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Abstract. Desert locust (*Schistocerca gregaria*, Forskål) plagues have historically had devastating consequences on food security in Africa and Asia. The current strategy to reduce the frequency of plagues and manage desert locust infestations is early warning and preventive control. To achieve this, the Food and Agriculture Organization of the United Nations operates one of the oldest, largest, and best-known migratory pest monitoring systems in the world. Within this system, remote sensing plays an important role in detecting rainfall and green vegetation. Despite recent technological advances in data management and analysis, communications, and remote sensing, monitoring desert locusts and preventing plagues in the years ahead will continue to be a challenge from a geopolitical and financial standpoint for affected countries and the international donor community. We present an overview of the use of remote sensing in desert locust early warning. © *2013 Society of Photo-Optical Instrumentation Engineers (SPIE).* [DOI: 10.1117/1.JRS.7.075098]

Keywords: desert locust; early warning; forecasting; Food and Agriculture Organization; plague prevention; geographic information system; remote sensing.

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1 Introduction

Low numbers of desert locust are normally present at any time during the year within a vast recession area that covers some 16 million km^2, stretching from West Africa to Southwest Asia. The transition from a recession situation to a plague is characterized by outbreaks and upsurges.[1] An outbreak occurs when good rains cause soil and vegetation conditions to become favorable and locust numbers increase through concentration, multiplication, and gregarization. Even though an outbreak is often localized and relatively small, consisting of dispersed populations, it can lead to the formation of hopper bands and swarms over several months, often coinciding with drying vegetation. If an outbreak is not controlled and substantial widespread rains occur, an upsurge can form. An upsurge is a very large increase in locust numbers from two or more successive seasons of transient-to-gregarious breeding in complementary seasonal breeding areas affecting several countries. If widespread and heavy infestations, the majority of which occur as bands or swarms, continue for another year or so accompanied by good rains, an upsurge can develop into a plague. A major plague exists when two or more regions are affected simultaneously.

Locust-affected countries and the Food and Agriculture Organization (FAO) of the United Nations have adopted a preventive control strategy to manage desert locust infestations. This strategy relies on early warning and early reaction; that is, to constantly monitor desert locust breeding habitats by carrying out ground surveys on a regular basis, identifying desert locust infestations that require treatment, and undertaking control operations before the locusts gregarize and form hopper bands and adult swarms that can lead to an outbreak. As not all outbreaks are easily controlled, the preventive control strategy is also applied to stop outbreaks from developing into upsurges.

The FAO operates a desert locust early warning system within the Desert Locust Information Service (DLIS) at its headquarters in Rome. The objective of the system is to monitor the

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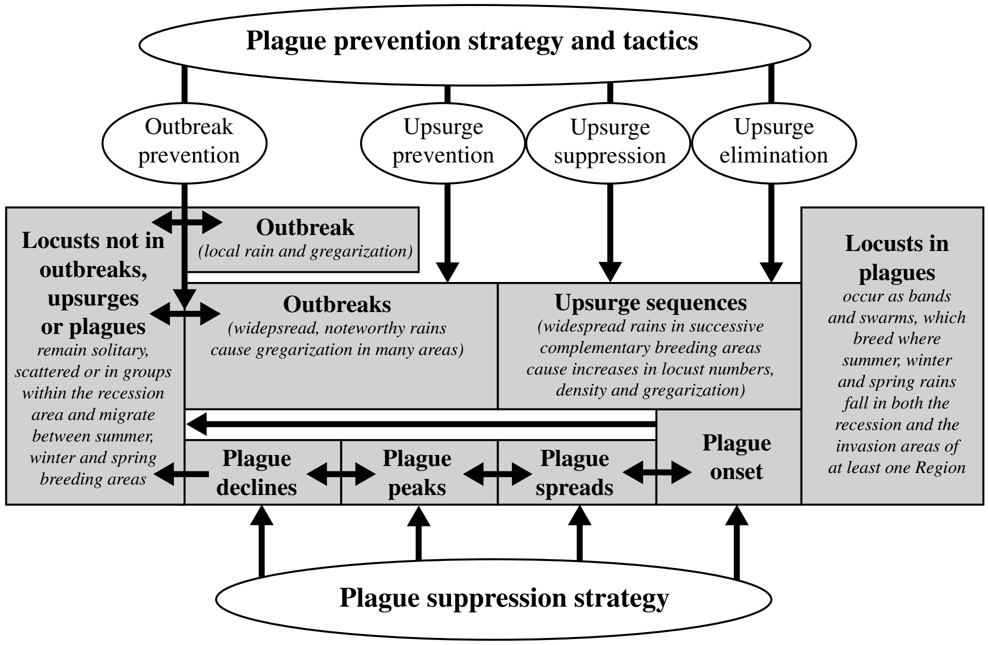

Fig. 1 The preventive control strategy adopted by the FAO and locust-affected countries to prevent outbreaks or prevent, suppress, or eliminate upsurges. These practices involve increasing intensities of survey and control operations applied sequentially as a plague develops.

weather, habitat conditions, and desert locust populations within the recession area. Data are analyzed in order to assess the current situation and predict developments. The system is one of the oldest, largest, and best-known migratory pest monitoring systems in the world. The origin of a centralized locust information service dates from 1929, when the British government requested the Imperial Bureau of Entomology (later the Commonwealth Institute) to organize and supervise locust work. In 1931, this work was extended to locust-affected territories in Africa under what informally became known as the International Center for Locust Research, the forerunner of the Anti-Locust Research Center (ALRC) that was formally established in 1945. The Center for Overseas Pest Research (COPR) eventually succeeded the ARLC. The FAO assumed the global mandate to monitor desert locusts in the 1950s and took over the day-to-day operational management of the monitoring system and responsibility for the centralized information service in 1978.

Some 50 locust-affected countries as well as donors rely on the early warning system as a means to keep up to date about the desert locust situation and be warned of impending developments in a regular, timely, and unbiased manner. National locust decision makers use the advice and outputs of the system for planning and implementing monitoring and control activities in their own country. Effective and timely early warning and reaction before and at the early stages of an outbreak can help to prevent desert locust regional upsurges and continental plagues or, at least, reduce the frequency of their occurrence, which can have devastating consequences on food security at the farmer, provincial, national, regional, and international levels (Fig. 1).[2]

This paper presents an overview of the early warning system from data collection in the field to data management and analysis at the national locust centers to global monitoring and forecasting at the FAO DLIS. The role of remote sensing and modeling is discussed, as well as current and future challenges.

2 Desert Locust Early Warning System

The desert locust early warning system consists of three primary levels, each with its own responsibilities, which interact with one another in the flow of data and information, culminating in collaborative decision making across several continents (Fig. 2).

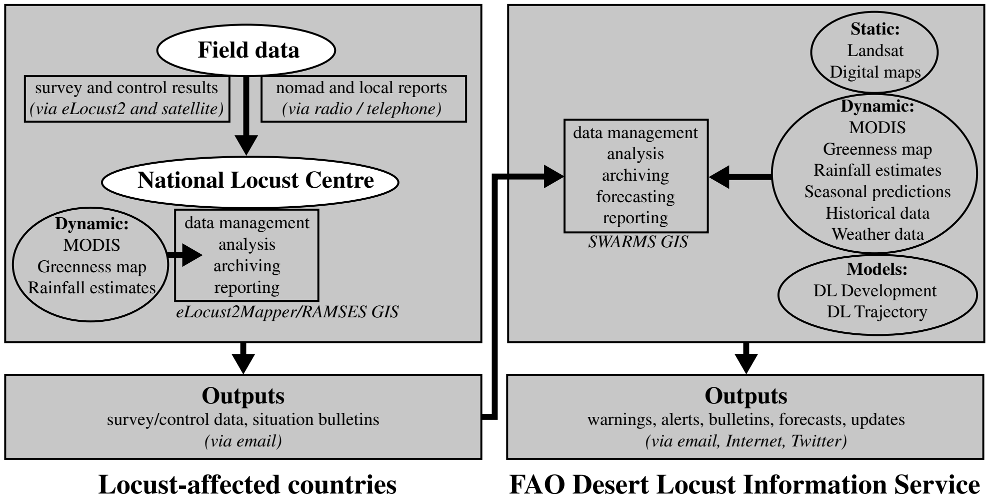

Fig. 2 The locust early warning network of field observations (from national survey and control teams) transmitted in real-time by satellite to national locust control centers (for data analysis in the RAMSES GIS) and forwarded to the FAO DLIS (where global-scale analysis and forecasting are undertaken).

2.1 *Field Level*

Each of the 17 front-line desert locust–affected countries from West Africa to Southwest Asia has an autonomous or semi-autonomous national locust center within its Ministry of Agriculture.* Highly trained specialized staffs undertake ground surveys with four-wheel drive vehicles in remote, unpopulated desert areas, looking for green vegetation and locusts. It is not uncommon for field teams to camp in these areas for several weeks or more in order to conduct monitoring and control operations. Traditionally, the teams recorded their observations on ecological conditions, locust populations, and control treatments in personal journals. High frequency (HF) radios were used to communicate observations by voice from the field to the national locust center, but this often resulted in the loss or misunderstanding of information during transmission. In the early 1990s, standardized forms were introduced and increasingly used in most countries. Although this helped to homogenize the data for analysis, the primary limitation of this system remained; that is, the time it took for the recorded observations to reach analysts and decision makers at the national locust center and beyond. Time is critical when dealing with a migratory pest that can rapidly increase in number and spread, owing to multiple overlapping generations per year.

In 2005, the FAO in collaboration with Novacom, the commercial division of the French Space Agency, developed a handheld data logger and transmitter, eLocust2, for use in the field by national locust survey and control officers. eLocust2 automatically connects to two satellite systems: the GPS network for determining the precise location of field observations and the Inmarsat network for data transmission in real-time. A touch screen is used to enter observations into a standard database. Data from each survey and control location are transmitted in less than 5 min to the corresponding national locust center via a Novacom server in Toulouse, France. Up to about three months of field data are stored on the server.

Field officers in most of the locust-affected countries record their observations in both eLocust2 and on standard forms. This double-entry system ensures that there is a backup of the data and that no data are lost during transmission. Questions that arise concerning incomprehensible or incomplete data often can be answered by referring to the original hardcopy data form.

*Algeria, Chad, Egypt, Eritrea, India, Iran, Libya, Mali, Mauritania, Morocco, Niger, Oman, Pakistan, Saudi Arabia, Somalia, Sudan, and Yemen.

2.2 *National Level*

Each of the front-line locust-affected countries has at least one designated locust information officer who is the focal person responsible for collating, summarizing, and analyzing all survey and control data in the country, as well as other information regarding rainfall and vegetation. Most of these officers have received specialized intensive training from the FAO.

Novacom automatically sends eLocust2 data by e-mail every day to the locust information office in the corresponding country. The locust information officer can access eLocust2 data on the Novacom sever via the Internet through a secure account in order to further query, display, and download the data. Once the data are downloaded to the PC in the national locust information office, it is checked, corrected, and completed using a custom application called eLocust2-Mapper. The final set of data is then exported as an MS Excel file.

In the late 1990s, the FAO developed a custom geographic information system (GIS) called RAMSES (Reconnaissance And Monitoring System of the Environment of *Schistocerca*) to allow national locust information officers to manage, query, display, analyze, and map field and other data.[3] RAMSES consists of ArcView 3.x for GIS functionality and MS Access as the database. The eLocust2Mapper export file is imported into RAMSES, where it can be overlaid on remote sensing products such as rainfall estimates (RFE) and MODIS imagery and other background reference layers.

The results of the data summary and analysis are presented in national locust bulletins that are issued every week, 10 days, fortnight, or month, depending on the country and the locust situation. The bulletins are distributed to concerned parties within the locust-affected country, such as national ministries and research institutes, embassies, donors, UN agencies, NGOs, and other relevant individuals and groups. The bulletins are also sent by e-mail to neighboring countries, regional locust organizations, and commissions such as the desert locust Control Organization for Eastern Africa (DLCO-EA), FAO Commissions for Controlling the desert locust in the western region (CLCPRO), central region (CRC), and Southwest Asia (SWAC), and to the FAO DLIS. In addition, RAMSES export files containing the corrected survey and control data are sent to the FAO DLIS within five days of the end of the survey or control operation.

2.3 *International Level*

RAMSES export files received by the FAO DLIS from national locust information officers in affected countries are checked for duplicate and incomplete data. The locust information assistant or Senior Locust Forecasting Officer in the DLIS will immediately contact the relevant national locust information officer to clarify any inconsistencies in the data. The data are then imported into a custom GIS called SWARMS (*Schistocerca* Warning and Management System) that uses ArcGIS 9.x for GIS functionality and Oracle as the database. SWARMS was developed in the mid-1990s by the FAO in collaboration with the University of Edinburgh and the Natural Resources Institute, United Kingdom.[4] SWARMS contains about 90 years of historical locust data dating to the 1920s.

SWARMS is a platform that allows the forecaster to query, display, compare, and map locust, ecological, rainfall, and historical data. The vector data can be combined with raster data such as daily, decadal, and monthly rainfall estimates, MODIS imagery, and MODIS-derived products and overlaid on to static base maps such as topography, roads, towns, hydrology, and administrative, and political boundaries to better understand the spatial relationship of locust infestations to the environment and to assess the current situation. In order to do this, the forecaster must try to determine the source and scale of initial populations; the timing and scale of migration into the currently infested areas; the timing, location, scale, and success of subsequent breeding; and the efficacy of survey and control operations. This involves knowing where, when, and how much it rained; the response of annual vegetation to recent rainfall; and the direction of the current and expected winds.

Once the current situation is understood, SWARMS helps to identify similar or analogous situations in the past that can be used to predict how the current situation will evolve and develop in terms of the scale, location, and timing of breeding and migration. Much of this portion of the analysis depends on the experience and intuition of the locust forecaster, since there are substantial gaps in the locust, ecology, rainfall, and historical data sets.

The results of the analysis are summarized and presented in a monthly FAO desert locust bulletin. The bulletin is written for a wide-ranging audience that includes locust technicians, decision makers, scientists, researchers, administrators, politicians, donors, international development agencies, and the general public. Therefore, the most salient points are presented in one overview paragraph on the front page of the bulletin. On the same page, single-paragraph summaries of the situation and forecast are presented for the three locust regions: western, central, and eastern. On the subsequent pages, ecological and weather conditions are summarized for each region, and country control operations totals are listed. Thereafter, a detailed summary of the current situation and forecast for the next six weeks are presented for each country—some 50 countries in all. A map shows the location of locust infestations, undetected breeding areas, and the six-week forecast. A color-coded banner on top of the first page of the bulletin indicates the perceived risk or threat of current desert locust infestations to crops as green for calm, yellow for caution, orange for threat, and red for danger. Appropriate response actions are suggested for each level. This same system is used on the Locust Watch Internet pages (www.fao.org/ag/locusts). The bulletin is issued in the first days of each month in English, French, and Arabic. The FAO DLIS has issued more than 400 monthly desert locust bulletins since 1978.

During periods of increased locust activity, the FAO DLIS issues submonthly updates every week, 10 days, or fortnight, depending on the situation. When specific threats are detected, the FAO DLIS will send locust warnings directly to the concerned authorities in the affected country. If the situation is potentially serious, a locust alert will be issued in English, French, and Arabic and disseminated in a similar manner as the monthly locust bulletins.

The FAO DLIS relies on e-mail and the Internet as the mechanisms to provide accurate information, warnings, and alerts about the current locust situation and expected developments to the widest possible audience, as well as to specific target audiences in the shortest amount of time. Locust alerts, updates, and bulletins are distributed by e-mail as a compressed portable document file (PDF) with copies posted on Locust Watch. Social media, such as Twitter and Facebook, are being used increasingly as another means of sharing and disseminating locust information. For example, the FAO DLIS posts short overviews of the latest situation in a particular country as a tweet of up to 160 characters on Twitter, designated by the keywords unfao and DesertLocust. This is often done within minutes of receiving and confirming field data from the locust-affected country.

3 Use of Remote Sensing

One of the key elements of preventive desert locust management is the early detection of locust populations in arid noncropping areas. Desert locust infestations cannot be detected directly by satellite due to the non-availability of extremely high-resolution imagery for civilian uses on an operational basis. But remote sensing plays an important role in detecting changes in desert locust habitats. Recent technological advances in instruments and processing have contributed to the improved monitoring of these areas at the national and international levels. Although the FAO DLIS has used remotely sensed products since the mid-1980s, it is only in the past few years that the technology has matured sufficiently to yield more reliable and accurate results that are useful for estimating rainfall and green vegetation in arid areas.

Historically, countries and the FAO relied on meteorological and rainfall stations to provide data on the occurrence of rain. However, few such stations exist in the vast and remote desert locust recession area. Remote sensing, specifically Meteosat cloud imagery, was used to fill in the gaps during the 1980s and early 1990s, but image analysis was difficult, time-consuming, and imprecise. Since the mid-1990s, satellite sensors, meteorological numerical models, and rainfall algorithms have steadily improved to the extent that they can now be used reliably in monitoring locust habitats. Model-based estimates are relatively accurate in determining rainfall quantity, while satellite-based estimates are better in determining the spatial distribution of rainfall.[5] It is the latter that is more important and relevant to locust early warning, plague prevention, and field operations. Columbia University's International Research Institute for Climate

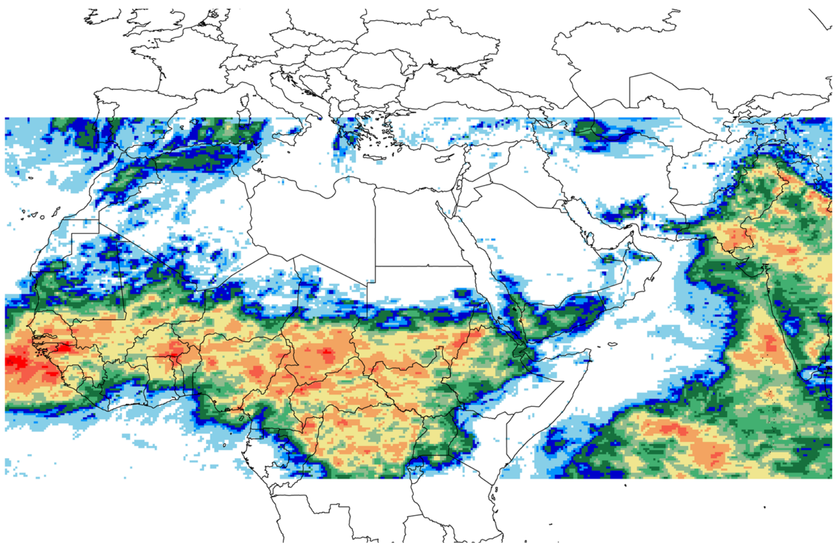

Fig. 3 Satellite-derived geo-referenced rainfall estimates are used on a daily, decadal, and monthly basis to estimate the spatial and temporal distribution of rainfall in the desert locust recession area; warmer colors indicate greater amounts of rain (example: August 2011).

and Society (IRI) produces daily, decadal, and monthly geo-referenced rainfall estimates on a 0.25×0.25 latitude/longitude grid from passive microwave and infrared data at high spatial and temporal resolution based on the CMORPH algorithm (Fig. 3). It is a robust methodology that is specifically fine-tuned for arid areas.[6] National locust centers and the FAO DLIS download these products on an operational basis from the Internet and incorporate them into their respective GIS for data analysis.

At present, 250-m-resolution MODIS imagery and its derivatives [normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI)] are used to determine the location of green vegetation in desert locust habitats between West Africa and India (Fig. 4). The images are available every 16 days, which is sufficient to detect changes in ecological conditions, i.e., annual vegetation that is becoming green or drying out. National locust centers download the image for their particular country and import it into RAMSES for analysis. The FAO DLIS analyzes imagery for the entire recession area in SWARMS.

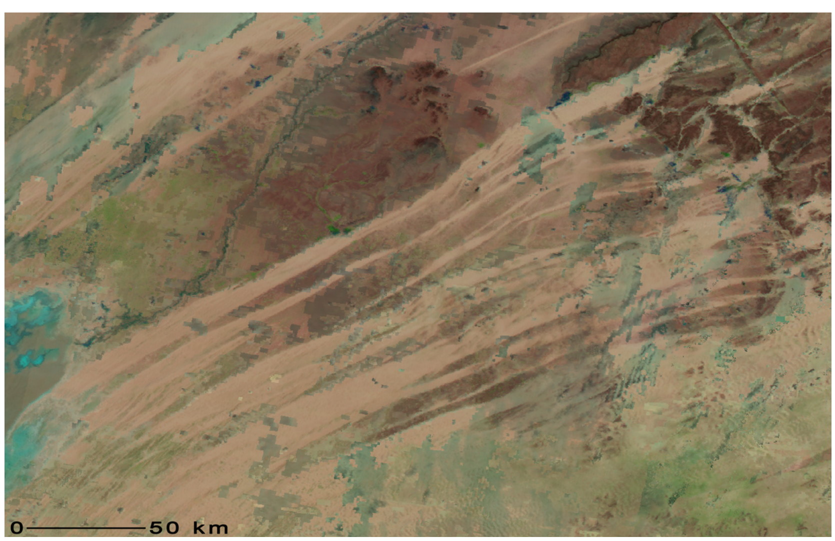

Fig. 4 MODIS imagery is used every 16 days to estimate the spatial distribution of green vegetation in the desert locust recession area (example: western Mauritania, October 2010).

During the 2003–2005 desert locust upsurge in West Africa, remote sensing imagery was used to verify the location and duration of favorable ecological conditions for breeding. For example, a combination of IRI rainfall estimates and MODIS vegetation imagery was used to monitor four unrelated outbreaks that occurred simultaneously in Mauritania, northern Mali and Niger, and northeast Sudan during the summer and autumn of 2003. MODIS imagery suggested that the northern limit of green vegetation was some 100 km further north in the northern Sahel than in previous years. IRI rainfall estimates indicated that a large area from Senegal and western Mauritania to the Western Sahara, western Algeria, and the Atlas Mountains in Morocco received unusually heavy rains October 21 and 22, 2003, which caused flooding. Rainfall station reports and photos taken in the field later confirmed the rainfall. It is clear that this single rainfall event caused the upsurge to develop from the three outbreaks in West Africa. Thereafter, MODIS imagery was used to confirm that vegetation became green, remaining so for up to six months, and to direct national ground survey teams to areas of potential locust infestations. In this way, large areas of the desert could be prioritized for survey, and national locust centers in Morocco and Mauritania were able to plan survey and control operations during the winter of 2003 and the spring of 2004 much better than in previous years.

Although the FAO DLIS provided sufficiently precise early warning with the aid of remote sensing to initiate control operations, affected countries only had limited resources available. These resources were quickly exhausted, and it took another nine months before the international donor community responded, waiting until large swarms formed and appeared in the media. During this time, several generations of breeding occurred, giving rise to sizable infestations of gregarious hoppers and adults. By then, it was too late, and large areas—some 13 million hectares—required treatment to bring the situation under control.

In early 2011, a new MODIS-derived product, a dynamic greenness map that includes both spatial and temporal information to show changes over time in vegetation conditions, became operational (Fig. 5). A new algorithm was developed by the Université catholique de Louvain (Belgium) that involves the fine discrimination of NDVI and Hue values and employs mean compositioning to minimize cloud contamination and reduce variations in reflectance values due to image acquisition with varying geometries.[7] The Flemish Institute for Technological Research/VITO (Belgium) applies the algorithm to 250-m-resolution MODIS imagery, which is then reprojected, and the color space is transformed from red, green, blue (RGB) to hue, saturation, value (HSV). The resulting map indicates the evolution of vegetation development for the previous 11 decades (i.e., 11 periods of 10 days each) for each 250-m pixel, displayed in varying shades of red, orange, and green. This period corresponds roughly to the length of one locust generation. The product informs the user of the spatial-temporal

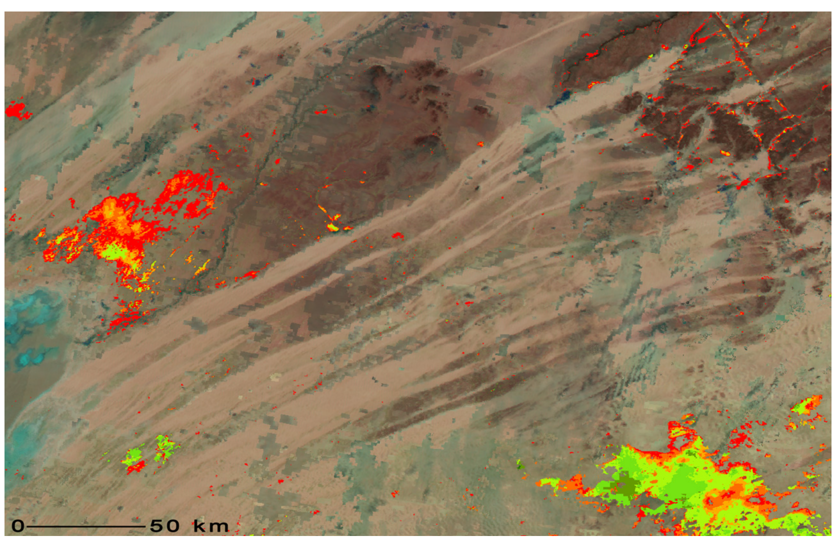

Fig. 5 Dynamic greenness maps are used every 10 days to determine how long vegetation has been green in the desert locust recession area (example: western Mauritania, October 2010, where warmer colors indicate newly green vegetation).

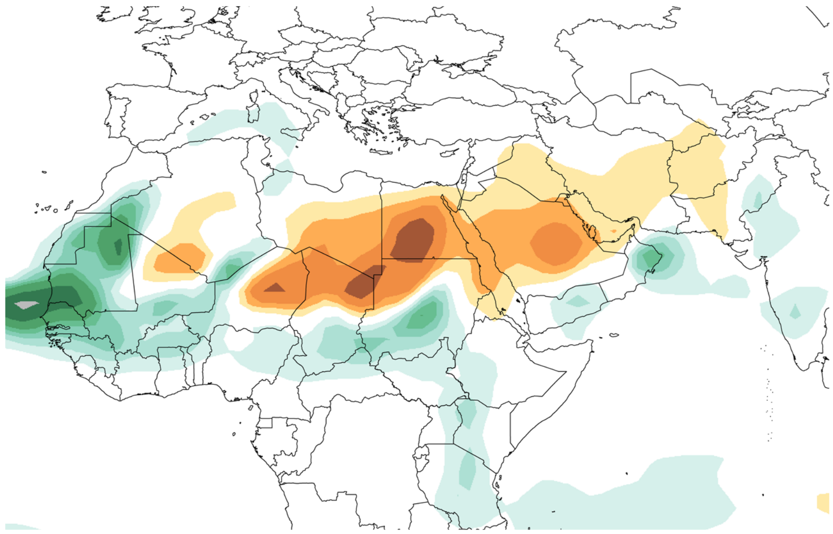

Fig. 6 Seasonal predictions of rainfall anomalies up to six months in advance are incorporated into FAO DLIS locust analysis and forecasts (warmer colors indicate below-normal rainfall, and cooler colors indicate above-normal deviations).

variations in the green vegetation and indirectly of the rainfall distribution through vegetation development. This allows the onset of green vegetation and ephemeral vegetation (false starts) and the disappearance of vegetation at the end of its developmental cycle to be identified. It also indicates the location of evergreen vegetation that is of less importance to the desert locust. Users can download the geo-referenced greenness map and incorporate it into a GIS for analysis with other vector and raster data.

The FAO DLIS also uses seasonal predictions of rainfall and temperature anomalies and probabilities up to six months in advance (Fig. 6). The aim of seasonal forecasting is to estimate quantitatively the probability distribution of the deviations of rainfall and temperature from normal.[8,9] Monthly forecast maps are produced under contract for the FAO DLIS by Prescient Weather (USA). The forecasts are computed from numerical weather models of the European Center for Medium-Range Weather (ECMWF) and the U.S. National Weather Service's Climate Forecast System (CFS), and then running tens of cases to encompass the range of uncertainties. The probabilities are calculated from the ensemble of individual forecasts. The maps indicate the percentage of normal rainfall that is to be expected, the probability the rainfall is above or below normal, the deviation from average of the mean temperature, and the probability that the temperature is above or below average. The basic resolution of the maps is approximately 1.5 to 2.0 deg latitude/longitude. The geo-referenced maps are incorporated into the SWARMS GIS for analysis.

In addition to the dynamic products mentioned above, the FAO DLIS uses static maps such as Landsat (15-m terracolor mosaic), NASA Shuttle Radar Topographic Mission digital elevation map (90-m DEM SRTM), and digital versions of Tactical Pilotage Charts (1:500,000), Joint Operations Graphics (1:250,000), and Soviet topographic maps (1:200,000) as background reference layers in SWARMS (Figs. 7 and 8).

4 Use of GIS and Models

The incorporation of geographic information systems into the desert locust early warning system at the FAO in the mid-1990s and at the national locust centers a few years later has had a great impact on data management and analysis. GIS technology allows for a large volume of vector and raster data to be easily and effectively managed, analyzed, and archived in a rapid manner. Speed, ease, and effectiveness are critical elements when dealing with a pest that can very quickly increase in number and form swarms that can move rapidly across continents.[10] Data from a wide variety of sources, consisting of different formats, scale, and resolution,

Fig. 7 Geo-referenced Landsat imagery is used as a background layer to assist in analysis in the SWARMS GIS at the FAO (example: Western Mauritania).

can be integrated on one platform and displayed as a series of layers on a single map. Vector data such as past and present field observations on ecological conditions and locust infestations, survey and control results, and unconfirmed reports can be combined with raster data such as daily, decadal, or monthly satellite-derived rainfall estimates; 16-day MODIS vegetation imagery; decadal dynamic greenness maps; and six-month seasonal predictions of rainfall and temperature anomalies and overlaid on background reference layers such as Landsat and digital cartographic maps (Fig. 9). This allows users at the national locust centers and the FAO to visualize the past and present situations as a means to assess current infestations and predict changes in population numbers and spatial distribution.

The FAO uses two models that are partially incorporated into SWARMS. The Desert Locust Egg and Hopper Development Model use 30-year surface air temperature averages at the nearest meteorological station (up to about 250 km) to estimate the developmental rates of locust eggs and hoppers.[11] For example, if third instar hoppers are reported, the model can estimate when the eggs were laid and hatched and when the hoppers will fledge. The Desert Locust Trajectory

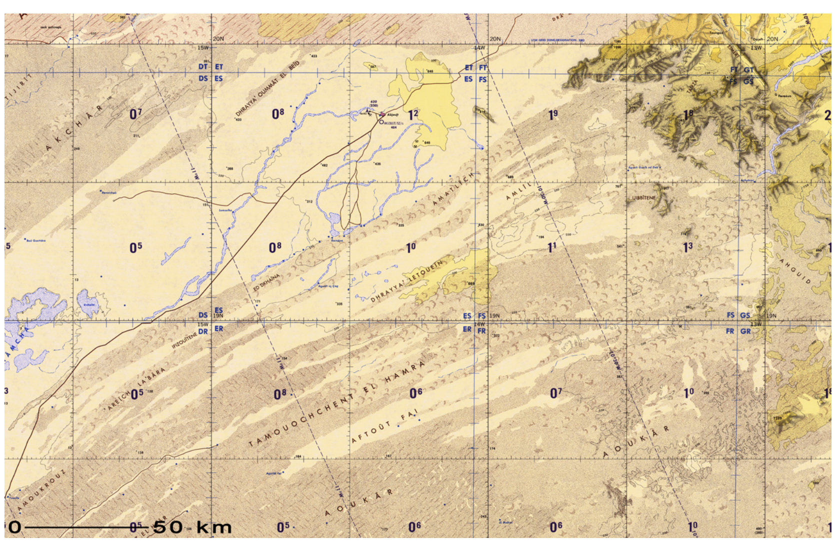

Fig. 8 Geo-referenced digital cartographic maps such as 1:500,000 scale Tactical Pilotage Charts are used as a background layer to assist in analysis in the SWARMS GIS at the FAO (example: western Mauritania).

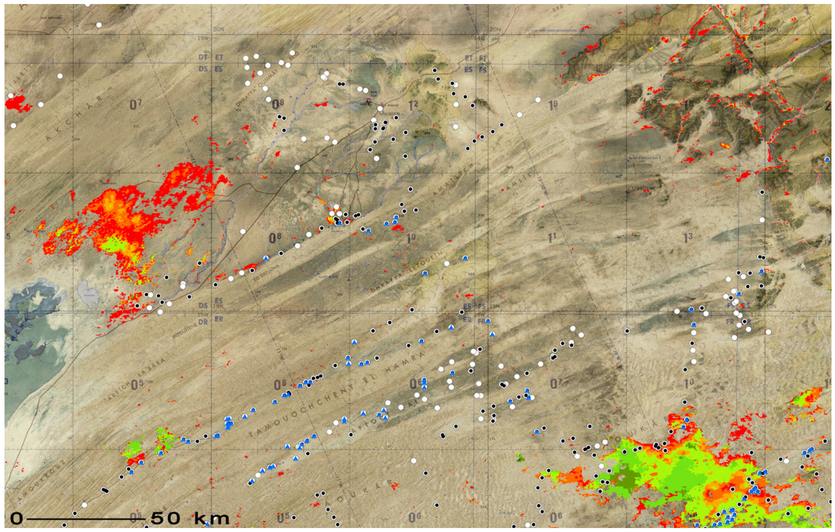

Fig. 9 An example of integrating vector data [field observations of hoppers (black dots), adults (blue triangles), and no locusts (white dots)] and raster imagery (the warmer the color, the more recent the green vegetation) in the SWARMS GIS for analysis and forecasting (example: western Mauritania, October 2010).

Model estimates adult and swarm migration trajectories forward and backward in time (up to 10 days) using temperature, pressure, and wind direction and speed data at 16 atmospheric levels every 6 h.

It is worthwhile to note that SWARMS was one of the first examples of using GIS technology for operational monitoring, rather than simple map production. The reliance on GIS has forced all contributors to the locust early warning system to provide accurate geo-referenced data. Initially, national locust information officers spent an enormous amount of time entering field data manually and had very little time left over for analysis. In the past five years, this responsibility has shifted to the field, where national survey and control officers enter geo-referenced data on the spot at each location using eLocust2. In addition, the FAO undertook several projects to geo-reference historical data, so that the entire data set from the late 1920s can be accessed using GIS.

5 Current and Future Challenges

There are several technical challenges that should be addressed to improve desert locust early warning and reaction further.

- The current generation of rainfall estimates is very good at estimating the spatial distribution of rainfall, especially during the summer season in Northern Africa and in Southwest Asia.[6] However, the estimates can be problematic during the winter breeding season along the Red Sea coastal plains, because lower level warmer clouds produce rain that falls over relatively small, spatially restricted areas.
- Despite improvements in resolution and post-processing, it remains difficult to detect sparse vegetation in the desert that is so critical for locust survival and reproduction. MODIS imagery is being used currently at its very technological limit in terms of instrumental and sensory capability. The Sentinel 3 satellite, which is not expected before 2013, should offer a significantly better solution, since it will provide a single 10-day image of 10-m resolution. In the next few years, the interim satellite Proba-V could also be considered, since it will offer a resolution of 100 to 300 m.
- Greenness maps require further refinement and validation using field data for a recession year to reduce omission errors (false negatives where vegetation is present but not indicated on the product). Errors caused by the algorithm methodology should be corrected, while little can be done about instrumental (sensory) errors that are an inherent technological limitation of MODIS in detecting sparse vegetation in arid areas.

- Much skill and experience are required when interpreting seasonal rainfall and temperature forecasts, because of the tendency for the results to vary dramatically from month to month. Normally, consistent trends over time are indicative of the most reliable estimates. Although seasonal forecasts may not be sufficiently accurate to rely on for planning and operational purposes, they can provide insight to potential locust developments up to six months in advance. More reliable and precise seasonal forecasts would greatly assist desert locust early warning efforts.
- Slow and unreliable Internet service in some countries limits access to data and its timely transmission to other countries and the FAO DLIS. New compression algorithms that reduce the size of some of the remote sensing products disseminated through the Internet have addressed some of these issues. Yet the need for a reliable and fast 24/7 broadband service in locust-affected countries has increased dramatically in recent years as more emphasis is placed on the Internet for data transmission and information dissemination.

Apart from the aforementioned technical constraints, there are several other challenges faced by national locust centers and the FAO DLIS in locust early warning and preventive control.

- Due to the specific technical nature of the work, national staffs need to be well trained and continuously updated, despite large staff turnover rates. This in turn affects the quality of field data, which are the foundation for locust early warning and preventive control.
- Locust-affected countries are responsible for financing the costs of surveying, reporting, control, and training. Some countries face financial shortcomings if locust-monitoring activities are not incorporated into the national budget on an annual basis or when national concerns shift to other priorities.
- Political insecurity is becoming an increasing problem in many of the locust habitats throughout the northern Sahel in Africa, in parts of the Horn of Africa and the Arabian Peninsula, and in Southwest Asia. A large portion of the important locust breeding areas straddles both sides of sensitive international boundaries.
- Desert locust outbreaks, upsurges, and plagues do not occur on a regular basis, which often makes it difficult to maintain and sustain an effective national early warning and preventive program over the long term.

In the past decade, technological advancements in remote sensing, as well as in communications, have led to improvements in the precision and timeliness in early warning and the better management of this historical pest. Nevertheless, monitoring the desert locust and preventing plagues in the years ahead will continue to be a challenge from a geo-political and financial standpoint for all concerned parties.

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