THE USE OF NEW TECHNOLOGIES IN DESERT LOCUST EARLY WARNING

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Abstract

A number of new technologies have been introduced by the Food and Agriculture Organization (FAO) of the United Nations and adopted for use by countries affected by the Desert Locust (*Schistocerca gregaria*). This paper describes how field teams, decision makers, and analysts use these technologies to record, transmit and manage survey and control data, to monitor ecological conditions and to forecast locust breeding and migration. The regular and rational use of such technologies has led to better early warning and prevention of Desert Locust plagues.

Introduction

Desert Locust plagues can affect some 50 countries in Africa and Asia which is equivalent to about twenty percent of the land mass of the Earth. To minimize the occurrence of plagues, a preventive strategy is employed by affected countries and the international community, which relies on early warning and rapid response (Van Huis, Cressman *et al*. 2007). Failing this, locust numbers can rapidly increase during periods of optimal ecological and weather conditions, forming increasingly larger and denser hopper bands and swarms, causing upsurges and plagues. The cost of controlling plagues can be enormous. For example, more than $400 million was spent by affected countries and donors to end a regional Desert Locust plague in West Africa in 2004-05 (Brader, Djibo *et al*. 2006).

Locust plagues are initiated by a local outbreak that develops and is not controlled in one of the dozen frontline countries between Mauritania and India. Outbreaks often occur within relatively small and remote areas of less than 10,000 km^2 (van Huis 2007). If unusually good rains follow, outbreaks can develop into larger upsurges that affect a region. If good rains continue and upsurge control is not successful, then a plague may develop within a region or across several regions. It often takes at least a year or more for a plague to become established. Not all outbreaks and upsurges lead to plagues, either because of successful control, a failure in the rains, migration to unfavourable areas or a combination of any of these factors.

Successful early warning relies on regular surveillance in which geo-referenced data need to be rapidly collected and transmitted to decision makers who are responsible for implementing survey and control operations at the national level. Data need to be properly managed and well analyzed. Outputs such as summaries, forecasts and warnings must be clearly written, well-targeted and made available in a variety of formats and by different means to affected countries and the international community. Recent developments in new technologies can be adopted for use in early warning. This paper explains how some of these technologies have been applied by the Food and Agriculture Organization (FAO) of the United Nations in its locust early warning and plague prevention programme.

Data recording and transmission

The Desert Locust by its very nature is present in some of the most remote and difficult areas on this planet. It is here where national ground teams must check habitats for locusts, report their findings and undertake any necessary control operations. During survey and control operations, the teams collect important data that must be accurately recorded and geo-referenced. Until the late 1980s, most observations were written down in a narrative style. This was gradually replaced by brief summaries and the use of standard survey and control forms. Maps that were used to estimate the team's position have been replaced with handheld global positioning systems (GPS) that accurately indicate the team's position anywhere on Earth within a few metres. Consequently, the quality of the data has gradually improved during the past ten years but, until recently, its rapid transmission remained a major problem.

Field teams never had a reliable means to send their survey and control results quickly to decision makers who are usually hundreds of kilometers or several days' drive away in the national capital. Narrative reports were sent by post once a team reached a town with a post office. The report would often arrive in centralized locust monitoring bureaus in London and Rome several months later. In some cases, the data was transmitted by voice through high-frequency (HF) radios but this form of communication was unreliable, misunderstandings would occur and sophisticated equipment was required and needed to be maintained. In other cases, the team would deliver the data once they returned to the National Locust Control Centre in the capital

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of an affected country after several days or weeks. From there, it was summarized and sent by telex (until the late 1980s), facsimile (1988 onwards), or email (1996 onwards) to the Desert Locust Information Service (DLIS) at FAO Headquarters in Rome (Line a in Fig. 1).

In 2000, a prototype data logger was developed for field officers, consisting of a custom database that was linked to a navigation mapping programme. The software was installed on a commercially available palmtop computer (Psion 5mx) which could connect to a handheld GPS and was powered by a vehicle's cigarette lighter socket. Although the prototype, called eLocust, successfully showed that survey and control results could be recorded in a database by officers in the field, it remained difficult to transmit this data in real time. HF radio modems proved too complicated to install and operate reliably on a regular basis.

During the 2004-05 regional plague in West Africa, additional emergency funds were available for addressing the issue of data transmission. FAO, in collaboration with the French Space Agency (CNES) and its commercial branch Novacom, developed an all-in-one handheld system that allows field staff to record and transmit geo-referenced locust survey and control data in real-time to national decision makers. The system, called eLocust2, consists of a commercially available handheld data logger with touch screen, custom software in English and French, an antenna that connects to the GPS system of satellites for geo-referencing the data and to the Inmarsat system for data transmission, and a cable to connect the data logger and antenna so that they are powered by the vehicle's cigarette lighter socket. The data can be transmitted by satellite or directly downloaded to a personal computer. When the data are transmitted by satellite, they are received by the National Locust Control Centre within a few minutes by email as an encoded attachment. The data as well as the position of the field teams and management of the eLocust2 units are accessible by a secure web page on the Internet at the Novacom web site. National Locust Directors have found this to be a useful way to manage the teams in the field, to quickly see survey and control results, and to readily identify gaps in the field operations. To sustain data transmission by satellite, its costs (roughly US$1 per survey or control location) are paid for by trust funds of the three FAO regional locust commissions.

eLocust2 usage is gradually becoming incorporated into the national survey and control programmes of all locust-affected countries. Since its introduction in early 2006, more than 400 units have been distributed to field teams (Line b in Fig. 1). Extremely positive comments have been received from locust staff in the countries who say it is reliable and easy to use. eLocust2 is probably the single most important new technology that has been developed and adopted by countries since it has had the greatest impact on locust early warning and plague prevention.

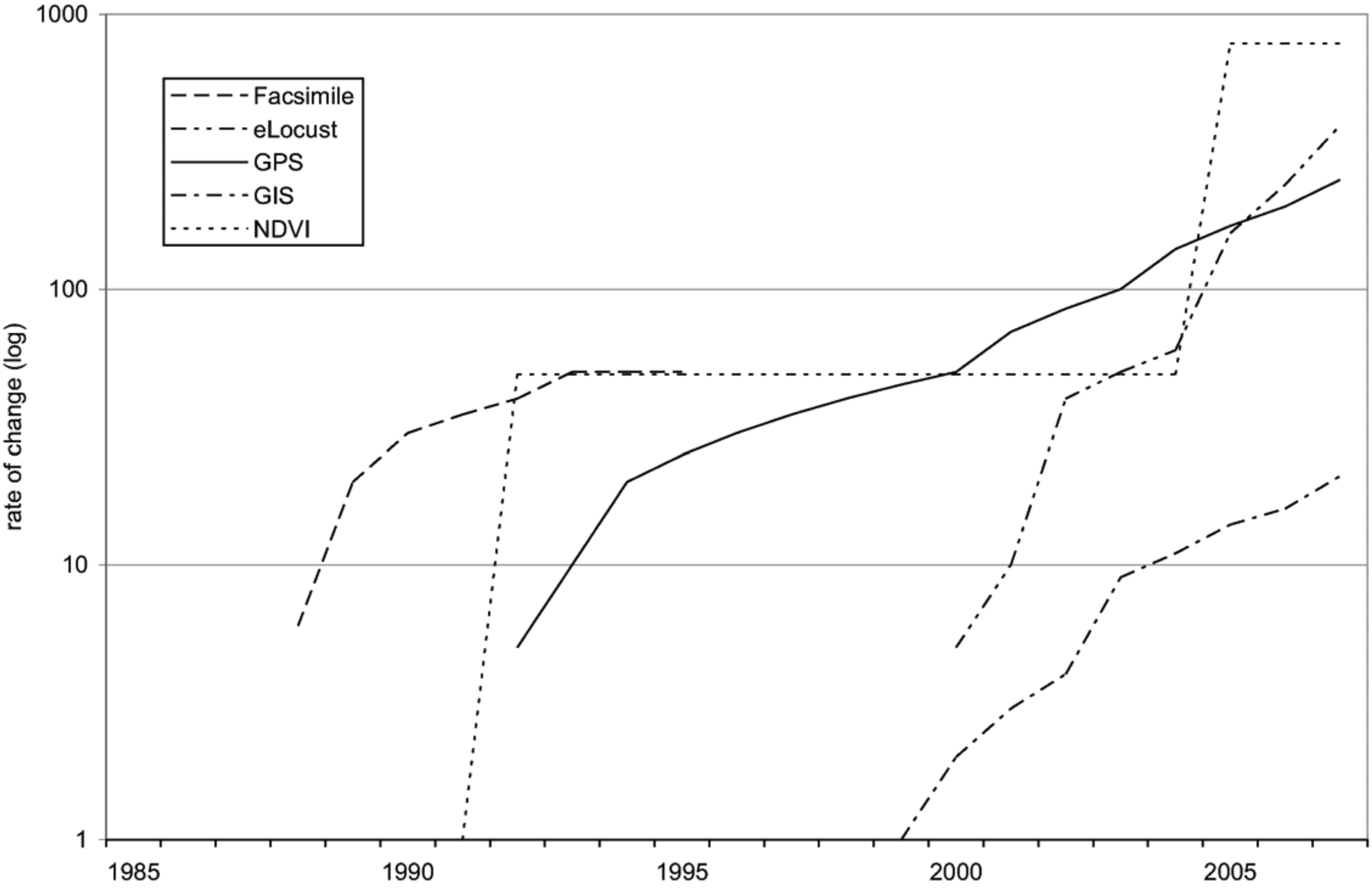

Figure 1. **The development and growth of selected new technologies in locust affected countries from 1985 to 2007: (a) facsimile machines, (b) eLocust and eLocust2 devices, (c) handheld GPS units, (d) GIS systems, and (e) resolution of NDVI imagery.**

Global positioning systems (GPS) and geographic information systems (GIS)

During the late 1980s, the first global positioning systems became commercially available but were not very affordable. These systems could determine one's latitude and longitude position anywhere in the world within about 100 metres. During the next decades, GPS units became increasingly smaller and more affordable. This allowed their gradual introduction and eventual adoption by national locust control programmes so that by the late 1990s most field teams were using a handheld GPS unit to record the locations of survey and control operations (Line c in Fig. 1). Shortly thereafter, GPS precision increased to about 10 metres or less. Differential GPS systems were developed that are accurate to within a metre or so but this usually requires a paid subscription service. Given the accuracy of the freely available standard GPS signal, there is little need for the more sophisticated and costly DGPS in locust survey operations.

Advances in communication technologies have allowed easier and more rapid transmission of field data which has resulted in a steady increase in the volume of environmental observations and locust survey and control data that must be managed by national locust control centres in affected countries and by FAO DLIS in Rome. In the early 1990s as personal computers became more prevalent, geographic information systems were introduced to address an increasing interest in maps and mapping. Most of the early systems were designed to produce maps. In 1994, FAO 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, SWARMS (*Schistocerca* **War**ning and **M**anagement **S**ystem) was being used at FAO DLIS in Rome on a daily basis to manage and analyze environmental and locust data. It was one of the first GIS used for operational rather than production purposes (Healey, Robertson *et al.* 1996).

SWARMS is a custom GIS that consists of an Oracle database, which holds all the data received from affected countries as well as meteorological data and historical records that date back to the early 1930s, and ESRI's ArcGIS software for querying, displaying and analyzing the data. SWARMS is hosted on a UNIX server that supports several PC workstations, allowing users to work with the data simultaneously. The system is extremely dynamic and is under constant revision and updating in order to take advantage of and incorporate the latest GIS developments and technologies. It is extremely powerful and allows the locust forecaster to rapidly assess the current situation, including recent rainfall and vegetation conditions, and determine if analogous situations exist from the past. Before SWARMS, a very laborious manual system of plotting survey routes and locust sightings on paper maps and transparencies using coloured pencils was used to analyze and forecast locusts.

In the late 1990s, it became apparent that national locust centres in affected countries were having difficulty in managing the increased volume of field data in a timely and accurate manner. A smaller and simpler GIS, RAMSES (**R**econnaissance **A**nd **M**anagement **S**ystem of the **E**nvironment of *Schistocerca*), was developed for countries which was introduced in 2000. RAMSES operates on a personal computer and consists of a Microsoft Access database and ESRI's ArcView software (Cherlet 1993). The system is used by the designated Locust Information Officer at the National Locust Control Centre in every frontline country (Line d in Fig. 1).

4. Remote sensing

Although it is not possible to detect locust populations by satellites, remote sensing imagery is used to help estimate rainfall and where ecological conditions may be favourable in locust-affected countries. From the early 1980s to the late 1990s, the visible and infrared channels of Meteosat imagery for Africa were analyzed to determine which clouds might produce sufficient rainfall for locust survival and breeding. Equivalent imagery for the Near East and southwest Asia was not available, so it remained difficult to know where it had rained in these regions. Satellite sensors, meteorological numerical models and rainfall algorithms have improved since the late 1990s, and new products have been developed to estimate rainfall on a local, regional or global level. Model-based rainfall estimates are relatively accurate in determining rain quantity while satellite-based products are better at estimating the spatial distribution of rainfall (Pinker, Zhao *et al.* 2006). For Desert Locust, the latter is more important than the former. One of the most useful of these products is a daily and decadal rainfall estimate map produced by Columbia University's International Research Institute for Climate and Society (IRI) which can be displayed and downloaded for free from the Internet and imported easily into any GIS such as SWARMS or RAMSES (IRI 2007). FAO DLIS has been using IRI rainfall estimates since 2006 and has found that they are a much better estimate of rainfall than data from the relatively few national meteorological stations in the Desert Locust breeding areas.

Remote sensing imagery used for detecting green vegetation has evolved during the past three decades. In the mid 1980s, FAO started producing and using 7 km resolution NOAA-AVHRR normalized difference vegetation index (NDVI) imagery (Tucker, Hielkema *et al.* 1985). In the mid 1990s, 1 km NOAA-AVHRR resolution imagery became available, but this was replaced in about 2000 by 1 km resolution SPOT imagery because the SPOT sensor was specifically designed for vegetation monitoring. However, this imagery has now been superseded by 250 metre resolution MODIS imagery since 2006 (Line e in Fig. 1). Despite the dramatic improvements in spatial resolution, remotely sensed vegetation imagery continue to suffer from two limitations: accuracy and dissemination (Ceccato, Veroustraete *et al.* 2004). Although resolution has increased nearly 800 fold, it is still not sufficient to detect the thin green vegetation that hosts Desert Locust. In other words, imagery often indicates that an area is dry when in reality it is green, so-called false negatives. With increased resolution, comes increased file size for each image. This makes it difficult to distribute high resolution imagery such as MODIS to affected countries by Internet, email or ftp because most countries have very slow and erratic connections.

Models and seasonal forecasts

The DLIS in Rome uses two different models within the SWARMS GIS when analyzing data and forecasting locust developments. The Desert Locust Egg and Hopper Development Model estimates the rate of egg and hopper development (in days) which helps to understand better any given situation, to estimate when undetected laying or hatching may have occurred, and to predict when hatching and fledging may take place. The model relies on the well documented relationship between temperature and locust development (Pedgley 1981; Reus and Symmons 1992).

The other model used in analysis and forecasting is the Desert Locust Trajectory Model which estimates the displacement of adults forward or backward in time from any given point (Meteo Consult 1995). The model uses 6-hour 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.

Both models are not entirely accurate and must be used with a reasonable amount of caution and intelligence by an experienced forecaster. Nevertheless, the models are useful in examining different scenarios and providing early warning of potential invasions to countries at risk.

Longer-term forecasting of locust breeding and migration beyond a few weeks in advance depends very much on seasonal predictions of rainfall and temperature. In the past few years, there have been some dramatic advances in seasonal forecasting as data, models, algorithms and methodologies continue to evolve and improve. FAO DLIS has been using six-month forecasts of rainfall and temperature on an experimental basis since 2004. Monthly forecasts are provided each month for the next five months that indicate anomalies and probabilities of rainfall and temperature (Ceccato, Cressman *et al*. 2007).

Much skill is required to interpret a given month's forecast because it tends to vary from month to month, depending on how far in advance the forecast is produced. For example, a forecast issued in July for December rainfall can be very different compared to one that is issued in October or November. Normally, the locust forecaster looks for consistent trends over time in the seasonal rainfall and temperature forecasts. Although it is difficult to rely on such forecasts for planning and operational purposes, they can be useful in providing insight to potential locust developments up to six months in advance.

Networking and telecommunications

As Desert Locust can migrate quickly from country to country, region to region and continent to continent, it is imperative that a reliable network of information exists and is maintained. The current Desert Locust information network dates back to the 1920s when it was established by the Anti-Locust Research Centre in London. One of FAO's original mandates is to provide locust early warning and by 1975 it had taken over this responsibility from the UK. Since then, the Organization has encouraged locust affected countries to establish small national locust control centres that have sufficient resources for survey and control and well-trained specialized staff. These countries are the foundation of the early warning system. Each country has a national locust information officer who is responsible for collating, managing and analyzing data received from field teams, and to keep FAO DLIS informed in a timely manner on a regular basis.

The introduction of new technologies, mainly email, has made it easier for national information officers to exchange data and reports with FAO and other countries, and to be in contact with each other on a regular basis. It is this contact that is critical in maintaining a well functioning network of information. FAO has introduced several concepts to strengthen networking further. For example, an information officer from an affected country is trained in DLIS at FAO Headquarters in Rome for 11 months on data management and analysis, remote sensing interpretation, GIS and forecasting. Recently, DLIS has established an Internet-based discussion group to encourage national locust information officers to exchange experiences, problems and solutions.

Most of the Desert Locust breeding habitats are not covered by telephone or mobile services yet efficient, effective and timely field operations depend on good communications. Many locust affected countries rely on HF radios for voice communications amongst field teams and between the field and the National Locust Control Centre. During the past few years, satellite phones have become more prevalent, the cost of using their services has become more affordable, and governments are authorizing their use. Consequently, many national locust programmes are starting to provide survey and control teams with satellite phones. FAO locust staff and consultants regularly use satellite phones during surveys and control campaigns. Satellite phones can be used anywhere as long as it is outside within clear view of the satellite.

Conclusion

During the past two decades, a number of new technologies have emerged with potential applications to locust early warning and plague prevention. FAO has made a considerable effort to develop and test those technologies that showed the most promise with the affected countries. The integration and sustaining of these new technologies in national locust programmes represents a greater challenge than their initial identification and development. A considerable amount of training, retraining and continual support is required before a new technology is successfully adopted and effectively used on a regular basis. The aforementioned technologies are examples that have been integrated into national and international programmes and that are used on a daily basis. While all of these technologies have contributed to better early warning and reaction by affected countries and FAO, eLocust2 and satellite-based rainfall estimates have probably had the greatest impact on monitoring locust populations in Africa and Asia.

Technological developments continue to advance in a number of areas related to locust early warning such as telecommunications, data management, remote sensing, computing and meteorology. FAO will continue to keep abreast of these developments and will investigate their applicability and potential usefulness in locust early warning. Nevertheless, technology should be used wisely and expectations of its benefits should be realistic. New technologies cannot replace well trained and highly motivated individuals who carry out survey and control operations. They are not a remedy for poor management. Technology alone will not prevent locust plagues but, if used within a framework of well functioning national locust programmes with sufficient resources, reliable governmental support, an autonomous budget and regular financing, it can contribute to improving early warning as a means of reducing the frequency of locust plagues.

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