.com/faolocust), Twitter (www.twitter.com/faolocust), Slideshare (www.slideshare.net/faolocust), and YouTube.

normally would be controlled without any problem since both countries have strong, well-resourced national locust units. However, this was not possible in 2012 due to political upheaval in Libya that affected the national locust program and made it unsafe to undertake the necessary control operations in the outbreak area. As a result, swarms formed and invaded Mali and Niger during the summer where at least one generation of breeding occurred. Survey and control operations were not possible in northern Mali due to civil unrest so breeding occurred unchecked within a large area and locusts increased and spread to other countries. In Niger, large military escorts had to accompany field teams to ensure their safety in the north but this slowed down and hampered survey and control operations.

Nearly a dozen important locust habitats and breeding areas straddle both sides of a common international boundary such as Mauritania/Western Sahara, Algeria/Libya, Mali/Niger, Sudan/Egypt, Sudan/Eritrea, Eritrea/Ethiopia, Ethiopia/Somalia, Yemen/Saudi Arabia, India/Pakistan, and Iran/Pakistan. Border areas are by nature sensitive places, but during periods of intense or prolonged conflict, such areas can be dangerous or simply off-limits. For example, a joint Iran/Pakistan team conducts an annual survey in spring breeding areas on both sides of their common border, south of Afghanistan, to confirm habitat conditions and check for locust infestations and breeding. The results of the joint spring survey are used for planning the summer campaign along the Indo−Pakistan border. The month-long joint survey has been carried out every year since 1995 but recent insecurity in Baluchistan, Pakistan has prevented the Iranian team from participating in the past few years.

As a consequence, the NLCC's ability to monitor ecological conditions and locust infestations as well as to undertake the necessary control operations is gradually being compromised. This is resulting in an increasing number of spatial gaps within the early warning system, where no information from ground observations is made by field teams. Remote sensing can help address such gaps but satellite-based estimates are not a substitute for *in situ* verification on the ground. Thus, in many cases, DLIS must forecast the current situation as well as future developments.

Sustaining an effective early warning system, whose foundation is based on national surveillance relies on a number of important elements in each locust-affected country. First and foremost, the NLCC must be a fully funded unit that is autonomous and centralized, with dedicated resources and well-trained staff that can be shifted easily from one side of the country to other at a moment's notice in order to monitor field conditions and respond quickly to infestations and invasions. The individuals that make up the unit, such as locust survey and control officers, and NLIOs need to be energetic, motivated, and curious. NLCC master trainers must provide regular training to national staff on a continual basis in survey methodologies, data collection and transmission, and the use of standard equipment. Field teams need to be properly equipped with GPS, maps, eLocust3, radios, 4WD vehicles, and camping equipment.

Financial support required for survey, control, reporting, and training should be a standard item in the annual national budget of the Ministry of Agriculture in all locust-affected countries. Field officers should receive incentives to encourage their participation in field operations, especially when such operations entail being away from families or in remote areas for several weeks or months. The NLCC should manage field teams effectively and provide feedback regarding their performance. Field officers should be reminded of their critical role within the early warning system as the primary source of information and data. In this way, they are the most important stakeholders within the global system. Lastly, the regular monitoring of desert locust habitats should become a routine activity that is done on a regular basis every year, especially after good rainfall. All of these elements must be fully integrated if early warning is to be effective in reducing the duration, severity, and frequency of desert locust plagues.

4.2.5 CONCLUSION

The success of the early warning system for desert locust depends on a well-organized and funded NLCC in every locust-affected country that can monitor field conditions and respond to locust infestations by: (1) conducting ground surveys and control operations; (2) collecting and transmitting accurate geospatial data rapidly; (3) using a GIS to analyze the data; (4) keeping all stakeholders informed on a regular and timely basis through simple well-targeted outputs; (5) sharing reports within a robust and reliable information network; and (6) maintaining a cadre of well-trained and dedicated individuals. Each national component should be fused together and feed into a centralized DLIS that has a global overview of the situation. The overall strength of the system will be only as strong as its weakest link.

No doubt exists that technological advances have led to dramatic improvements in locust early warning, resulting in plagues that occur less frequently and of shorter duration. Yet, despite the decline of plagues, the desert locust remains a very serious and important threat. More than \$500 million, 13 million liters of pesticide, and 2 years were required to bring the last regional desert locust plague under control in Northern Africa. Even with this effort, locust spread to the Middle East, control operations were conducted in 23 countries, up to 100% cereal loss occurred, 3 out 5 household heads went into debt in Mauritania, and \$100 million was spent on food aid. The annual cost of preventive control for the 10 frontline countries in West and Northwest Africa is \$3.3 million. The cost of the 2003−2005 regional plague was equivalent to 170 years of preventive control. It seems obvious that undisputed benefits exist in continuing efforts to adopt new technologies for improving and sustaining monitoring, early warning, and preventive control in order to prevent desert locust plagues, protect food security, and reduce hunger throughout the world. The success and lessons learned from the desert locust early warning system can be adopted and modified for use in early warning systems of other migratory pests.

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