OPERATIONAL EARLY WARNING SYSTEM USING SPOT-VEGETATION AND TERRA-MODIS TO PREDICT DESERT LOCUST OUTBREAKS

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ABSTRACT

The Desert Locust (*Schistocerca gregaria*) is an insect whose distribution area extends from North Africa through the Near East to Southwest Asia. During invasion periods, adults form swarms that can fly or be carried by wind over great distances. These swarms can threaten crops located thousands of kilometres from their places of origin. Supported by its member countries, FAO established the "Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases" (EMPRES programme – Desert Locust Component) to minimize the risk of emergencies developing as a result of Desert Locust plagues.

EMPRES has created an operational early warning system involving surveying for Locusts in order to find Desert Locust outbreaks as early as possible and prevent them from developing into serious upsurges or plagues. The system includes the use of SPOT-VEGETATION images received on a ten-day basis at FAO through ARTEMIS. The S10 SPOT-VEGETATION NDVI product and single channels (RED-NIR-SWIR) are analysed at the Desert Locust Information Service, FAO HQ for conditions favourable for Desert Locust reproduction and development. The images and analyses are then provided to each of the twenty countries via a FTP site where the Locust Information Officers can have direct access. The analyses aim to identify two sorts of error: i) Commission error (when NDVI indicates that there is vegetation but there is no real vegetation on the ground) ii) Omission error (when NDVI indicates no presence of vegetation but there is vegetation on the ground). To reduce the first type of error, S10 single channels (Red, NIR, and SWIR) are needed and provided to the users. To reduce the second type of error, TERRA-MODIS images are used to detect sparse vegetation not identified with SPOT-VEGETATION.

The satellite images (SPOT-VEGETATION and TERRA-MODIS) are now used operationally by some Locust survey teams to direct their surveys toward high-risk regions and allow them to optimize use of available resources. Once in the field, survey teams introduce field observations into a palm-top computer and send the information to the National Locust Unit (LCU) in real-time via radio signal. The information arriving at the centre is then automatically integrated into a GIS system that was developed specifically to manage Locust and environmental data. This system, called the Reconnaissance And Management System of the Environment of *Schistocerca* (RAMSES), allows Locust Information Officers to orient field surveys geographically, to predict Desert Locust breeding and migration and to develop control strategies in case of emergency. The integration of satellite images within RAMSES also allows the officers to assess the areas covered by vegetation where control operations must be carried out. At the Desert Locust Information Service (DLIS), FAO HQ (Rome, Italy), all of the data collected at national levels are automatically imported into a much larger UNIX-based GIS called SWARMS (*Schistocerca* WARning Management System) where short and medium-term forecasts are prepared indicating potential locust migrations and areas of breeding.

1. INTRODUCTION

The Desert Locust (*Schistocerca gregaria, Forskål 1775*) is an insect whose distribution area extends from North Africa through the Near East to South-West Asia (Fig. 1). It lives in vast desert zones, far from populated centres and difficult to access. It constitutes a permanent threat to the agriculture of all the countries of the arid and semi-arid regions. During invasion periods, adults form swarms that can fly or be carried by wind over great distances and can threaten crops and pasturelands in about 50 countries. The Desert Locust plague of 1986-89 and subsequent upsurges in 1992-94 and 1996-98 demonstrated how quickly this pest can spread across national borders [1] and cause economical and environmental damage, including side-effects from chemical pesticides used during control measures.

In order to avoid extensive and costly operations, it is necessary to detect Desert Locust populations at the outbreak or early upsurge stages before their populations can expand into full-scale plagues. To achieve detection of Desert Locust at an early stage, survey teams must visit potential breeding areas to assess the condition of the habitat and the state of any Desert Locust populations. The potential breeding areas cover areas that are spread over vast regions that are remote and difficult to access. To survey them involves considerable preparation and travel time, costly transport, as well as significant financial and staff resources. Reaching them all on a regular basis presents serious logistical problems. Availability of transportation and operational allotments are limiting factors. Survey teams cannot afford to monitor the potential areas by guesswork, without knowing exactly where to find vegetation conditions that are favourable to Desert Locust reproduction.

To direct survey teams precisely to those areas with the highest potential for Desert Locust breeding, satellite imagery combined with ancillary data represents an invaluable tool because it provides, in almost real time, an indication of the daily or weekly evolution of the vegetation cover. In addition, the use of satellite data in combination with data collected in the fields and analysed through a Geographical Information System (GIS) allows the Locust Officer to assess the area to be treated and plan control operations.

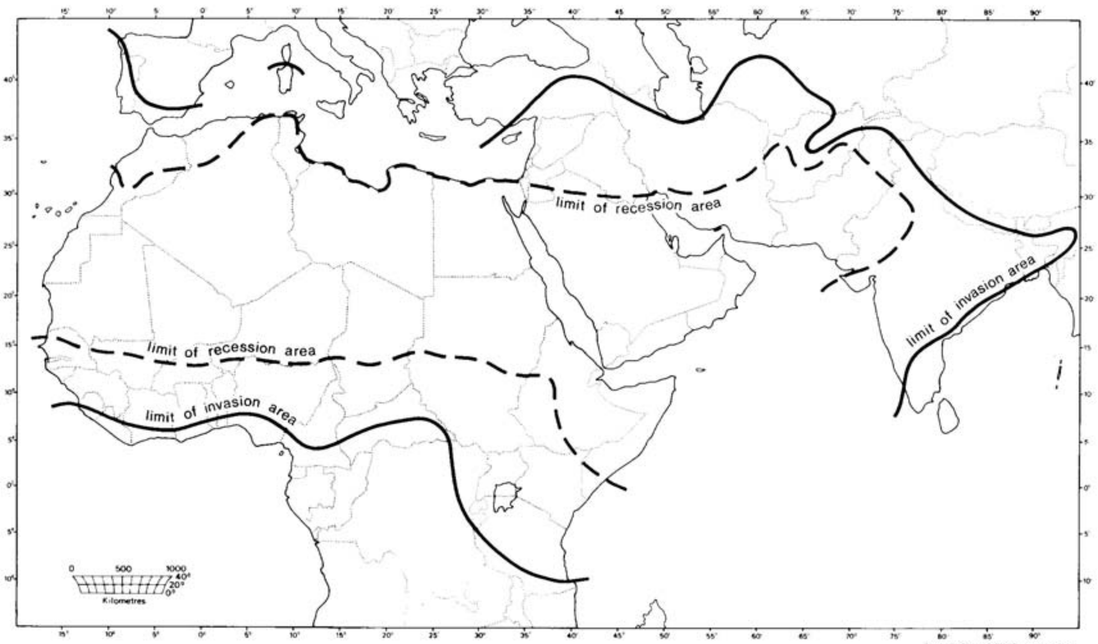


Figure 1: Invasion and recession areas of the Desert Locust

This article presents the operational Early Warning System developed by the Food and Agriculture Organization (FAO) to provide information to the National Locust Control Units to plan field surveys and assess the size of vegetated areas to be treated using satellite imagery SPOT-VEGETATION and TERRA-MODIS in combination with a GIS. This Early Warning System was developed and implemented for the benefit of the twenty countries located in the recession area showed in Fig. 1.

2. METHODOLOGY

Adequate monitoring of Desert Locust habitats and rapid treatment of important infestations by national LCU requires information in almost real time to i) detect the presence of vegetation in the desert to direct the field survey teams towards potential infested areas and ii) estimate the size of vegetated areas where Locust infestations requiring control may be present. In addition, the information should be made available free of charge since the countries have limited resources and cannot afford to pay for expensive satellite data.

Satellites currently available for civilian use cannot directly detect individual locusts or locust swarms. Some sophisticated satellites and forthcoming civilian satellites could potentially detect locust swarms but these images are not yet available operationally. Current satellites can, however, provide a continuous overview of meteorological and ecological conditions, such as rain and vegetation development, which are important factors for monitoring Desert Locust habitats and forecasting locust developments.

There are a number of satellites which can aid the monitoring of rainfall and locust habitats from space, including the NOAA series, METEOSAT, SPOT-4 and SPOT-5. The temporal, spectral and spatial characteristics of the sensor instruments on board these satellites provide a wide range of sensing capabilities. Information on vegetation status such as vegetation greenness, percentages of vegetation cover and vegetation moisture content [2] can be retrieved using these satellites. NOAA-AVHRR images were used by the FAO Locusts and other Migratory Pests Group until the launch of SPOT4-VEGETATION in April 1998. SPOT4-VEGETATION images offer better image positioning compared to NOAA-AVHRR and are optimized for global scale vegetation monitoring [3]. Therefore SPOT-VEGETATION images have been adopted for routine monitoring of vegetation.

2.1 SPOT-VEGETATION images

SPOT-4 VEGETATION (since 1998) and SPOT-5 VEGETATION (since 2003) images are received at FAO from the *Vlaamse Instelling voor Technologisch Onderzoek* (VITO), based in Belgium. A synthesis of the daily images is performed on a 10-day basis (SPOT-VEGETATION S10 products) both on single channel (Blue, Red, Near infrared and Short-wave infrared) and on a vegetation index, the Normalized Difference Vegetation Index (NDVI) at VITO. Each 10-day synthesis is sent to FAO Headquarters in Rome where images are cut in small windows corresponding to each country and made available for downloading on the File Transfer Protocol (FTP) server. Each national LCU can then access the images via Internet connection and analyse them to identify vegetation. Training is provided to the Locust Information Officers in each of the 20 affected countries in the recession area to understand, analyse and extract relevant information on the presence of the vegetation using the SPOT-VEGETATION images. Extraction of the relevant information is based on the use of the 10-day composite NDVI and the 10-day composite single channels.

2.1.1. NDVI 10-day composite

The vegetation index NDVI is the most commonly used index for monitoring vegetation presence and properties. NDVI values vary between -1.00 and 1.00 and are computed as follow:

$$NDVI = \frac{(NIR - \mathrm{Re}\,d)}{(NIR + \mathrm{Re}\,d)} \qquad (1)$$

Where: *NIR* is the reflectance measured in the near infrared channel (expressed in %)
Red is the reflectance measured in the red channel (expressed in %)

Presence of dense green vegetation implies that NDVI is high due to high concentration of chlorophyll (low reflectance in the red) and high quantity of leaves (high reflectance in the near-infrared). However, sparse vegetation as it is the case in desert and semi-desert areas implies that NDVI values are lower due to less chlorophyll and leaves (see Fig. 2).

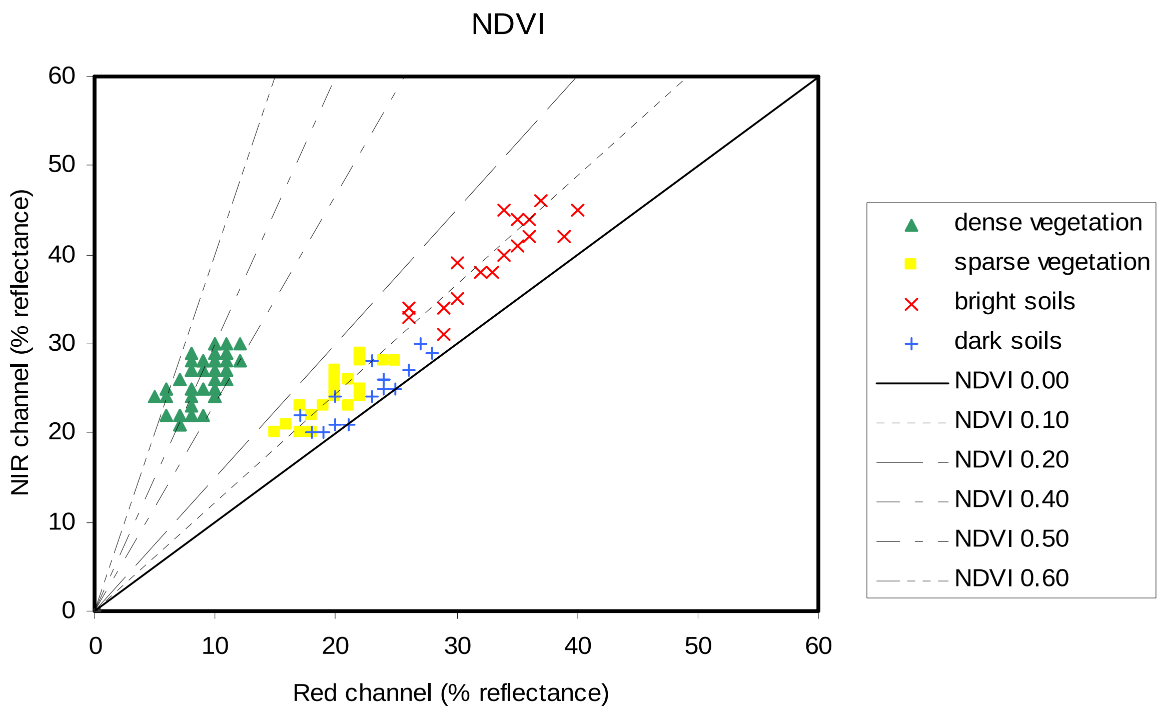


Figure 2: Scatter plot of Red and NIR channel values showing the NDVI isolines and different types of vegetation and bare soil values.

Sparse vegetation in desert areas has therefore low values of NDVI that can be confused with bare soils (bright and dark) whose spectral characteristics (in the Red and NIR bands) can result in NDVI values close to the NDVI values of sparse vegetation. It is therefore very difficult in the semi-arid and arid regions to distinguish vegetation from soil using NDVI only.

Methodology based on a fixed NDVI threshold value (*e.g.* NDVI = 0.14, [4]) to distinguish between bare soil and sparse vegetation can result in the identification of bare soils as vegetation, thereby producing an overestimation of the area covered by vegetation. This type of error is called a commission error (NDVI shows the presence of vegetation when there is no vegetation in the field). The solution adopted by the FAO Locust Group to separate vegetation from soil using NDVI is to complete the NDVI analysis by studying the reflectance in the single channels (Red, Near-Infrared and Short Wave Infrared channels).

2.1.2. Single channels analysis

The use of the red and near-infrared (NIR) channels provides complementary information to distinguish between bright soil (high reflectance in both the NIR and Red bands) and sparse vegetation (low reflectance in the Red). However, it is still difficult to distinguish dark soil from sparse vegetation. The solution proposed by the Locust Group is to use complementary information provided by the SPOT-VEGETATION short-wave infrared (SWIR) channel (located at 1.6 µm). The SWIR is sensitive to water in the soil and vegetation [2]. On a 10-day composite image, the soil usually dries more quickly than the vegetation leading to SWIR reflectance values of soil that are higher than the SWIR reflectance values of vegetation (Fig. 3). By analysing each single channel Red, NIR and SWIR, the user can identify the properties of the vegetation from the bare soils. Such training on understanding the properties of the single channels is provided to the national Locust Information Officers who can analyse and interpret the images in the context of their own areas of study. By comparing the reflectance values of the single channels within the surrounding background, the officer can decide whether a pixel can be classified as vegetation or bare soil.

An additional facility is provided to the officers for identifying vegetation. By combining the three channels, allocating the SWIR channel to the Red colour, the NIR channel to the green colour and the Red channel to the blue colour, a colour composite image is produced where the vegetation (due to the spectral properties) appears green in the image and the bare soil appears with a pinkish tinge (see Fig. 4b).

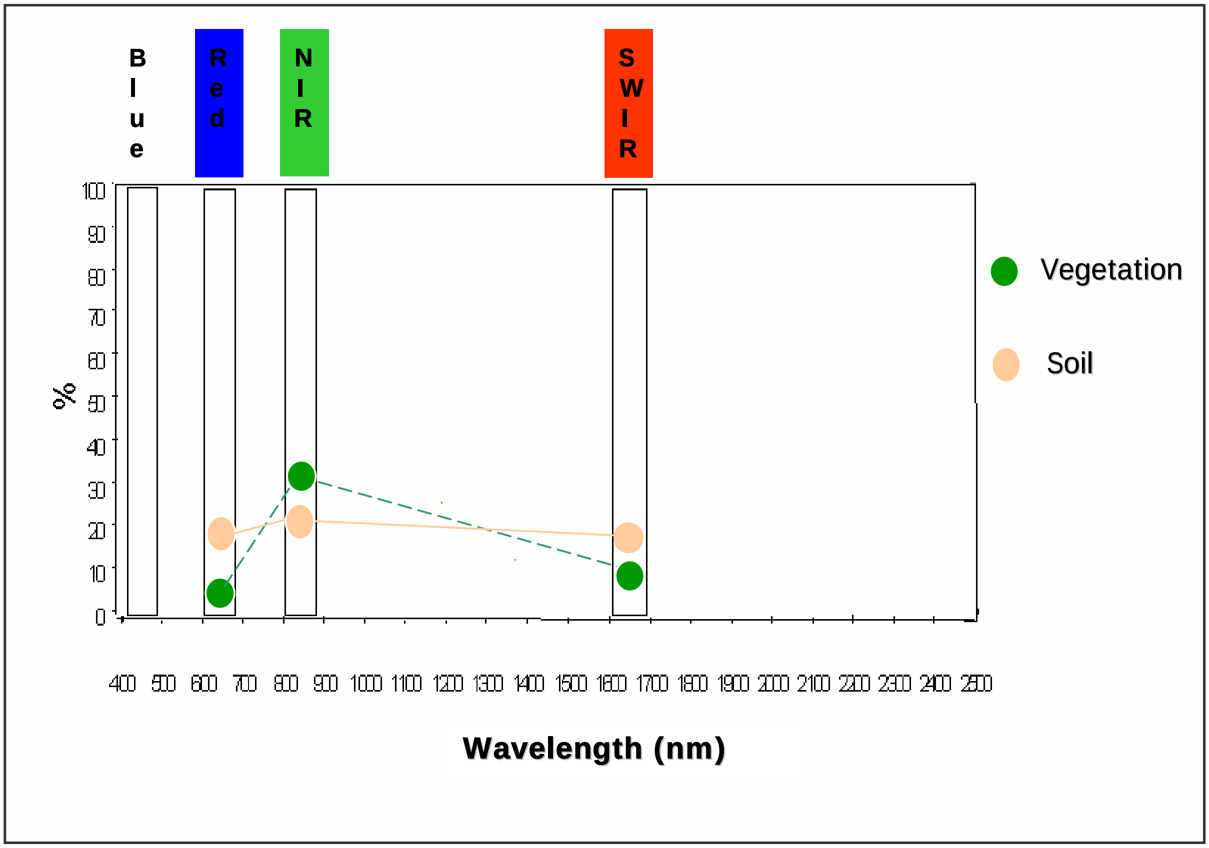
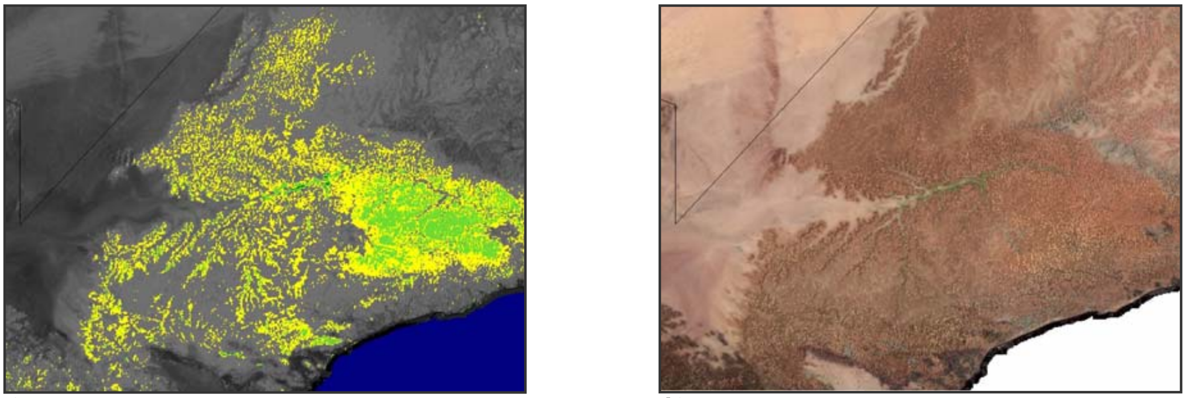


Figure 3: Location of the four SPOT-VEGETATION sensor bands, vegetation and bare soils properties.

The composite colour image produced can improve detection of the vegetation by eliminating the NDVI commission error as shown in Figs. 4a and 4b. Fig. 4a shows an area in Yemen where NDVI values between 0.14 and 0.16 (in yellow) and between 0.16 and 0.18 (in green) might indicate the presence of vegetation in vast areas. The composite image, however, (Fig. 4b) clearly indicates in green the presence of real vegetation in the river valley and the presence of real bare soil (validated by field measurements) in the majority of the area detected as vegetation with NDVI.



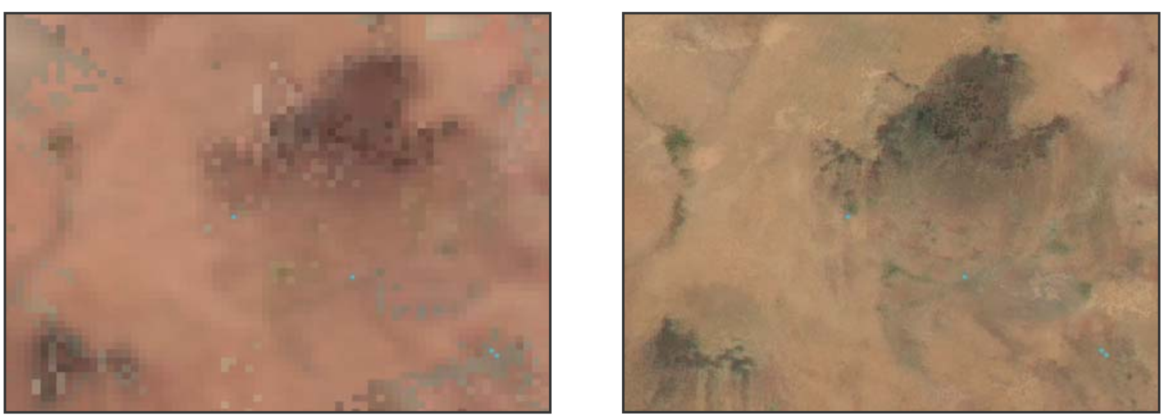
a) b)

Figure 4: a) NDVI values (yellow equals 0.14-0.16 and green equals 0.16-0.18) for the *Hadhramaut* region located in Southern Yemen. b) RGB composite (SWIR, NIR and Red) for the same region.

SPOT-VEGETATION, NDVI and single channel products are now used on a regular basis by many national Locust Information Officers. However, due to the spatial resolution of 1 by 1 km, some sparse vegetation in desert areas cannot be detected even using the composite technique because the vegetation is not dense enough to influence the signal in all three channels at the 1 km^2 spatial resolution. To avoid this omission error (composite image showing the absence of vegetation when there is indeed vegetation in the field), the use of a sensor with a higher spatial resolution is required. For operational use (*i.e.* frequent images of the same area, easy access to the images soon after the last acquisition and free of charge) in the countries mentioned above, the only sensor providing useful information at this time is the MODIS sensor on board the satellites TERRA and ACQUA.

2.2 TERRA-MODIS

MODIS images at 250m spatial resolution are accessible free of charge. Therefore, they are used on a regular basis to detect sparse vegetation where the spatial resolution of SPOT-VEGETATION cannot detect it. Using the same compositing method developed for SPOT-VEGETATION images, images are produced using the SWIR, NIR and Red channels from MODIS and made available to the national Locust Information Officers via the FAO FTP site. Fig. 5 shows the same area in Sudan where Fig. 5a (SPOT-VEGETATION image) shows no presence of vegetation near the two blue dots corresponding to field measurements and Fig. 5b (TERRA-MODIS) of the same area shows the presence of vegetation which is confirmed by field measurement.



a) b)

Figure 5: a) RGB composite using SPOT-VEGETATION. b) RGB composite using TERRA-MODIS, in central Sudan.

In addition to the information on vegetation presence provided to the national Locust Information Officers using SPOT-VEGETATION and TERRA-MODIS, complementary information on the type of vegetation suitable for Desert Locust is needed in order to direct field surveys towards regions of interest avoiding vegetation type that is not favourable. Vegetation type cannot be identified easily at spatial resolutions of both SPOT-VEGETATION and TERRA-MODIS. In order to provide relevant information to the officers, a database of digital pictures taken each time that a survey team goes to the field has been created and is continuously updated within a Geographical Information System (GIS). The pictures are geo-located with a GPS on the ground and combined with the satellite images as shown in Fig. 6.

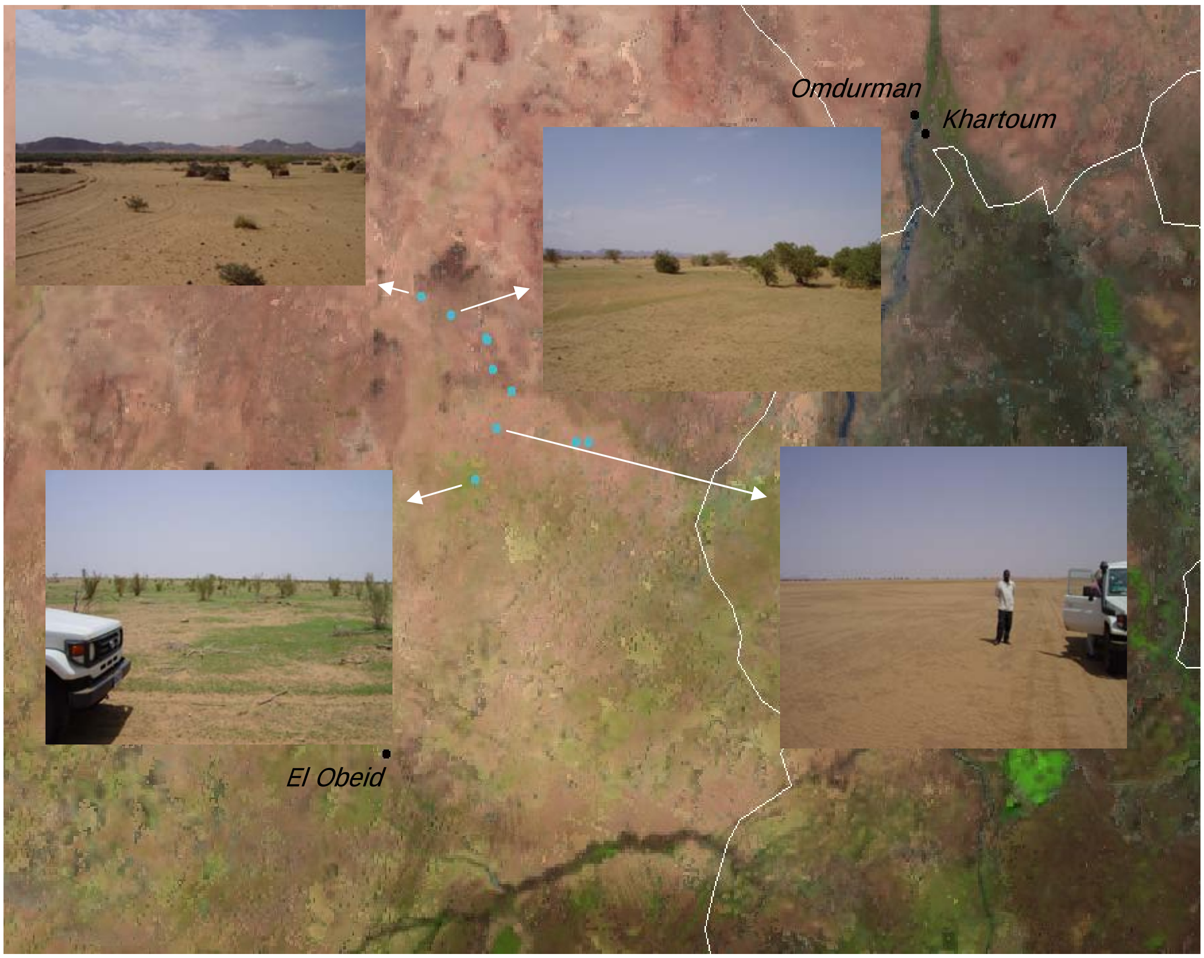


Figure 6: Integration of digital pictures geo-located with a GPS and satellite images in Sudan.

Finally, the combination of satellite images within a GIS should allow the Desert Locust Officers to produce maps for the field survey teams in order to direct them towards areas of interest and to estimate the size of infested areas to be treated. This possibility has been developed in an automatic way in order to combine satellite images with field measurements on the presence of Desert Locust. The combination of these two elements creates the tool needed to support the early warning strategy.

3. INTEGRATION OF SATELLITE IMAGES WITH DESERT LOCUST AND ENVIRONMENTAL DATA

A Geographical Information System, called RAMSES (Reconnaissance And Management System for the Environment of *Schistocerca*), has been developed by FAO Locust Group in collaboration with the Natural Resources Institute (U.K.). RAMSES is able to integrate and manage a variety of data sources within a country. It allows both the regular input of field survey data on Desert Locust, synoptic environmental parameters (vegetation, meteorological information), assessment of the current situation and planning of future field surveys. The system is a computerized application that allows the nationally designated Locust Information Officer to store, view and retrieve locust-related data for his/her country. The RAMSES application works on a personal computer using the Windows operating system with MS Access ^{TM} to manage the data and ArcView^{TM} to visualize field data and satellite images. RAMSES is used to create maps (Fig. 7) that are given to the field survey teams in order plan survey routes.

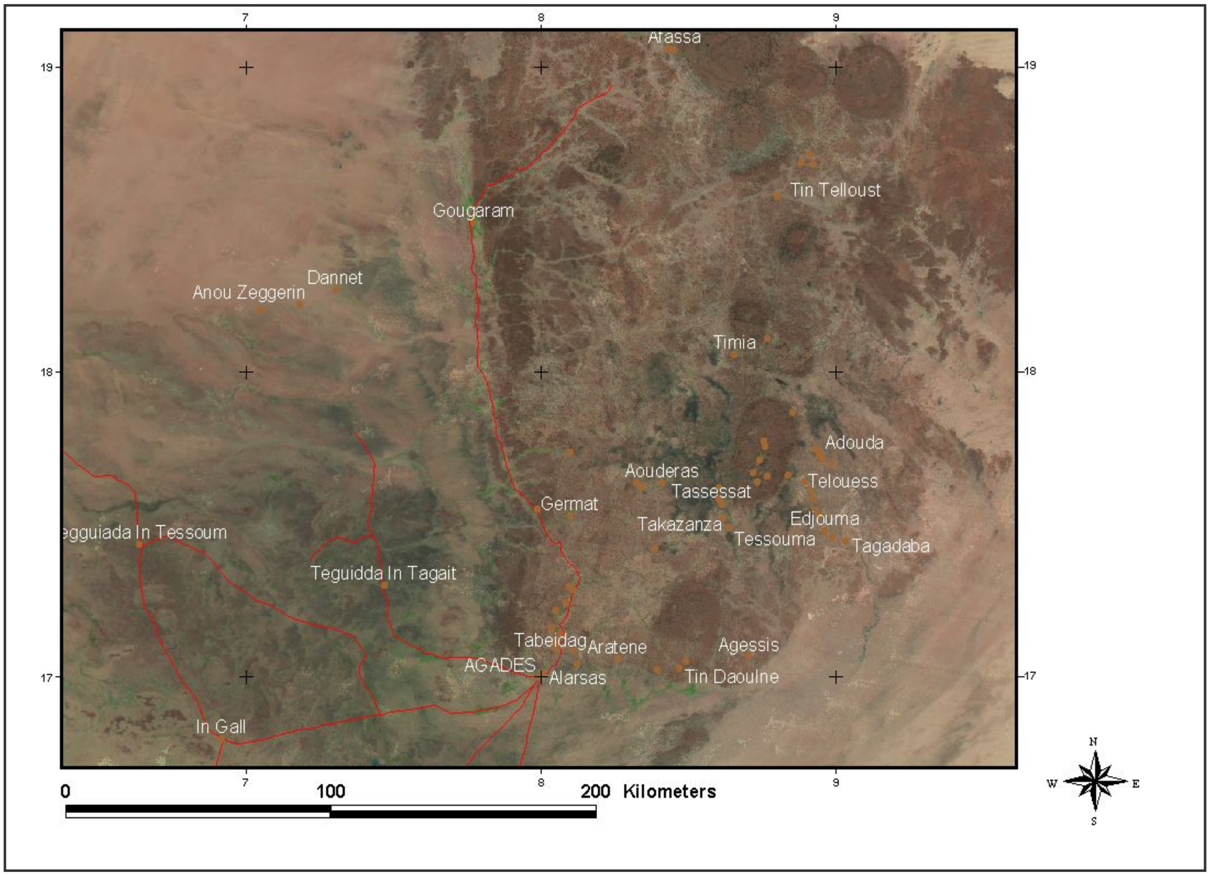


Figure 7: Map created for the field survey teams (example of Aïr region in Niger)

Once the survey team reaches the area of interest, Desert Locust and environmental data are collected and stored in an electronic form on a palm-top computer and then transmitted via HF radio modem to the national LCU. At the LCU, the data are automatically integrated into RAMSES and can then be displayed and used for analysis (Fig. 8). The resulting maps allow Locust Officers to decide the control strategy and the quantity of inputs required in terms of pesticides and material.

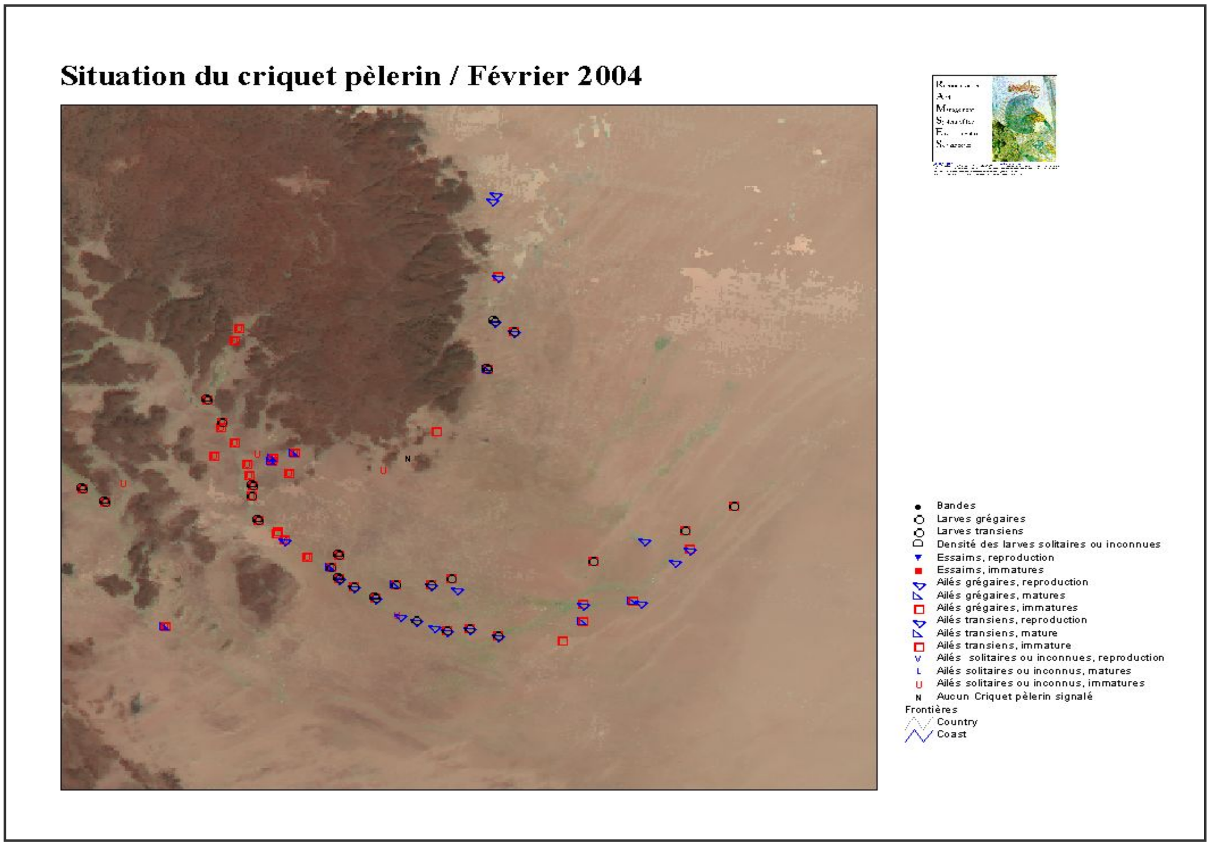


Figure 8: Map automatically produced within RAMSES showing the different stages of Desert Locust observed in the field during February 2004 and combined with TERRA-MODIS imagery.

In addition, the information on Desert Locust and the environmental data collected can be exchanged through email and displayed within each RAMSES system, thereby creating a network of information between the affected countries and FAO HQ. An automatic exchange procedure allows the information to be exchanged between English and French-speaking countries, thereby allowing each LCU to know what the Desert Locust situation is in the neighbouring countries and enabling them to take necessary actions to prepare for a possible invasion from neighbouring countries.

At the Desert Locust Information Service (DLIS), FAO HQ (Rome, Italy), all of the data collected at national levels are automatically imported into a much larger UNIX-based GIS called SWARMS (*Schistocerca* WARning Management System). Locust situation and environmental conditions in affected countries are monitored on a daily basis using output data from RAMSES systems, meteorological data and remote-sensing images. Short and medium-term forecasts are prepared indicating potential locust migrations and areas of breeding. Subsequently, early warnings are provided to affected countries of potential Locust invasions and advice is provided to the international donor community when required.

4. CONCLUSION

To avoid extended and costly control operations, it is necessary to detect Desert Locust populations at the outbreak or early upsurge stages before their populations can expand into full-scale plagues. The use of satellite images (SPOT-VEGETATION and TERRA-MODIS) combined with a Geographical Information System (RAMSES) is now operational for Desert Locust early warning. The images are routinely used to direct field survey teams towards regions with a high potential for Desert Locust infestation and to estimate control measures required. The relevant sensors were chosen because they provide frequent images of the same area, are easy to access soon after the last acquisition and are available free of charge (an important requirement considering the economic realities of the countries in the affected region). However, there is still scope for improvement in terms of frequency and resolution of the images used. In particular, higher resolution images are required in some regions to avoid omission errors in which a composite image shows the absence of vegetation when it does exist in the field.

An important characteristic of the Early Warning System is the automatic way in which it has been developed. Data is entered in the field using a palm-top computer and transferred to the country's local RAMSES database. Digital pictures may also be incorporated so that sites will not be visited if the vegetation is not likely to be hosting Desert Locust. The country databases are then networked via the Internet to neighbouring countries and to DLIS FAO HQ, thereby creating a powerful information network to allow countries to identify a potential invasion, prepare in advance to minimize its impact and provide early warning to potentially affected countries. National Locust Information Officers are trained in-country to enable them to use this powerful analysis tool and support is provided from FAO HQ. Continuing training and support is still required, however, to help officers use the newly available technologies to their fullest extent and to improve the accuracy and user-friendliness of the system.

5. REFERENCES

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