REMOTE SENSING AS AN OPERATIONAL TOOL FOR DESERT LOCUST HABITAT MONITORING: REALIZATIONS AND REQUIREMENTS

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Abstract

The Desert Locust, *Schistocerca gregaria*, is a recurrent major agricultural pest throughout Africa north of the equator, the Near East and South West Asia. Significant upsurges occur usually following a sequence of favourable rainfall, improving overall ecological conditions in remote desert areas. In these habitats, populations can build up, gregarize and become large swarms, migrating over long distances. Early detection and preventive control is the key approach to prevent damage to agro-pastoral systems. Past experience at FAO in the use of remote sensing data offers now the potential to significantly improve current forecasting methods by providing synoptic knowledge on a real time basis. FAO outlined a programme framework to achieve improvements at national, regional and global scale to optimize resources. The RAMSES programme is to establish an improved computer based system providing instant access and processing of all data essential for forecasting and for conducting cost effective and more efficient field survey and control operations. The programme will combine past achievements with improved remote sensing and GIS technology and relevant models

1. Background

The Desert Locust, *Schistocerca gregaria*, is a recurrent major agricultural pest throughout Africa north of the equator, the Near East and South West Asia. The recent plagues, from 1986-1989 and 1992-1993, demonstrated that this age-old pest is still a menacing threat. Major upsurges develop usually following a sequence of adequate rainfall, improving overall ecological conditions in desert areas and can develop into generalized plagues posing serious risks to food production and security.

Preventive control of locusts at an early stage of population development, i.e. upsurge prevention, is the current policy adopted by locust-affected countries to ensure the sustainability of agro-pastoral systems in the arid areas. Early detection of populations offers the best prospect for control in a relatively small area, thereby minimizing cost and environmental hazard. Therefore, survey and forecasting operations are a vital part in the activities of the national locust units. FAO is assisting these by operating a global forecasting unit at the headquarters in Rome.

Critical stages in potential plague development are characterized not only by population densities, but by favourable ecological conditions described in terms of rainfall, windfields, soil type and moisture content, and the vegetation (species, growth stage and cover) The immense geographical extent of the potential breeding areas and their location in desert regions which negatively affects their accessibility, are serious constraints to maintaining a routine monitoring using conventional ground and aerial surveys Moreover, the erratic characteristic of eco-climatic events, significant for locust survival and development, makes survey planning very difficult. Hence, sufficient information on eco-climatic events and locust situations often does not exist.

Satellite based information is an exploitable source providing, on a real time basis, the necessary synoptic knowledge on the status of the areas potentially favourable for locust breeding and development. By delineating such areas, remote sensing contributes to more effective and efficient use of limited locust survey and resources.

2. Realizations and present use of remote sensing

The main need for Desert Locust forecasters is information which will allow them to forecast where, when and how Desert Locust populations grow, move and decline. Apart from the required entomological information, the information set should contain environmental data, such as rainfall, air temperature, vegetation status and soil moisture Remote sensing products giving such information are routinely available at the moment. They can be regarded as first level products in the sense that their development was mainly based on centralized technical capacities and influenced conceptually by the broad spectrum of users which had to be satisfied

FAO consolidated experience and established, in cooperation with NASA Goddard Space Flight Center, the National Aerospace Laboratory of the Netherlands and the University of Reading, the ARTEMIS (Africa Real Time Environmental Monitoring Information System). This system uses high frequency environmental satellite data to produce on a ten day and monthly basis images indicating rainfall and vegetation development at a continental scale (Hielkema and van Herwaarden, 1993).

Locust forecasters have access to the following satellite image products:

- Cold Cloud Duration (CCD):
• Indicates areas of rainfall probability.
• Based on Meteosat infra-red data, convective cloud systems are detected on the basis of their top temperature, when less than -40C.
• By accumulating the hourly Meteosat data, decade and monthly CCD images are produced, showing for each pixel how many hours cold clouds have been present.

- Number of Rainfall Days (NRFD):
• Indicates the number of rainy days in a decade/month.
• A rainday is defined as a day on which cold clouds have been detected for more than two hours.
• This image gives a good impression of the distribution of rainfall over time.

- Normalized Difference Vegetation Index (NDVI):
• Indicates the amount of green biomass.
• Based on NOAA AVHRR channels 1 and 2 , 4 km resolution data.

These products have a spatial resolution of 7.6 km, meaning the smallest detail is of 58 km^2. (Hielkema, 1990).

Since 1988 locust forecasters introduced these images in their information chain to increase the synoptic aspect of the available field information. Particularly the precipitation related products, CCD and NRFD proved to be useful as a first qualitative indication of potential rain. Even to date, in many cases no meteorological information is available and the CCD is the only indication of probability of rainfall. However, reliable quantitative information on rainfall distribution is a crucial requirement since it enables the forecasters to issue early alerts and to direct field surveys. CCD doesn't give any direct information on precipitation and derived rainfall estimates are often inaccurate. It was experienced that existing rainfall estimation procedures are valid for tropical convective systems but not so much for systems over semi arid and arid areas in the lower latitudes Forecasters in Rome developed their methodology combining, in a rather manual way, field meteorological information, data obtained through Meteo-France and satellite imagery. This way, data are interpreted on a user-defined basis resulting in direct applicable knowledge. This experience will be of high value in developing better computer assisted methods for precipitation estimation.

Monitoring of vegetation status is an important asset since vegetation integrates prior climatological events. Using the NDVI images at the low resolution of 7.6 km, it became clear very soon that this level of detail was not sufficient to detect the relatively small patches of vegetation, significant for locust development, throughout the desert. Only major plant development can be detected at a late stage. This evaluation led to the use of the NOAA AVHRR High Resolution Picture Transmission (HRPT) 1.1 km resolution imagery. Such resolution allows observation of localized vegetation at a much earlier stage of development.

On a test basis, FAO received the NOAA HRPT data covering West Africa from the European Space Agency (ESA) reception station in Maspalomas, Canary Islands. A near real time data communication was established with the station by which the satellite scenes, classified by ESA in four classes (clouds, land, sea, ice), were sent by fax to FAO for direct evaluation upon which the order was confirmed. The final products, based on various orbit swaths, are produced on the ARTEMIS, taking into account the cloud masking, standard reflection calibration and maximization of pixel values. The products are available a week after the considered decade period.

This information proved very useful. A good example was obtained during the most recent plague, in the summer of 1993, when locust swarms, originating from the Red Sea coasts, were about to migrate to West Africa using the traditional prevailing easterly winds. A crucial moment is when swarms reach the Tamesna in Niger and the Adrar Des Iforas in Mali. Normal vegetation development in this time of the year would boom the populations resulting in huge plague proportions extremely hazardous for agriculture areas Forecasts were determinant in mobilizing resources and donor assistance. However, no information on these areas in Mali and Niger was available due to lack of surveys conditioned by security problems. The NOAA HRPT NDVI images indicated an abnormal absence of green vegetation over the whole of that area. Forecasts could be reviewed warning for anticipated invasions of Mauritania, northern Senegal and southern Morocco. Efforts were then, correctly, concentrated on these countries.

Full use of these data is hampered by uncertain reliability, especially in the low vegetation range with

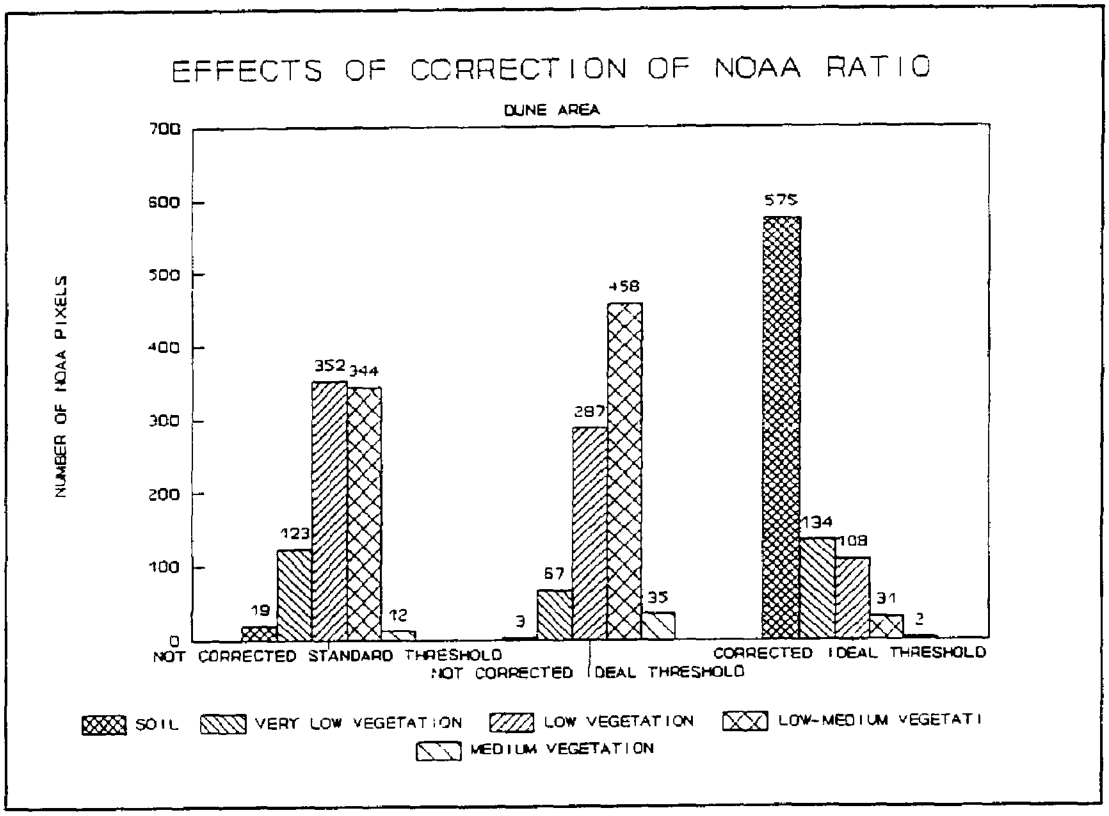

Figure 1. Statistics on correction for soil background on a NOAA 1.1 km Vegetation Index image. The area considered is a dune area, typical habitat for Schouwia vegetation. The left bars indicate the percentage of representation of each class when applying a visual defined threshold value to separate soil from vegetation (decision based on field knowledge). The middle bars are the result when applying on an uncorrected image the 'ideal threshold', e.g. a threshold value which was defined using Landsat TM, 30 m resolution, data and ground-based observations. The right bars are the results applying the same threshold but on an image corrected for soil background interference.

which locust breeding areas are associated. Soil background reflection is an important disturbing factor. Soil types however influence the NDVI in a more or less predictable way: light quartzite sands will increase the NDVI value while dark clay soils decrease the NDVI, even masking vegetation. When a single threshold is applied over a whole scene, the interpretation of vegetation is overestimated in the sandy areas and underestimated in the dark soil areas.

A study undertaken by FAO in the Tamesna area in Niger (Cherlet and Di Gregorio, 1993) proved that NOAA HRPT data, when corrected using integrated ecological information, has the capacity to adequately monitor very low vegetation cover in desert environments. A study on the spectral behaviour of plant associations and their habitat soils proved that a simple model for correction of soil background can be applied. Map units reflecting the relation between the plant associations and the pedo-morphological characteristics are then used as a spatial basis to apply the soil correction model. Doing this, thresholds at lower vegetation index values can be applied over the whole scene. If, for instance, on an uncorrected image a dune area was interpreted as 3% soil and 97% vegetation (high infra-red reflection of the light quartzite sands results in relatively high vegetation index), after the correction of the index values and applying an even lower threshold value, the same area is interpreted as 67% soil and 33% vegetation (see figure 1). This was found to conform to the observed reality in the field. The final obtained product, a 'soil'-corrected NOAA vegetation index image, proves to be more reliable and minimizes over- (as in dune areas) or under-estimation of vegetation.

3. Further requirements and future programmes

In general we can state that remote sensing products available to date have proved to be very useful for locust habitat monitoring and an even greater potential value can be envisaged. The main improvements are in the field of:

- increased data reliability, application of spectral correction models
- better data calibration, especially focused on desert areas
- further development of systematic operational applications
- operational integration with other information, using models
- improved data availability, for local locust units and the FAO global forecasting unit (specifically for NOAA data).

Figure 2 shows a flow chart for Desert Locust Assessment and Control (SAC, 1993). This is an idealized situation whereby ground surveillance is highly reduced and dependent on the forecasts solely based on remote sensing and meteorological inputs This application is however very complex and many aspects, especially for modelling, are not known. The chart model, however, forms a directive for future work.

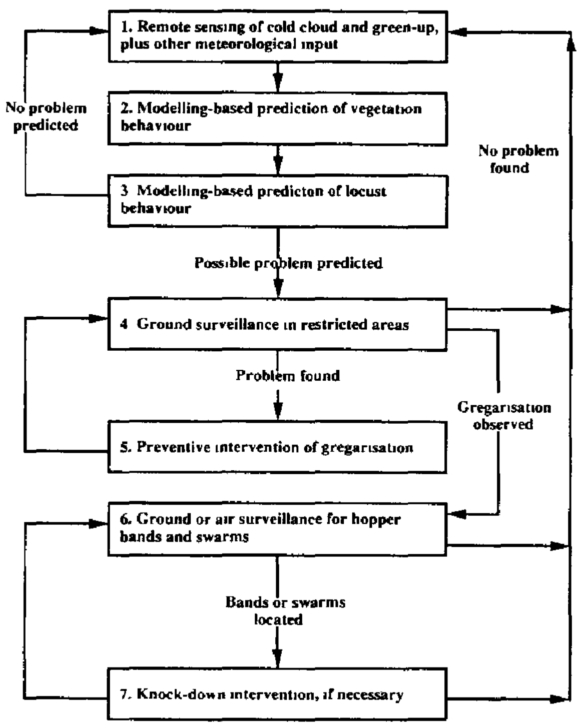

Figure 2 Flow chart for Desert locust Assessment and Control (SAC, 1993)

Based on the practical experiences and consultation with the Scientific Advisory Committee (SAC) for the Consultative Group on Locust Research (CGLR), FAO summarized the potential and further requirements for use of remote sensing for locust forecasting. Described objectives and related activities form the backbone of a programme to develop operational applications. The proposed FAO RAMSES (Reconnaissance And Management System of the Environment of Schistocerca (Desert Locust)) programme is an umbrella under which international research and development activities are harmonized and coordinated. The modular structure of the programme allows for the implementation of individual topics whilst providing an overall framework for co-ordination.

RAMSES addresses various urgent requirements, needed to enhance the operational use of remote sensing:

a. Improvement of precipitation estimation

- Specific calibration and further testing of the CCD and French EPSAT rainfall estimation procedures.
- Testing the inclusion in CCD/EPSAT procedures of alternative data (such as WMO, Global Telecommunication System (GTS), cloud differentiation, storm dynamics, NOAA Tiros Operational Vertical Sounder (TOVS).
- Development of operational evapotranspiration estimation.

b. Improvement of vegetation monitoring

- A proposed pilot phase will further assess the reliability and utility of the above described NOAA HRPT data correction in view of operational use. This project will initially focus on the Desert Locust central region, comprising the countries of the Horn of Africa. This region is often the source region from which other regions such as the Sahel and South West Asia are infested.
- Besides development of reliable detection methods for low cover vegetation, the geographic pixel accuracy of NOAA based products should be increased to allow more accurate comparisons with archive NOAA products.
- Further work is needed on operational atmospheric correction procedures.

c. Soil moisture detection

Desert Locust egg laying and successful hatching of the eggs depend largely on the soil moisture conditions in the top 12 cm of the soil. Interpretation and monitoring of soil moisture is important for judging whether, at a given time, a certain area is suitable for breeding or not.

- Development of methodologies to reliably detect soil moisture based on rainfall data or on NOAA or Meteosat data.
- Evaluation of the potential for operational application of active microwave data for obtaining soil moisture information.

d. Modelling

- Development of plant phenology and spectral models.
- Soil reflection models.
- Development of population models with improved remote sensing data as input.

In order (a) to support these activities in terms of calibration and validation, and (b) to immediately improve forecasts, the following realizations are needed:

- Development of standardized field observation methods, adapted to local survey staff and prepared in view of digital storage of the data. All observations should be geographically localized with Global Positioning System (GPS) measurements.

- Local and centralized digital databases have to be compiled. Data on entomology, ecology, meteorology and pedo-morphology should be stored with the geographic coordinates of the observation in order to link the information to thematic maps and remote sensing data.

- Improved telecommunication is a prime requirement. Satellite communication has been tested and offers a realistic possibility (Hielkema, 1990). Current possibilities, however, should be optimized.

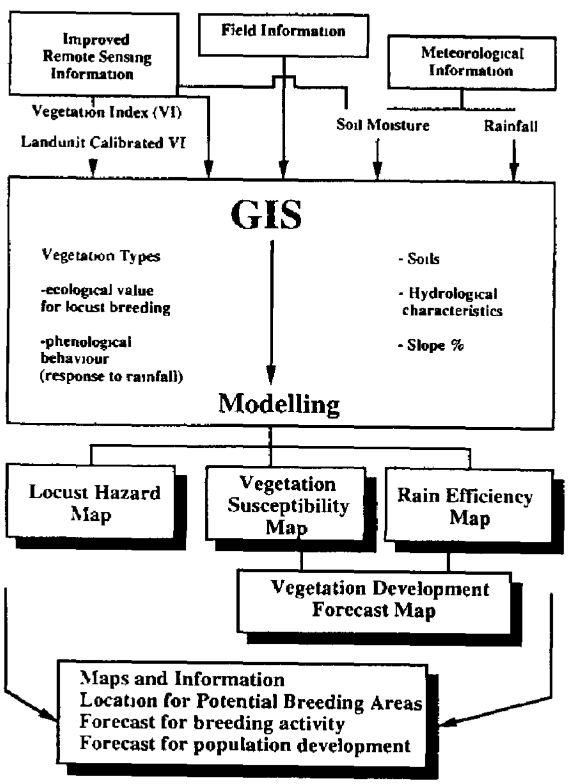

Figure 3. Flowchart for a proposal of an integrated method to apply remote sensing information for Desert Locust Habitat monitoring.

A final envisaged tool could be a PC-based system which contains all the necessary information to run models and which provides the user with simple and interactive forecasting tools. The information available will be various historical information, such as the database on archived locust sightings developed for FAO by the NRI/University of Edinburgh (UNDP Project; Healey, 1992), improved remote sensing products and field data. Remote sensing is considered a prime input in such system. Figure 3 shows a schematic proposal. It is clear that data organization, integration and exchange are key features.

Capacity building has to be provided to relevant services in locust affected countries to support and improve local locust habitat monitoring and situation forecast. Satellite data reception is now possible through low cost, user friendly and PC-based systems, adapted to field use. Initial remote sensing data processing could be done locally and secondary synoptic products, such as a 4 bit vegetation index image classified in a few classes, could be send to the FAO forecasting unit in Rome where regional information is synthesized Inter-regional forecasts are then to be sent back to the field and to the donor community for emergency assistance.

4. Conclusions

By now, remote sensing is considered to be a useful source of synoptic information, giving the possibility to monitor probable rainfall and vegetation development. Current available user products, mainly based on Meteosat and NOAA data, are operationally used to improve locust forecasts. Based on these experiences, shortcomings of remote sensing information have been defined. FAO has summarized realizations and further requirements to improve remote sensing based products and fully integrate them with other sources of information in order to increase reliability and to contribute to more automated data management and improve forecasts. To obtain practical operational results, harmonization and co-ordination of efforts is needed. The proposed FAO RAMSES programme could form a common framework, networking efforts in improving Desert Locust habitat monitoring.

5. References

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Discussion

Dr. Grimes (U. of Reading) asked if the CCD method to estimate rainfall was based on the use of single pixels. The answer was yes, events are so small there is no choice even though the results are not very reliable. Dr. Walter (NASA) asked if passive microwave sensors such as SSMI were too coarse a resolution. Little research had been done and data accessibility was far from operational. Dr. Blyth (Inst. Hydrology) suggested that ERS-1 SAR could be used to monitor seasonal variations in soil moisture.