Plant Pests Diseases: the FAO Experience

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Abstract

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The Desert Locust (*Schistocerca gregaria* Forskål) is probably the oldest and most dangerous migratory pest in the world. The UN's Food and Agriculture Organization (FAO) has been operating a surveillance and early warning system for the past 30 years. The system incorporates the collection, transmission and analysis of locust and ecological field data with models, meteorological data and remote sensing imagery to assess current conditions and forecast the scale, timing and location of locust breeding and migration. A variety of information products are disseminated to warn affected countries and donors so that early action can be taken to avoid the development of locust plagues and protect crops and food security. Lessons learned in the Desert Locust system can be applied to other surveillance and monitoring systems. This paper provides an overview of the Desert Locust early warning system and its current application to other transboundary plant pests and diseases, such as wheat rusts.

Keywords: Desert locust, remote sensing, monitoring system

Historic overview

Man has interacted with the Desert Locust (*Schistocerca gregaria* Forskål) since ancient times as reflected in the decorations of 6th dynasty Egyptian tombs (2420 BC) and in Greek, Roman, Rabbinical, Biblical and Koranic literature. The appearance of locust swarms had been popularly regarded as Divine Wrath that had to be endured passively as there was no remedy for it. This attitude prevailed for the most part until the early 20th Century when the first report on the problem on a worldwide scale was published in 1916 (5). In 1920, locust affected countries met in Rome in under the auspices of the International Institute of Agriculture (IAA), the forerunner of today's Food and Agriculture Organization (FAO) of the United Nations, and adopted an international convention, referred to as the Rome Convention, to cooperate in efforts to combat the Desert Locust (6). These efforts were bolstered in the following year when Sir Boris Uvarov explained that the Desert Locust usually lives as a solitarious insect that, under optimal environmental conditions, can increase rapidly and change its behaviour to form swarms of gregarious individuals that are capable of migrating across regions and continents. In 1929, the Anti-Locust Research Centre (ALRC) was established in London to investigate locust plagues and the means to control them. During the following decade, locust-affected countries agreed to collect an agreed upon set of data and a centralized information and forecast unit at ALRC started to map, analyze and archive the data. Five international conferences were subsequently convened to address issues related to locust biology, migration and control. Thus, the institutionalization of the international fight against the Desert Locust had commenced.

As one of its original mandates, FAO assumed responsibility for locust control in 1946. Locust information and forecasting, on the other hand, remained a centralized activity under the guidance of ALRC in London for another three decades (3). In 1973, these activities were decentralized to regional units but five years later it was recentralized at FAO because the regional units were insufficiently staffed, mapping and analysis for forecasting were inadequate and a major inter-regional migration was not predicted (7). Since 1978, FAO has operated the Desert Locust Information Service (DLIS) in Rome on a continual basis for monitoring the weather, ecological conditions and Desert Locust infestations.

FAO's Desert Locust early warning system

(a) Data collection, recording and transmission

The foundation of the Desert Locust early warning system is the regular monitoring of ecological conditions and locust populations in the deserts that stretch from the Atlantic Ocean to the Indian subcontinent, an area of 16 million km^2 (Figure 1). This activity is undertaken by specialized national locust teams that check locust breeding areas in their country using four-wheeled drive vehicles. As most of locust habitats are remote and far from towns and roads, national teams often camp for several weeks at a time in the field, changing location every day in order to cover the largest possible area in the shortest amount of time. A single team usually consists of one highly trained locust officer and two drivers. Two vehicles are used to carry the necessary food, water, fuel and camping equipment, allowing the team to be fully self sufficient and independent. Ideally, each vehicle is equipped with an HF radio to allow communications with the national locust centre and other teams, and a GPS unit and high-resolution maps for navigation. A two-vehicle team is also desirable in case one vehicle breaks down or becomes stuck in deep sand or when crossing a flooded seasonal river (or wadi).

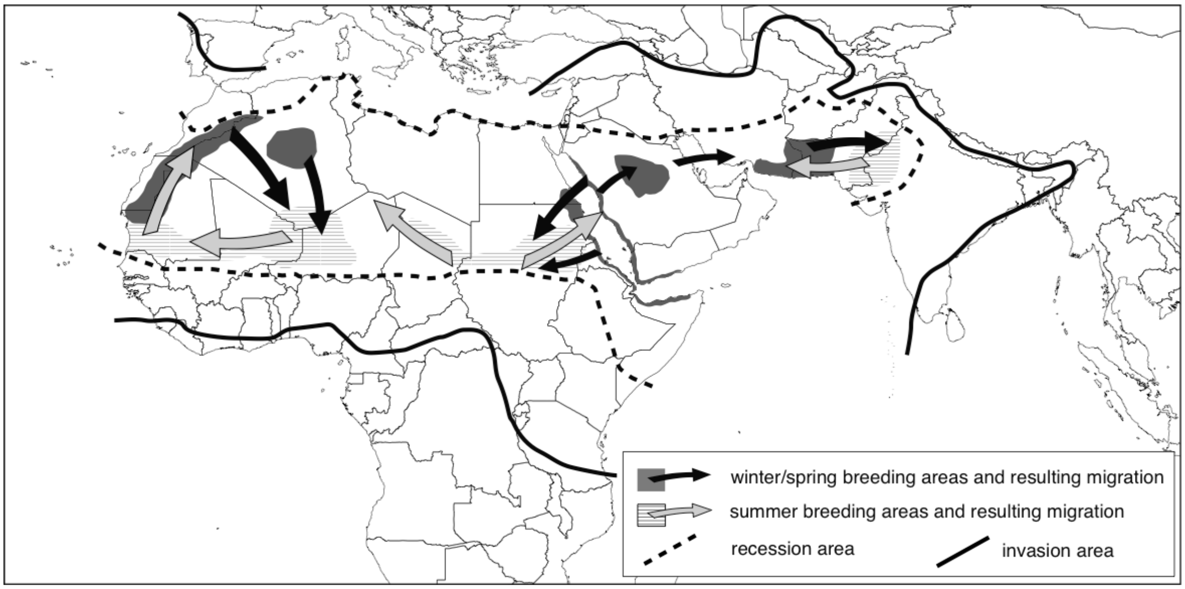

Figure 1. Desert Locust are normally found within a large area of about 16 million km^2 with movements in between seasonal breeding areas. During plagues, this area doubles are swarms move further south, north and east.

The national teams record their observations on a standard form, the FAO Locust Survey & Control Form, which has been adopted by all locust-affected countries and translated into English, French and Arabic. Completed forms are passed onto the national locust centre, usually based in the capital of front-line locust-affected countries, for review, analysis and on forwarding to FAO's DLIS in Rome. The form contains site-specific information on date, location, vegetation state and density, soil moisture, latest rainfall, details of locust infestations (type, appearance, maturity, density, size, and behaviour), control operations and damage. Although it is fairly easy to record field observations in a systematic manner, until recently it was very difficult to transmit these data in a timely manner to the national locust centre because of the absence of reliable communication systems, including mobile coverage, facsimile facilities and Internet access, in the remote desert areas where field surveys are undertaken.

In 2005, this situation changed with the development and introduction of a handheld data logger with satellite transmission capabilities called eLocust2 (2). This system was based on a prototype that was developed and tested in the field in 2000-2004. The prototype contained a custom database, mimicking the FAO Locust Survey & Control Form, linked to a mapping program. The system operated on a handheld Psion personal digital assistant and was connected to a GPS to obtain the latitude and longitude coordinates of the position in the field and an HF radio modem for data transmission. The equipment was powered from the vehicle's battery. Although the prototype proved that it was possible to digitally record data on site in the desert under hot and dusty conditions, the challenge of transmitting data quickly, reliably and easily from the deep desert to the national locust centre remained. Users indicated that the system was too complicated with too many different cables and pieces of hardware and software to manage.

The eLocust2 system is a simplified and more robust system that allows field officers to enter their observations into a custom database in English of French via a touch screen and send the data in real time to the national locust centre. The database contains the same information that is present on the FAO Locust Survey & Control Form. eLocust2 operates on a commercially available handheld device (Wescor) that contains a built-in GPS as well as satellite transmission capabilities using the Inmarsat network that covers the entire Desert Locust recession area from Mauritania to India. The system consists of the Wescor handheld device, a small antenna that is magnetically secured to the roof of the vehicle and connects to the GPS and Inmarsat satellite communication networks, a cable connecting the antenna to the Wescor and another cable that provides power from the vehicle's cigarette lighter (Figure 2). It takes less than ten minutes to automatically obtain the position location by GPS, enter all of the field observations and transmit the data to the national locust centre where it arrives a few minutes later. Data can also be saved to a small internal hard disk in the Wescor for later downloading to a PC. The eLocust2 system can be used in any locust-affected country, day or night, rain or shine. Some 400 eLocust2 units are currently deployed and are in use in nearly two dozen locust-affected countries to monitor ecological conditions and locust populations.

(b) Remote sensing

It is not possible to check everywhere for locusts in most of the countries because of the sheer size, remoteness and inaccessibility of the desert. National locust centers and FAO DLIS use several remotely sensed products on a regular basis to identify areas in which there is the highest probability of finding green vegetation and locust populations. In this way, areas can be reduced and prioritized for checking by ground survey teams. Two main products are currently utilized for this purpose: 25 km resolution daily rainfall estimates to understand where it has rained in the desert and 250 m resolution 16-day MODIS imagery to detect areas of green vegetation. Both of these products have evolved from and superseded earlier visible and infrared channels of Meteosat cloud imagery and 7 km resolution NOAA-AVHRR and 1 km resolution SPOT normalized difference vegetation index (NDVI) imagery (1, 10). Rainfall estimate and MODIS products are available for free online at Columbia University's International Research Institute for Climate and Society (USA). Users can select their area of interest and download a geo-referenced file that can be incorporated into geographic information systems (GIS) for display and analysis.

The rainfall estimates are based on satellite-derived estimates rather than from meteorological models because the former offer a higher degree of spatial reliability (i.e. where it has rained) while the latter are more precise in estimating the actual amount of rain that fell but can miss important areas that received rain (8). In Desert Locust early warning, it is more important to know where it may have rained rather than knowing the exact number of millimeters. The estimates provided by IRI are derived from some of the most sophisticated algorithms available and have been fine tuned for use in arid areas.

Although the resolution of satellite-derived imagery used for detecting green vegetation has improved, omission errors (false negatives where vegetation is present but not indicated on the MODIS image) still occur in parts of the Desert Locust recession area at certain times of the year. Work is in progress by several research institutes to further refine and validate MODIS imagery. A new product that is derived from MODIS imagery is in the final stages of development by the Université catholique de Louvain (Belgium) and the Flemish Institute for Technological Research (VITO). The product shows changes over time in vegetation conditions in the Desert Locust recession area (9). It is a dynamic green vegetation map that includes both spatial and temporal information in one geotiff-formatted file suitable for analysis within geographic information systems. The map shows the evolution of vegetation development for the previous 11 decades (i.e. eleven 10-day periods) for each 250 m pixel, indicated in varying shades of red, orange and green. The product informs users of the spatial-temporal variations of 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 Desert Locust. This product should become a valuable tool for locust early warning at the national and international levels.

(c) Meteorology

In addition to rainfall estimates, other meteorological information is valuable for assessing the current locust situation and forecasting its developments such as rainfall station reports, high and low daily temperatures and wind speed and direction at various heights. Daily NOAA rainfall station data are used to compliment and confirm rainfall estimates although the former are limited because of the low number of rainfall stations in the Desert Locust recession area. Temperature can be critical at specific times of the year, mainly from late to autumn to late spring, because it influences the rate development for Desert Locust eggs, hoppers and adults. Adult migration, that is, take-off, flight and landing is affected by rainfall, temperature and wind.

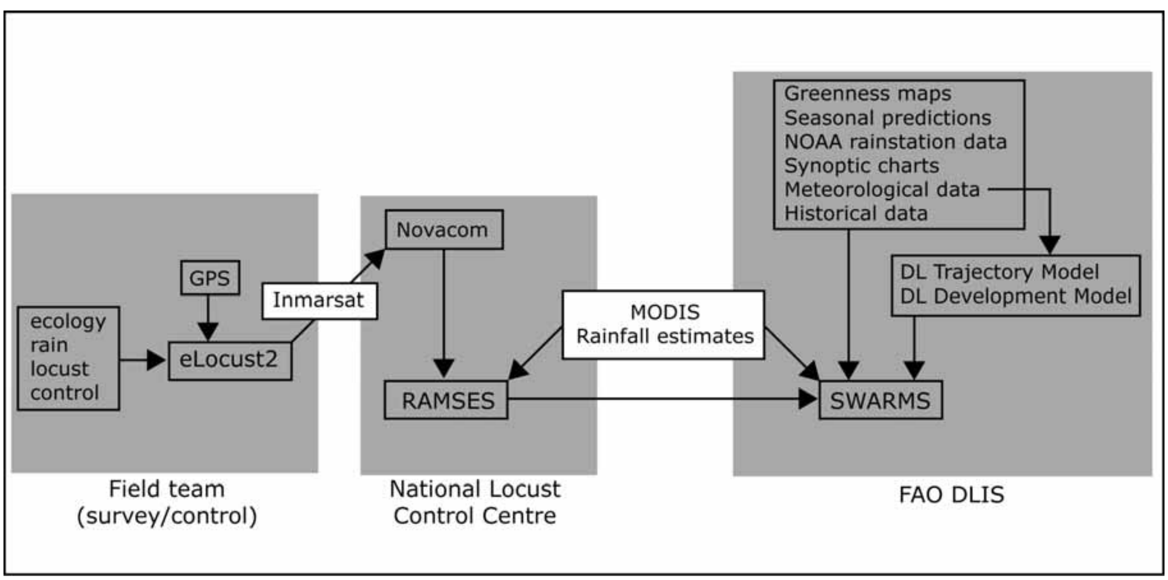

Figure 2. National field teams enter data into eLocust2 which is transmitted via satellite to national locust control centres for checking, analysis and onforwarding to FAO DLIS for further analysis and forecasting.

Monthly seasonal predictions of rainfall and temperature anomalies up to six months in advance have been utilized regularly since 2005 by FAO DLIS when forecasting the timing and scale of breeding in the short and medium term. These products are extremely difficult to interpret and the predictions may change from month to month. Nevertheless, they can add value and precision to forecasts when used in combination with other data by an experienced forecaster.

In some of the locust-affected countries, the national meteorological service provides temperature, rainfall and wind data to the national locust centre in the country. During periods of increased locust activity, information exchange between the two services often increases.

(d) Geographic information systems

Custom geographic information systems are used by nationally designated locust information officers in each frontline Desert Locust country and by the locust forecaster at FAO DLIS to manage and analyze locust and environmental data. The system used at the national level, called RAMSES (Reconnaissance and Management System of the Environment of Schistocerca), consists of a MS Access database and ArcView software. It was first introduced in 2000 and has been updated several times since then to include new requirements and needs of the countries. It is available in English and French. It is used to manage the data received from survey and control teams in the field, and analyze it in conjunction with rainfall estimates and NDVI imagery.

Since 1996, FAO DLIS has used a more sophisticated GIS called SWARMS (Schistocerca Warning and Management System) that initially operated on a Unix workstation using an Oracle database and ArcInfo software (4). It was one of the first examples of using GIS for operational monitoring and early warning rather than for map production. The system is used for managing and analyzing the survey and control data received from locust-affected countries that consists of details on the locust populations, ecological conditions, soil moisture and rainfall. This data is combined with data from other sources such as rainfall estimates, MODIS imagery, NOAA rainfall station data, seasonal rainfall and temperature predictions, and historical locust data (from the 1930s to present) to assess the current situation and forecast the scale, timing and location of breeding and migration. An egg and hopper development model and a wind trajectory model are used to estimate the timing of breeding and the location and duration of migration, respectively. The former uses 30-year temperature averages while the latter is driven by 6-hourly temperature, pressure and wind direction and speed at different atmospheric levels.

In the past year, the Unix workstation has been replaced by PC workstations operating the latest version of ArcGIS software. The Oracle database continues to reside on a Unix server so that data can be downloaded automatically from external providers and incorporated into the system in the middle of the night. SWARMS is constantly being updated and improved in order to take advantage of the latest technology and meet additional needs of the locust forecaster at FAO. This work is outsourced to the original developers at the Department of Geography, University of Edinburgh (UK).

(e) Reporting

Every locust-affected country typically sends the corrected survey and control data to FAO DLIS within a few days of the end of each survey. During periods of increased locust activity, data is received on a daily basis while during calmer periods, data is received every week or two. The national locust centres also prepare regular situation bulletins on a decadal, fortnightly or monthly basis. These bulletins are distributed mainly within the country to government agencies and non-government partners as a means of keeping decision makers and the general public informed about the Desert Locust situation. The bulletins are also sent to FAO DLIS and to the donor community.

(f) Data analysis and forecasting

The results of the data analysis at FAO DLIS form the basis for assessing the current situation and forecasting its development at a national and global level. However, significant gaps exist in the operational monitoring of the large Desert Locust recession area because some areas cannot be surveyed due to insecurity, remoteness or lack of resources. Consequently, data are incomplete, imprecise and not fully quantitative. Therefore, the data must be interpreted based on experience that is only obtained after many years of working with the data and data providers, combined with an intimate knowledge of and first hand visits to the Desert Locust breeding areas.

(g) Early warning

The current strategy of Desert Locust management adopted by locust-affected countries and FAO consists of early warning and reaction in order to prevent the development of locust plagues. This means that well-trained national teams must check Desert Locust habitats after rainfall to follow the growth of natural vegetation and determine if there are a sufficient number of locusts present that warrant treatment. Countries attempt to carry out control operations as soon as possible but if they are initiated too early this will result in using a large volume of pesticide to kill a relatively low number of locusts. Therefore, countries generally wait until higher numbers of locusts concentrate in smaller areas before undertaking control. This often coincides with shrinking areas of green vegetation at the end of the seasonal rains. The exchange of high quality information and forecasts are paramount to this strategy and can help to reduce the risk of missing important locust infestations that could eventually lead to the development of a plague.

FAO with its centralized DLIS unit plays an important role in facilitating information exchange as well as monitoring the current situation on a daily basis. At any given time, DLIS has a global view of the situation. This is critical given the extreme migratory nature of the Desert Locust in which swarms can rapidly move across continents and seas. DLIS keeps the situation under watch and alerts countries whenever unusually good rains may have fallen, when there is a risk of increased locust activity and if there is a threat of an invasion. Since 1975, FAO DLIS has issued monthly bulletins and forecasts. Each bulletin consists of a general overview, followed by the current situation and forecast for each country. The bulletins are disseminated by email and are available on the Internet. They are used by national decision makers to help plan survey and control operations and by donors when providing assistance.

Lessons learned

The success of FAO's Desert Locust early warning system can be attributed to a number of different factors. First and foremost is a robust network of information that spans nearly 30 countries and consists of rapid data collection, recording and transmission from the field to the national and international levels. This network relies on effective partnerships with locust-affected countries and other sources of information and data in Africa, Asia, Europe and North America. The information network must be sufficiently streamlined and direct to avoid bureaucratic delays and political interference. The effectiveness and efficiency of the current Desert Locust network is the result of decades of training, technical assistance, development projects, financial support, country visits, technological innovations and personal efforts to strengthen national capacities in locust survey, control, reporting and campaign planning. The human component of this network is by far the most critical and should not be under-estimated. People need to feel comfortable with each other before they can are willing to share information and data on a regular and reliable basis. The development of trust amongst shareholders of different cultures, backgrounds, education, language and religion takes time.

Second, locust forecasters require real-time access to data from the entire locust distribution area from West Africa to India. The data for this area must be analyzed in unison at a global level rather than separately at national or regional levels. Consequently, a centralized forecasting unit such as DLIS is required to act as a central repository of information where all locust and environmental data can be properly analyzed using the most sophisticated tools available to provide objective non-biased forecasts that are as accurate and timely as possible. A centralized unit can easily maintain historical archives and be used as a training centre for national locust information officers.

Third, DLIS has adopted a number of emerging technologies during the past three decades and incorporated them into its centralized service for use in locust-affected countries (Figure 3). Of all of these technologies, GPS and the use of eLocust2 has had the greatest impact on Desert Locust early warning. The former allows the accurate pinpointing of green vegetation and locust surveys, infestations and control operations while the latter is used to record and transmit valuable survey and control results from anywhere in the field at any time day or night under any weather conditions to the national locust centres. DLIS is continuing to look at new ways to monitor the environment, display and analyze data, and deliver information products.

Lastly, the Desert Locust early warning system is based on four key principles: (i) regular surveillance and accurate GPS field data, (ii) data that is transmitted rapidly and made easily accessible to analysts, (iii) complete analysis of the data within a geographic information system, and (iv) simple well-targeted outputs for decision makers based on the results of a thorough, non-biased analysis. These components are likely to be essential in any pest and disease monitoring system at the national, regional and international levels.

Other emerging early warning systems at FAO

New virulent races of wheat stem rust, commonly known as Ug99, are spreading from East Africa to Asia. It is estimated that as much as 80 percent of all wheat varieties planted in Africa and Asia are susceptible to the Ug99 lineage of wheat stem rust (Puccinia graminis tritici). The fungus is spreading rapidly and could seriously lower wheat production in countries at direct risk and pose an enormous threat to global food security.

FAO, in collaboration with the Borlaug Global Rust Initiative (BGRI), is establishing a system to monitor the fungus. The BGRI is a broad-based global partnership that brings together academic institutes including Cornell University and University of Sydney, international research centres such as the International Maize and Wheat Improvement Center (CIMMYT) and the International Center for Agricultural Research in the Dry Areas (ICARDA). The BGRI aims to mitigate the threat posed by wheat rust diseases (stem, yellow and leaf rust) worldwide. The Global Cereal Rust Monitoring System (GCRMS) developed and managed by FAO will be based on the successes of the Desert Locust system. The GCRMS consists of national field surveyors and information system managers trained in cereal rust surveying and sampling. Standardized protocols and procedures have been developed for data collection and sample transmission and management. A data flow has been established in some countries, which is expanding to include other regions and countries. This allows an International Focal Point based at FAO Headquarters to analyze the data using GIS-based methodologies in order to have a global view of the potential spread of stem rust. Web-based visualization tools linked to a centralized database have been developed as a means of providing access to stem rust information in a timely fashion.

This is one example of how FAO, using its past experience and its current network of national contacts, is adopting and expanding its monitoring and early warning systems for other transboundary pests that cross international frontiers and can spread across regions and continents. Similar activities are either under consideration or have been initiated for other transboundary pests that may affect cassava and banana in Africa.

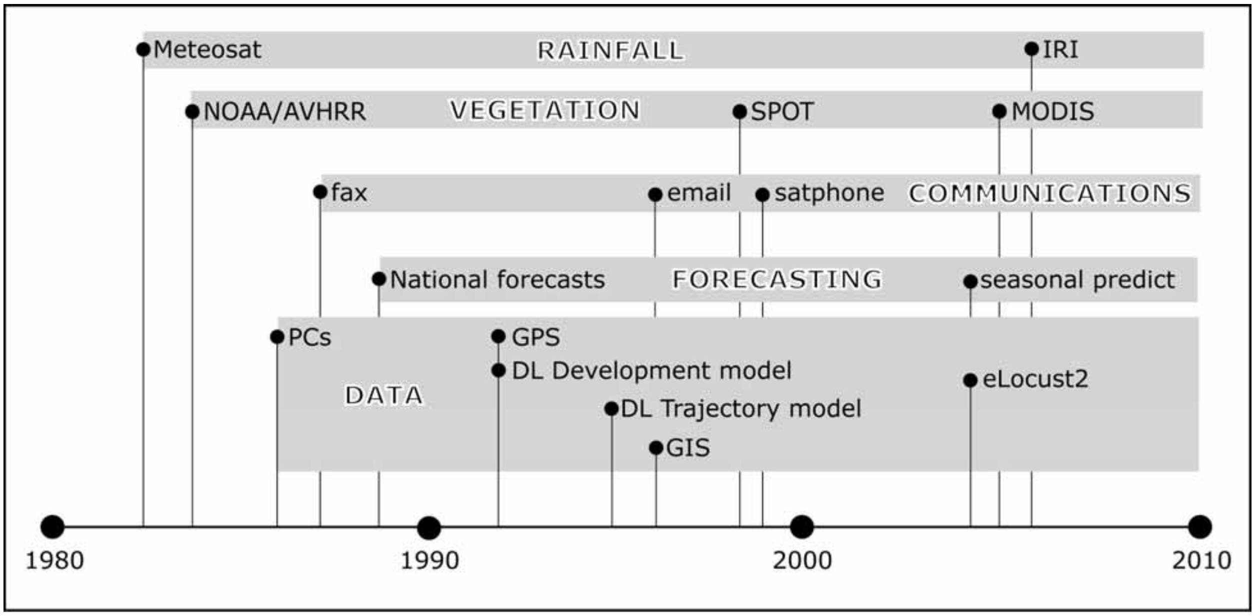

Figure 3. A timeline of emerging technologies that have been adopted and incorporated into FAO's Desert Locust early warning system.

The challenges ahead

The emerging GCRMS being developed by FAO has many additional challenges compared to the existing Desert Locust system. Additional complexity arises from the variability of the cereal rust pathogen populations. Unlike Desert Locust – a highly visible single species – wheat rust populations are highly variable and capable of rapid changes in virulence profiles. Already five known variants are recognized in the Ug99 lineage, most likely due to single step mutations. These variants exhibit different virulence/avirulence patterns to known resistance genes so represent new threats in terms of susceptibility of wheat cultivars. This continually changing nature of the pathogen population has major implications for any monitoring system. Any effective surveillance system must monitor these changes and also the migrations of known variants. A further challenge arises because identification of specific races or biotypes of wheat stem rust cannot be undertaken in the field; this requires controlled infection under laboratory conditions. Currently, race analysis can only be reliably undertaken at a very limited number of specialized rust labs; hence, considerable delays often exist between sample collection in the field and final identification of the race involved. Strengthening national and regional capacities to undertake race analysis and possible establishment of a Global Reference Centre, capable of rapid turnover of results, are two approaches that are being pursued to try and mitigate these problems.

Information sharing is another challenging issue, particularly when dealing with potentially damaging pest and pathogens such as Desert Locusts and Ug99 in which political sensitivities can occur. These issues can largely be addressed through the establishment of a network of officially nominated national focal points and good agreements with respective governments. This has already been achieved within the existing FAO Desert Locust system and is being replicated for the GCRMS. Establishment of timely, effective information flows will be vital to the success of the GCRMS.

The sheer complexity of factors associated with the emergence of wheat rust epidemics makes them by nature largely unpredictable. Although, models of suitability for disease occurrence may be developed over time it must be recognized that no perfect early warning system will be possible for pathogens like wheat rusts. Disease suitability may not always coincide with disease occurrence and vice versa. Managing expectations around precise predictions is another challenging factor.

Any system monitoring irregular outbreaks such as locust upsurges or wheat rust epidemics faces a considerable challenge in maintaining awareness, vigilance and political and financial support during long periods of inactivity. Considerable effort must therefore be made in advocacy efforts to maintain awareness. Such efforts may be supported by the historical record that details the devastating effects if complacency and lack of vigilance occurs.

Finally, effective early warning relies on the willingness of people to collect and share field surveillance data, a network to transmit the data, supplemental data from a variety of external sources, a geographic information system that can manage and analyze spatial data, highly qualified and properly trained users, and well-targeted information products that are disseminated in a timely manner to decision-makers. Each of these elements has associated risks that may limit the effectiveness of the early warning system. For example, field staff may not understand the importance of recording complete data and sending it on time; data collection protocol, sharing agreements and management procedures may not exist; Internet service may not be available or sufficiently reliable for data transmission or communications; supplemental data may be expensive, unavailable or incompatible; staff may be well-qualified but have little incentive to perform; GIS platforms require a certain level of on-going maintenance and upgrading; and, information products may be poorly presented or are received too late. These elements are further compounded in early warning systems for transboundary pests because they often involve shareholders and partners from different cultures, backgrounds, education, language and religion. The challenge is to overcome these pitfalls by giving sufficient attention, thought and funding from the onset of the establishment and during the operation of any early warning system, especially those that address transboundary pests.

الملخص

كريسمان، كيث وديفيد هودسون. 2009. المراقبة، اقتسام المعلومات ونظم الإنذار المبكر لآفات النبات وأمراضها العابرة للحدود: خبرة منظمة الأغذية والزراعة للأمم المتحدة. مجلة وقاية النبات العربية، 27: 226-232.

من المحتمل أن يكون الجراد الصحراوي (*Schistocerca gregaria* Forskål) الآفة الأقدم والأكثر خطورة في العالم. وكانت منظمة الأغذية والزراعة للأمم المتحدة شغلت نظام مراقبة وإنذار مبكر على مدى العقود الثلاثة الماضية. ويشتمل النظام على جمع ونقل وتحليل البيانات الحقلية البيئية، البيانات المناخية، وصور الاستشعار عن بعد لتقدير الظروف الراهنة والتنبؤ بمدى وتوقيت ومكان تزاوج الجراد وهجرته. ويتم تحديد مجموعة من المنتجات الإعلامية لتحذي البلدان المتضررة والمانحين ليتم اتخاذ عمل مبكر لاجتناب تطور جائحات الجراد وحماية المحاصيل والأمن الغذائي. يمكن تطبيق الدروس المستقاة من الجراد الصحراوي في لمراقبة ورصد آفات أخرى.

كلمات مفتاحية: الجراد الصحراوي، الإستشعار عن بعد، نظام المتابعة.

عنوان المراسلة: كيث كريسمان، قسم الإنتاج النباتي ووقاية النبات، منظمة الأغذية والزراعة للأمم المتحدة، روما، إيطاليا، البريد الإلكتروني: keith.cressman@fao.org

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