PILOT PROJECT FOR SEASONAL VEGETATION MONITORING IN SUPPORT OF GRASSHOPPER AND LOCUST CONTROL IN WEST AFRICA

EROS Data Center
U.S. Geological Survey
Sioux Falls, South Dakota 57198

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by G. G. Tappan, T. R. Loveland, D. G. Orr, D. G. Moore,

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EROS Data Center
National Mapping Division
U.S. Geological Survey
Sioux Falls, South Dakota

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ABSTRACT

The U.S. Geological Survey (USGS)/U.S. Agency for International Development (USAID)[4/] Pilot Project for Seasonal Vegetation Monitoring in Support of Grasshopper Control was recently completed in the countries of Senegal, The Gambia, Mauritania, Niger, and Chad. Its purpose was to develop, pilot test, and evaluate a near-real-time vegetation monitoring procedure using satellite data and information system technologies for use in grasshopper and locust control programs and other applications. Vegetation greenness data were derived from NOAA satellite image data and merged with cartographic information to produce greenness maps of the participating countries. The maps were produced every two weeks through the rainy season, depicting the complex green-up and drying patterns of seasonal vegetation.

The maps were evaluated and found to be useful, contributing new information to the planning and implementation of field and aerial surveys over areas of potential grasshopper and locust infestations. Their use and evaluation was based on the principle that seasonal rainfall triggers both the growth of herbaceous vegetation, and the hatching and development of grasshopper and locust populations. The maps were used as indicators of areas with conditions favorable to their development. By concentrating on areas that were greening or already green, survey teams were able to significantly narrow down areas to be surveyed by air and on the ground.

1/ This is an internal report and has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature. It can be obtained by writing the EROS Data Center, Sioux Falls, South Dakota 57198.

2/ TGS Technology, Inc. Work performed under U.S. Geological Survey contract 14-08-0001-22521.

3/ U.S. Geological Survey.

4/ The Project was sponsored by the U.S. Agency for International Development, African Bureau, Office of Technical Resources, PASA Number AFR-0510-P-GS7022-00.

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Users identified a number of other applications of the greenness maps. These included: monitoring and mapping of seasonal rangeland conditions, guiding nomadic pastoralists to favorable grazing areas, crop condition assessment, and as an indicator of drought pockets.

This report results from the project evaluation and is based on interviews with over 70 people in over 20 different agencies. It focuses on characteristics of the greenness maps, on their utility and effectiveness, project institutionalization considerations, and management recommendations.

RESUME

Le U.S. Geological Survey (USGS) et le U.S. Agency for International Development (USAID) ont récemment complété un projet pilote dont le but est le contrôle des acridiens par l'intermédiaire de monitoring la végétation saisonnière dans les pays suivants: le Sénégal, la Gambie, la Mauritanie, le Niger, et le Tchad. Plus exactement, le propos était surtout de mettre en pied un plan directeur, développer, et évaluer un procédé de monitoring à temps réel les végétations en utilisant les données des satellites et des systèmes d'information géographique dans les programmes de contrôle des acridiens ainsi que dans d'autres applications.

Les données d'indice de végétation ont été obtenues des images des satellites NOAA. Ces données ont été ensuite amalgamées avec d'autres informations cartographiques pour produire les plans d'indice de végétation des pays en question. Les plans ainsi obtenus se seraient ensuite reproduites chaque deux semaines durant toute la saison pluviale. Les plans donnent une description de différents modelés saisonniers relatifs au cycle complexe du commencement de la verdure et de sa fin.

Les plans ont été ensuite évalues et trouvés utiles. Ils contribuent de nouvelles informations pour la planification, l'application pratique sur le terrain et dans l'air de la prospection effectuée sur des étendus de terrains tout infestés d'un grand potentiel d'acridiens. Leurs usages et leurs évaluations sont basés sur le principe qu'une pluie annuelle déclencherait la détente, végétations herbacées et éclosion acridienne, de manière que se manifestent à la fois. Les plans ont été ainsi utilisés comme indicateurs des terrains présentant des conditions favorables à la croissance des acridiens. Se concentrer sur de tels terrains qui sont en train de végéter ou bien sur ceux qui sont déjà verdoyants, les équipes de prospection ont pu en rétrécir signifiquement l'étendu, que ce soit prospection par avion ou bien au sol.

D'autres applications de ces plans d'indice de végétation ont été identifiées par ceux qui s'en servent. Entre autre applications inclues, se trouvent le monitoring et la cartographie de l'état des pâturages et des cultures; ils servent aussi comme instrument de guide pour les nomades pastoralistes indiquant les pâturages dans les lieux plus favorables; enfin comme indicateur des poches de terrain déséchées.

Ce rapport est le résultat du projet d'évaluation. Il est basé sur des interviews avec plus de soixante-dix personnes de plus de vingt agences. Ce rapport, enfin, met en relief les éléments caractéristiques des plans d'indice de végétation, leur utilité et éffectivité. Il projète des considérations de portées institutionelles et donne d'importantes recommendations aux différentes directions.

PROJECT EVALUATION SUMMARY

Product Characteristics

The products consisted of vegetation index or "greenness" maps which served as indicators of green vegetation conditions and "change" maps showing changes in the vegetation index. The maps were derived from 2-week composites of daily NOAA satellite data. One-kilometer resolution Local Area Coverage (LAC) data from the Advanced Very High Resolution Radiometer (AVHRR) of the polar-orbiting NOAA series of satellites were used to compute Normalized Difference Vegetation Index (NDVI) values that relate to the amount and vigor of green vegetation. Map coverages were produced for each country every two weeks from April to November (map production for Niger and Chad began in August and continued through November). The main findings with regard to the maps are:

A. The basic map format and design are sound. Most users indicated that the addition of more geographic information to the maps would enhance their use. In particular, more levels of administrative boundaries are needed. The addition of more towns, roads, and other features would be very helpful in navigation and directing field survey teams. Overlays of land use information would be helpful in monitoring greenness within croplands, rangelands and woodlands.

B. The greenness information was correlated with actual vegetation green-up in the field, though only qualitative assessments were made.

C. The one-kilometer (LAC) resolution of the greenness data was useful in monitoring location and patterns of green-up. This was a considerable improvement over existing sources of greenness data at eight-kilometer or one-half degree by one-degree resolution that was previously available over the Sahel.

D. The map scales are adequate for the country-wide maps, but many users would like scale enlargements of problem areas (that is, larger scale maps).

E. Both the color scheme and the number of greenness-interval classes were acceptable to most users, though some requested that the greenness scale be expanded for increased sensitivity to both low and high amounts of green vegetation.

F. Landsat-MSS data were not effective for use within the grasshopper campaign due to the time lag between the satellite overpass and the availability of the Landsat image products.

Product Utility and Effectiveness

Nearly everyone interviewed considered the maps to be useful, providing new and valuable information. Users felt the maps have considerable potential for grasshopper/locust control and numerous other applications. The general findings are:

A. The maps were particularly useful in the Sahelian zone, where rainfall is highly erratic in time and space. In this zone, the maps reflect the complex patterns of green vegetation cover as well as dry pockets during the short wet season. In the more humid Sudanian zone, the maps were useful during the initial green-up period, but less useful later in the rainy season.

B. The widespread acceptance of the maps was a result of their ease of use and understandability.

C. The most universally recommended improvement was shortening of the map delivery timeframe. Most users felt a delivery time of a week or less following map production would greatly improve the utility of the product.

D. Both the USAID missions and the Crop Protection Service agencies in the five countries used the maps to varying degrees in support of grasshopper control efforts. Specific uses included:

- Monitoring the development of green vegetation in response to rainfall to target areas necessary to survey for grasshopper infestations.

- Planning aerial reconnaissance flights to look for areas of green-up and to reduce the amount of aerial surveying.

- In Senegal, for example, the Crop Protection Service used the maps to direct field personnel to survey only in "green" areas, thus avoiding unnecessary allocation of survey resources in dry areas.

- In Niger and Chad, the maps were used to prospect for grasshoppers and locusts in the Sahelian zone. By concentrating on the "green" areas, the USAID/Niger mission was able to keep the time and expense of conducting surveys by helicopter to a minimum.

- The Crop Protection Service agencies expressed confidence in the conclusions they drew from the maps, but felt that they could make more use of the maps if they could be delivered in a more timely manner.

- The maps should have potential for directing dry season egg pod surveys, especially in the Sahelian zone. The Chad Ministry of Agriculture intends to use the maps in this capacity.

E. The maps generated considerable interest among a number of agencies for other potential applications, particularly for crop and rangeland condition assessments. These included:

- Monitoring and mapping seasonal rangeland conditions in the Sudanian and Sahelian zones. The maps provided detailed information on green-up and senescence patterns not previously available.

- The positive correlation between greenness on the maps and green ground cover permitted such agencies as the Crop Protection Services to better evaluate the extent, availability, and changes in dynamic vegetation resources.

- The Crop Protection Service of Mauritania found the maps to be indispensible as both a general indicator of rainfall between the widely-spaced weather stations, and as a tool for determining locations and distribution of green pastures. The agency made the maps available to the President of Mauritania who requested the greenness information be broadcast by radio in order to make the information quickly available to nomadic populations. This helps the pastoralists find favorable grazing areas.

- Several agencies expressed interest in using the maps to identify grasslands with high fire potential in order to take action to prevent widespread burning.

- The maps generated considerable interest in their potential application towards crop condition assessment, and the identification of deficit food production areas.

- The maps were used by several agencies as one of several information sources for preparing weekly and decadal reports on rangeland and crop condition assessments at the national level.

- The greenness information can be incorporated with other resource information to increase even further beneficial applications.

- The maps were used by the FEWS program in Mauritania as an indicator of vegetation greenness and rainfall patterns. The program regularly made use of the greenness change maps in the preparation of field reports.

Institutional Considerations

A. The general concensus among users within various grasshopper control programs, host government agencies, and regional organizations is that the project should continue with a goal of becoming operational. Several organizations expressed interest in hosting the project provided the project would continue to receive donor agency funding. The main candidates were AGRHYMET, the Ministries of Rural Development, and the Presidencies. Selection of a host organization must carefully consider the numerous actual and potential applications of the product, and the need for rapid data dissemination.

B. The cost effectiveness of the product requires further investigation. Preliminary results indicate the products are cost effective, given the impact they have on such costly operations as conducting grasshopper and locust surveys by airplane and helicopter, or conducting extensive ground survey operations. Other benefits, not readily measured by dollar values, include the improvement of rangeland resource utilization by nomadic peoples, and the early identification of drought pockets and, indirectly, populations at-risk.

C. Many agencies have expressed interest in additional training in map use and interpretation. They also felt a part-time advisor should be available in-country during critical periods to provide technical assistance.

Recommendations

A. The concensus is the greenness mapping program should continue in the five countries involved in the Pilot Project. A number of users recommended that this activity should be expanded to include all of the Sahelian countries.

B. The map delivery time should be shortened to a week or less following the production of each map cycle. Several options for accomplishing this need investigation.

C. Minor deficiencies in map content should be remedied, including the addition of more locational information. Expansion of the greenness scale should be considered.

D. The maps should be integrated with other resource data information, using geographic information system technologies.

E. Host government agencies should be approached for coordination of continued greenness mapping activities.

F. Future project plans should be integrated with plans for NRMS, FEWS, and AGRHYMET.

G. Follow-on activities should work toward technology transfer, providing continued in country technical advice during critical seasons, and in-country satellite data reception for improved data dissemination.

H. Documentation of cost-savings as a result of decisions based upon greenness maps should be a major objective of follow-on activities.

1.0 Introduction

Large grasshopper populations plagued West Africa with the return of near normal rainfall in 1985 and 1986. The Senegalese grasshopper, Oedaleus senegalensis, threatened cropland in a number of Sahelian countries, and the U.S. Agency for International Development (USAID) and other donors mounted an emergency assistance program for grasshopper control. Major infestations of Senegalese grasshoppers were predicted for the 1987 rainy season, and USAID prepared for another major campaign in West Africa. A major goal of the program was to improve grasshopper prediction and survey techniques. The ability to monitor the distribution and growth of natural and agricultural vegetation in the Sahel is an integral part of grasshopper control efforts. For these reasons, the Bureau for Africa of USAID requested that the U.S. Geological Survey (USGS) conduct a pilot project to develop, test, and evaluate a near-real-time monitoring procedure using satellite data and geographic information system technologies in support of the grasshopper control programs.

This final report was prepared by the EROS Data Center of the U.S. Geological Survey to satisfy the requirements set forth in the PASA (AFR-0510-P-GS7022-00, Project Number 698-0510-95) between the U.S. Agency for International Development and the U.S. Geological Survey. The report outlines procedures, products, and an evaluation of the Pilot Project for Seasonal Vegetation Mapping in Support of Grasshopper/Locust Control in Senegal, The Gambia, Mauritania, Niger, and Chad.

2.0 Objectives and Scope of Pilot Project

The project objectives were to develop, test, and evaluate a near-real-time monitoring procedure using satellite remote sensing and geographic information system (GIS) technologies for support of grasshopper and locust control programs in West Africa. Inherent in this goal was the need to format and present information for acceptance and use by decision makers and grasshopper control technicians. This information was presented in the form of vegetation index or "greenness" maps for each two-week period through the potential grasshopper season. The maps were evaluated to determine their utility within the operational framework of the 1987 grasshopper and locust campaigns in Senegal, The Gambia, Mauritania, Niger, and Chad (Figure 1).

Figure 1.--Near here.

2.1 Project Tasks

The project was conducted in two phases. Under Phase I, the products were developed, delivered, and tested through field training and control operations. Phase II was an evaluation of the acceptance and uses of the procedures and products. Specific tasks included the following:

Figure 1. The Sahelian countries and map coverages of the Pilot Project.

Phase I: Pilot Test

1. Field train responsible host country decision makers and technicians involved in grasshopper control programs in the characteristics and potential uses of the products.

2. Define desired information contents and formats of test products.

3. Establish logistical procedures for delivering thematic maps to the field, obtaining necessary data, and producing the required products through image processing and GIS technologies.

4. Produce and deliver thematic maps every 14 days that indicate vegetation conditions including current greenness and greenness change. Beginning in April, two map coverages were produced: Senegal/Gambia, and southern Mauritania. In August two additional coverages were added in response to a locust emergency: Niger and Chad.

5. Establish and implement a simple geographically based cabling procedure for rapid transfer of information that identifies potential grasshopper areas as observed by EROS analysts.

6. Provide up to 12 selected Landsat multispectral scanner (MSS) scenes to field personnel on an as-needed basis.

7. Establish procedures and demonstrate a method to assess the area of apparent grasshopper damage for a selected site within one country.

8. Provide an in-country expert for three months during the pilot test. The expert will be based in Senegal and available on an on-call basis for Mauritania and The Gambia.

Phase II: Evaluation

The evaluation was conducted at three levels: (1) in Senegal where a technical expert was based during the three months of pilot test; (2) in Mauritania and The Gambia where only short-term training and advice were provided; and (3) in Niger and Chad where in-country technical assistance was not provided. The evaluation concentrated on the adequacy of the map products, on the product utility and effectiveness within both grasshopper/locust control programs and other programs, and on institutional considerations.

2.2 USAID Information Requirements

In 1986 and 1987, USAID provided emergency assistance for grasshopper and locust control in a number of sub-Saharan countries. USAID assistance to the various insect control campaigns was channeled in several ways, including technical assistance, training, prediction and survey operations, equipment support, and supplies. The successful execution of each phase of a control operation is required to ensure a successful campaign. Monitoring and early warning systems are essential components of effective control programs. One of the lessons learned during the 1986 and 1987 Sahelian campaigns was that adequate and timely monitoring of the environment is needed in order to plan efficient ground and aerial surveys to locate and control migratory pest populations in their early stages of development. In particular, monitoring systems should provide information to grasshopper/locust control teams, which will allow them to:

- predict locations and magnitudes of potential pest populations.
- survey areas likely to harbor significant grasshopper/locust populations as a result of favorable environmental conditions.

The prediction and survey of grasshopper/locust populations depend on analyses and syntheses of several major data sources. Traditionally, these have included historic records on pest occurrence, weather patterns, historic rainfall, current rainfall, egg pod occurrence, biological models, and other inputs. In the vast Sahelian and Saharan environments, these data are often inadequate or unavailable. In recent years, the use of satellite data for monitoring vegetation conditions has added another dimension towards improved environmental monitoring of these large areas. Following the 1986 grasshopper campaign in West Africa, USAID and other donors called for improving systems of survey and early warning in control operations. This pilot project was, in part, an outcome of these recommendations.

2.3 Host Government Information Requirements

Grasshopper and locust monitoring and control activities within the countries of Senegal, Mauritania, The Gambia, Niger and Chad are the responsibility of the crop protection services in each country. These agencies oversee all aspects of crop protection. Monitoring environmental parameters that affect the general health of croplands is one of their major tasks. This includes survey and control of insect species which may have a significant economic impact. Typically, these agencies are faced with the problem of relying on poor communication networks and widely scattered field reports in order to assess pest situations over large areas. Although communication networks have improved in the last two years with donor procurement of radios and other equipment, there remains a critical need for uniform, rapid monitoring of weather and vegetation conditions that trigger the hatching and development of pest populations. Information needs of host country agencies parallel those of the USAID technical assistance teams.

3.0 Overview of the Senegalese Grasshopper and the Desert Locust

This section provides a brief overview of the grasshopper situation in West Africa in 1986 and 1987, and a short description of the Senegalese Grasshopper and the Desert Locust, two economically important species of Acrididae, which have been the focus of the control campaigns of the last two years.

3.1 Migratory Grasshopper/Locust Situation

Grasshoppers and locusts have had major impacts upon natural and agricultural vegetation in Africa. In 1986, a major reappearance of these pests occurred in West Africa with the return of near normal rainfall. Of particular concern was the return of Oedaleus senegalensis, the Senegalese Grasshopper, which is the major insect pest in the region. Damage to food crops in 1986 was reported in parts of Senegal, Mauritania, Gambia, Mali, Burkina, Niger, and Chad (FEWS, 1987). The greatest aggregate losses in production occurred in Niger, Senegal, and Mali. In terms of the potential harvests that were directly affected (lost or saved by control efforts) by the infestations, Mauritania had the highest level, followed by Senegal and Niger. While these infestations were considered to be severe at the time, later examinations of the data indicated that actual damage was less than feared, and that the infestations did not exceed the "normal realm of experience" in these countries (FEWS, 1987). However, the lack of historical data makes it difficult to judge the severity of the 1986 infestations with respect to other years.

Monsoon rains in 1986 also produced considerable increases of non-swarming Desert Locust populations in parts of the northern Sahel (FAO, 1987). In Mali and Niger small gregarious swarms were reported, and this led to gregarious breeding in October. The breeding became fairly extensive, spilling into Mauritania in November. Although control teams were able to treat the main infestation sites, the residual population at the end of 1986 was significant.

Despite the predictions for major infestations of grasshopper populations in the western Sahel in 1987, actual populations (particularly Oedaleus senegalensis) were limited. Localized pockets were found and treated in Senegal. In Mali and Mauritania, the situation was generally calm, though a serious outbreak occurred on their common east-west border in September. Some localized damage to cropland occurred before control efforts were carried out in October. In the central Sahel, infestations were more serious. In Niger, a rather large infestation of O. senegalensis occurred in the late rainy season in the south-central part of the country. This population threatened the already marginal agricultural areas which suffered from poor growing conditions (FEWS, 1987). Chad also experienced grasshopper problems, generally in the south.

Desert Locust populations in 1987 were reported in July in northeastern Chad following heavy rains and vegetation green-up in the area. Breeding continued through August to November in Chad and Niger producing several successive generations. Large-scale migrations were tracked into northern Mali and Mauritania and into Algeria and Morocco. Control operations have been limited (except in Morocco), and the situation could develop into plague proportions in 1988 (FAO, 1987).

3.2 The Senegalese Grasshopper

The Senegalese Grasshopper, Oedaleus senegalensis, is one of the most economically important species of acridids in the Sahel. They do not swarm the way locust do, but they can attain high densities and migrate on the wind, inflicting heavy damage on food crops.

The distribution range of O. senegalensis corresponds to a band across Africa corresponding roughly to the Sudanian and Sahelian zones, but also reaching south into Tanzania. The band falls within the area receiving roughly 250 mm to 1000 mm of annual rainfall. Launois (1979) identifies three subregions in West Africa which describe the migration of the grasshopper through the wet season (Figure 2). The three areas are: (1) the area of

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Figure 2.--Near here.

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initial multiplication, in the Sudanian zone, where the first generation hatches and develops with the first rains in April and May (750 to 1000 mm rainfall); (2) the transitional area of multiplication, which lies to the north, in the Sudano-Sahelian zone where rainfall averages 500 to 750 mm annually. First generation grasshoppers from the southern zone migrate into this transitional area with the advancing rains. Here, the first generation may breed and subsequent hatching and development produces a second generation, typically in June and July; and (3) the northern area of multiplication, which falls roughly into the Sahelian zone, with rainfall of 250 to 500 mm. Migrating grasshoppers from the first and second generations can produce a third generation in August and September. As rains diminish in this northern area and conditions become increasingly dry, the grasshoppers migrate back into the transitional and initial multiplication areas in October and November, laying egg pods as they migrate. The eggs enter into diapause dormancy in the dry season. A rain of 25 mm or more is generally needed to trigger a hatch. Development rates and migration patterns are determined by environmental conditions including moisture, temperature, vegetation conditions, photoperiod, grasshopper population levels, and accessibility to the biotope (Launois, 1979). There have been attempts to create a forecasting model for this species that predicts the timecourse for migration based on the above conditions (Launois, 1978).

O. senegalensis prefers to lay its eggs in light, sandy soils. They are found in open vegetation formations including shrub and tree savannas. They feed primarily on grasses, often moving into adjacent food crops, particularly millet and sorghum. The strategy of the USAID grasshopper teams has been to control the first generation of _O. senegalensis_ before it migrates into croplands and other breeding areas.

3.3 The Desert Locust

The biology and range of the Desert Locust, _Schistocerca gregaria_, is markedly different from that of the Senegalese Grasshopper. In the summer, the breeding and distribution range extends in a wide band across Africa within the Sahelian and southern Saharan zones. The range also covers Ethiopia and the Arabian Peninsula. Swarms migrate from the breeding grounds into Asia and westwards across Sahelian Africa into northwestern Africa (Mauritania, Morocco, Algeria). In winter, breeding is concentrated in the Somali peninsula and along the Red Sea (Sudan and Ethiopia). Most of the resulting swarms move south into East Africa.

Females can lay eggs up to three times in their lifetime. The eggs are deposited in sandy or silty soils, and if the soil is moist, the eggs may develop without going into dormancy. Otherwise, rainfall of 20 to 25 mm triggers egg development. This amount of rainfall also initiates ephemeral vegetative growth. Once the locusts reach adult stage, they fly in search of additional favorable habitats for continued breeding. If environmental

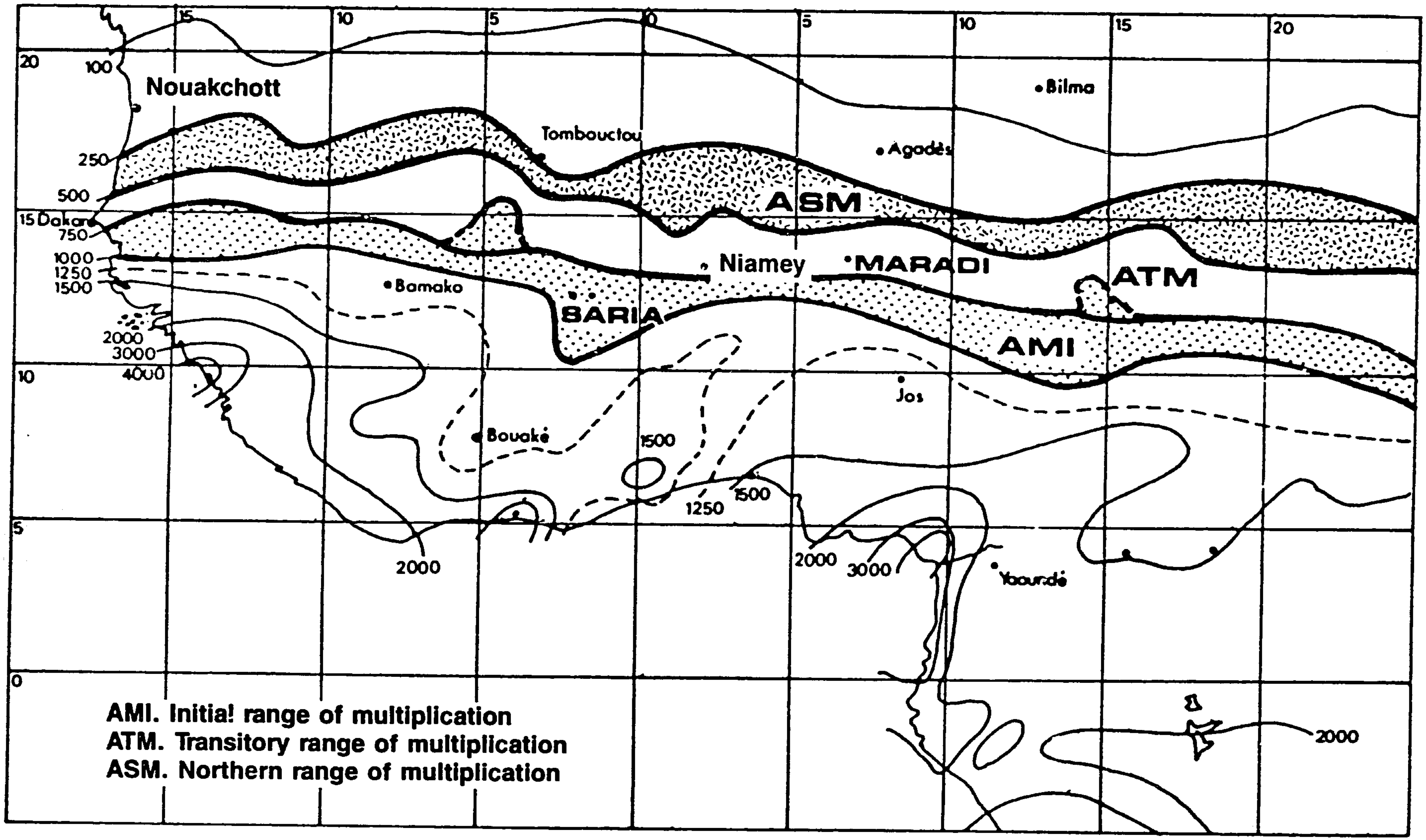

Figure 2. Distribution and breeding ranges of the Senegalese Grasshopper ***(Oedaleus senegalensis)***. *(Source: Launois, 1978).*

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conditions are suitable, locusts may swarm, and moving with the wind, may travel up to 200 km a day. They feed on a broad range of plants, and feed readily on the grass-related crops. Survey and control of the Desert Locust has always been difficult due to their ability to migrate long distances in short periods. The use of meteorological information has traditionally been the main method of tracking and forecasting of locust populations.

4.0 Description of the Technology and Products

During the six-month period of Phase I of the Pilot Project, image and map products were delivered to the field and tested for use in the grasshopper/locust control efforts. Training and technical assistance was also provided. This section presents an overview of the NOAA satellite system, the processing of the image data, a description of the map products, and the level of training and assistance provided to the data users.

4.1 The NOAA AVHRR System

The NOAA TIROS-N series of polar-orbiting satellites, carrying the AVHRR (Advanced Very High Resolution Radiometer) sensor, has been in operation since 1979. NOAA-9 data (the satellite was launched in 1984) were used for the present study.

NOAA-9 orbits at an altitude of 833 km, and crosses the equator at 1430 local time. The instantaneous field of view or "resolution" of the AVHRR is 1.1 km at the nadir track. The data are referred to as Local Area Coverage (LAC) data. The swath width of a scene is approximately 2400 km, but the useful portion of a scene is less, due to distortion at the edges of the image.

The sensor channels on NOAA-9 are:

Channel	Spectral Response (micrometers)	Spectral Region
1	0.58 - 0.68	visible
2	0.725 - 1.10	near infrared
3	3.55 - 3.93	middle infrared
4	10.30 - 11.30	thermal infrared
5	11.50 - 12.50	thermal infrared

Data from channels 1 and 2 are used for computing a vegetation index. Channel 4 was used in identifying and removing cloud-contaminated data.

The satellite can potentially obtain twice-daily (one mid-day and one mid-evening) coverage of any given geographic area. However, when the satellite is out of range of a ground receiving station (for example, parts of Africa), the LAC data are first recorded with an on-board recorder and then transmitted when the satellite is in view of a reception station. Competition for time on the recorder is high, so requests for data recording time is reviewed by NOAA and scheduled to accommodate as many users as possible. Data are received at one of three NOAA ground stations in the United States, and archived at the World Weather Building of NOAA 5/ (Kidwell, 1986).

4.2 Data Flow and Processing

The images were recorded by the satellite (NOAA-9) and transmitted to the National Climatic Data Center where the data are converted from wide-band video to computer-compatible tapes (CCT's). Approximately three images per week were sent for each test site. The CCT's were then sent to the EROS Data Center (EDC) via DHL Express mail. Each scene was ingested into the AVHRR Data Reception and Processing System (ADAPS) and previewed for cloud cover and to see whether the study area fell into the usable (central) portion of the scene. Scenes that passed this initial screening were processed further by ADAPS. The visible and near-infrared channels were calibrated, registered to a map base, and then used to compute the normalized difference vegetation index (NDVI).

Calibration converts the raw data counts into albedo using prelaunch calibration coefficients. The images were registered using an approach that aligns image features, such as rivers or coastlines, with computer maps of the same features. Transformations were applied to register the rest of the image (Boyd, 1987). Figure 3 is an example of a registered AVHRR image of West

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Figure 3.--Near here.

Africa. The NDVI was computed from the calibrated channels 1 and 2 using this formula:

$$\left(\frac{\text{Channel 2} - \text{Channel 1}}{\text{Channel 2} + \text{Channel 1}} + 1.005 \right) * 100 = \text{NDVI}$$

The NDVI is a data transformation that combines visible (Channel 1) and near-infrared (Channel 2) spectral data into a single variable, which is strongly correlated to amounts of green vegetation cover and green biomass (Deering and Haas, 1980). The NDVI image was then entered into the Land Analysis System (LAS) image processing system, and and a mask was generated for the areas hidden by clouds. This was done manually at first by visually determining a temperature threshold level in channel 4, which distinguishes between cool clouds and the warm land surface. Later, a combination of channels 1 and 4 were used to generate the cloud mask.

5/ The archived LAC data can be obtained by contacting: National Climatic Data Center, Satellite Data Services Division, Room 100, World Weather Building, Washington, D.C. 20233; Telephone: 301/763-8111; Telex: 24836.

Figure 3. A NOAA-9 AVHRR image of West Africa acquired on March 26, 1987.

As the season progressed, the vegetated land surfaces (cooler) could not be precisely separated from clouds with a simple threshold of the thermal data. In the visible channel, vegetation is dark, while clouds remain bright. The cloud mask was multiplied with the NDVI image with the result that cloudy areas in the NDVI image were removed.

The daily cloud masked NDVI images available for the two-week period were combined to generate a single composite scene. At any location, the maximum NDVI value over the two-week period was retained. In this way, areas obscured by clouds were filled in. At the end of each two-week cycle, the previous greenness composite image was compared with the current cycle to generate a change image. Finally, the change image and the current greenness composite was combined with other map data (described below) to produce the final vegetation index or "greenness" maps, which included locational information.

4.3 Vegetation Index Map Products

Vegetation index or greenness maps depicting the distribution and relative amounts of green vegetation were the primary products. They were produced every two weeks using a composite image of the satellite data to show current vegetation conditions. The map coverages were Senegal/Gambia, and Mauritania (produced from April to November), and Niger and Chad (July to November). In addition, change maps were produced for Senegal/Gambia and Mauritania to show areas of increasing or decreasing greenness and areas where no significant change occurred.

4.3.1 Map Formats

The maps contained locational information such as international and provincial boundaries; primary, secondary, and third order roads; cities and towns; and latitude/longitude tick marks. These features were taken from Operational Navigation Charts (ONC's) and Michelin road maps (Figure 4). The

Figure 4.--Near here

maps were geographically registered so geographic coordinates could be determined for any map location. Map scales were determined by the size of the area to be shown and the maximum paper size (34 x 22 inches) handled by the ink-jet plotter. The Senegal/Gambia map was plotted at a scale of 1:1,000,000; the southern half of Mauritania at 1:1,500,000; and Niger and Chad at 1:2,500,000. In addition, enlargements for critical areas of Niger and Chad were plotted at 1:1,000,000 and 1:1,500,000, respectively. Text for each map was presented in both French and English. All of the locational map information was processed using ARC/INFO geographic analysis and plotting software. Using this software, the map information and text were processed and arranged into a map "collar," including all of the locational data, legend, and text. The final maps were created by combining these data with the satellite-derived greenness information (Figures 5-8).

Figures 5-8.--Near here.

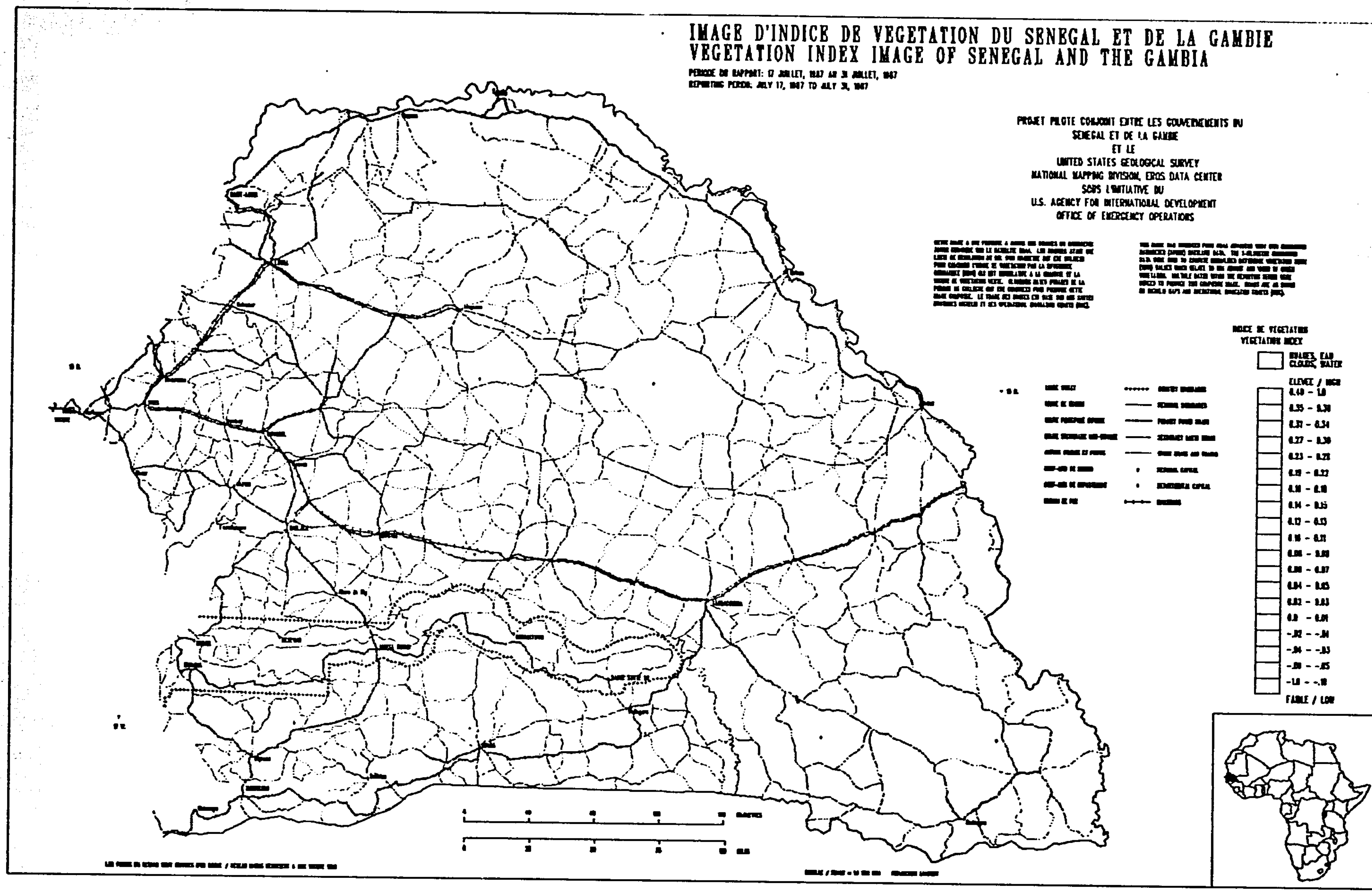

Figure 4. An example of the map information from the geographic database which is then merged with the NOAA image information to produce the final maps.

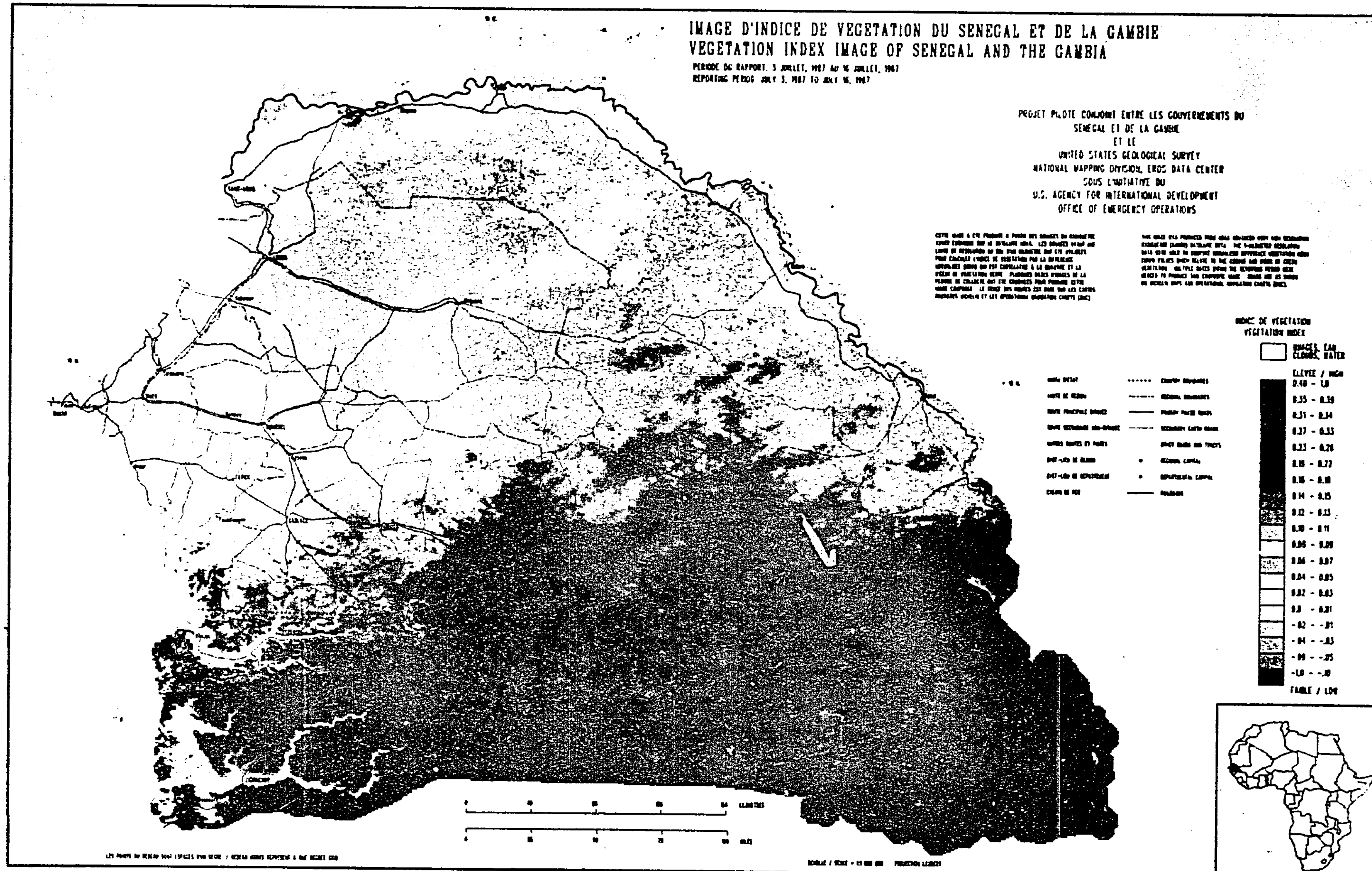

Figure 5. An example of one of the Vegetation Index Maps of Senegal/The Gambia. The map indicates maximum greenness during the July 3 to July 16 period of 1987.

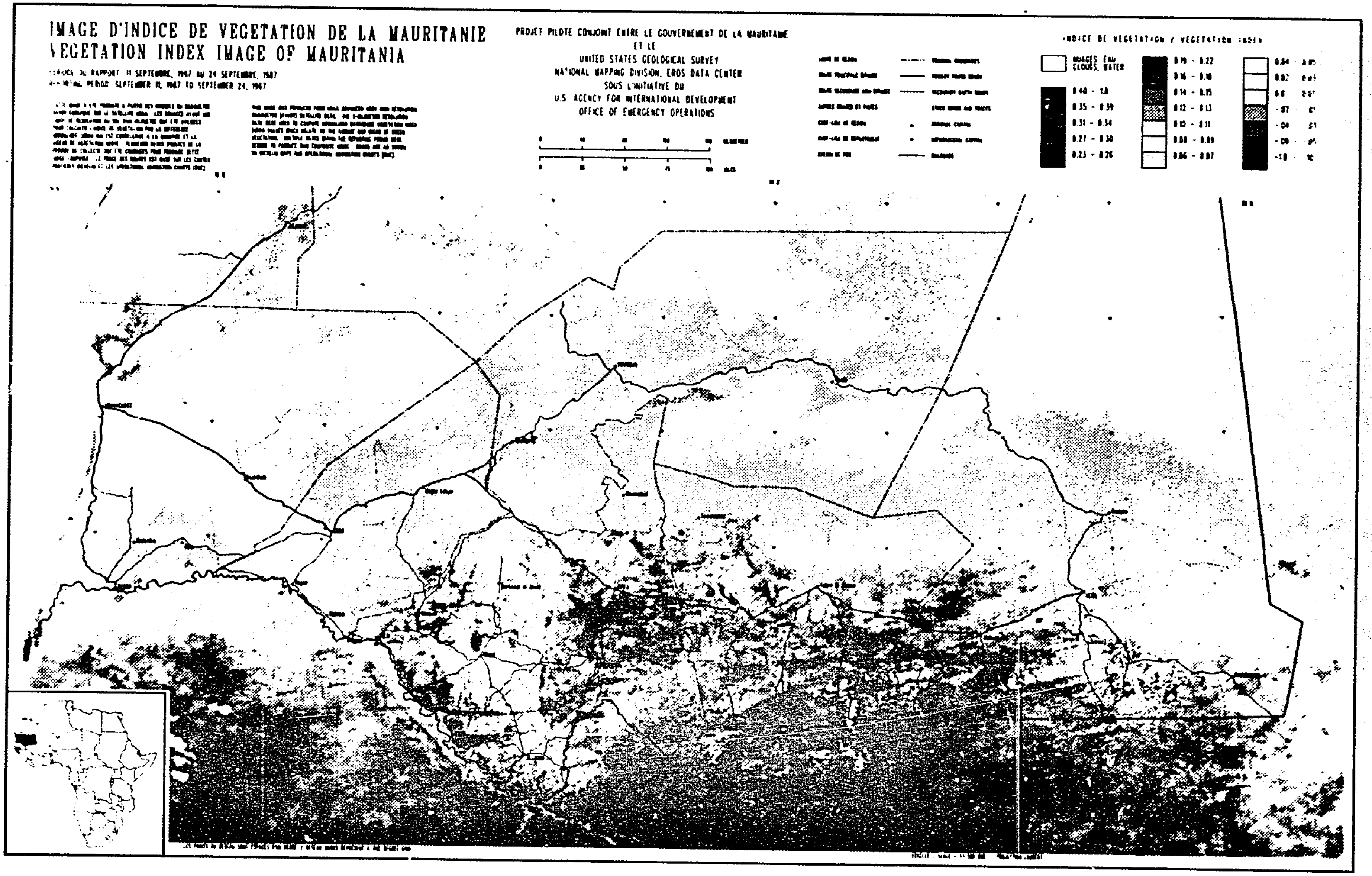

Figure 6. An example of one of the Vegetation Index Maps of Mauritania. The map reporting period is September 11 to 24, 1987.

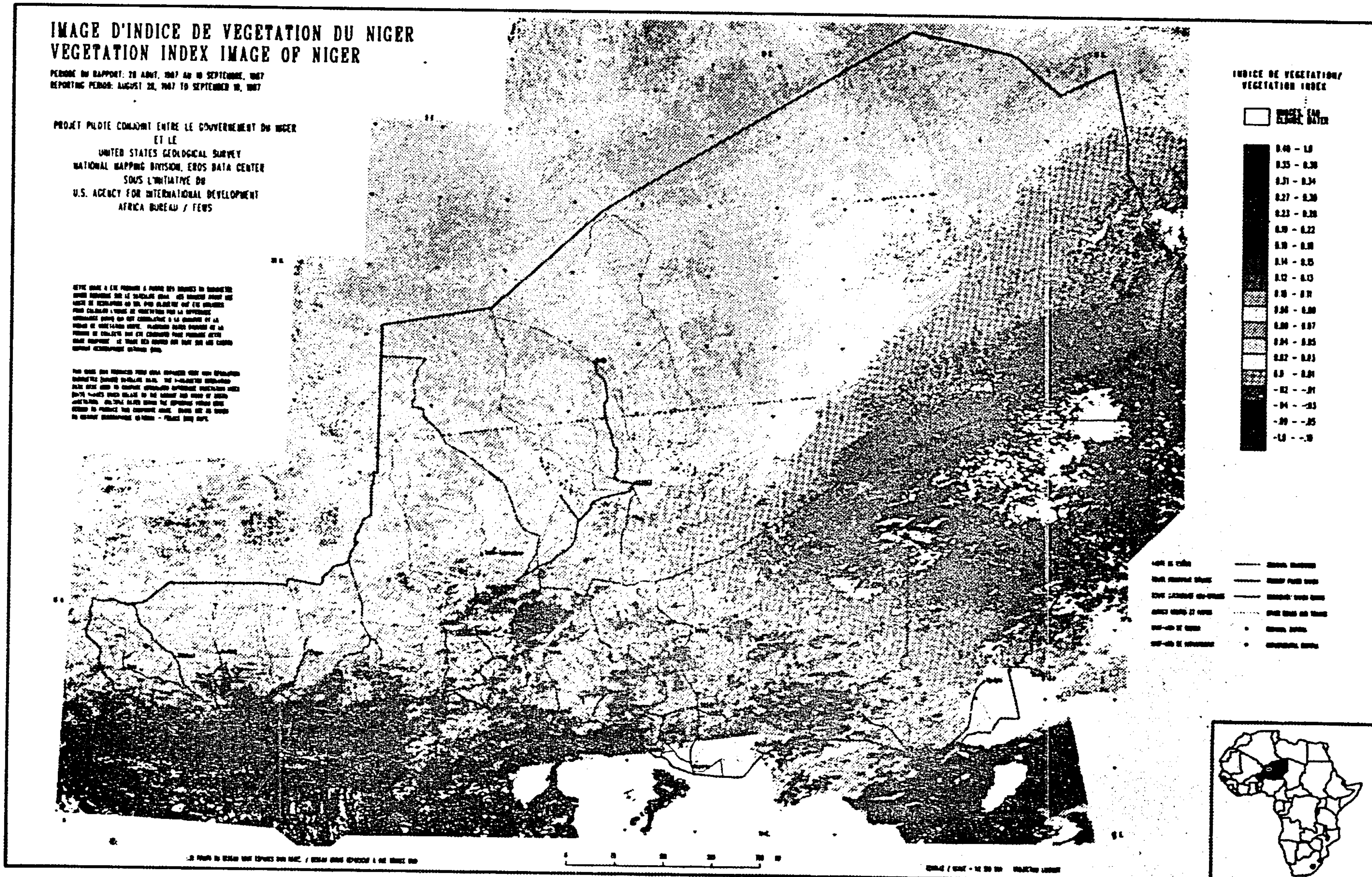

Figure 7. An example of one of the Vegetation Index Maps of Niger, from the period August 28 to September 10, 1987.

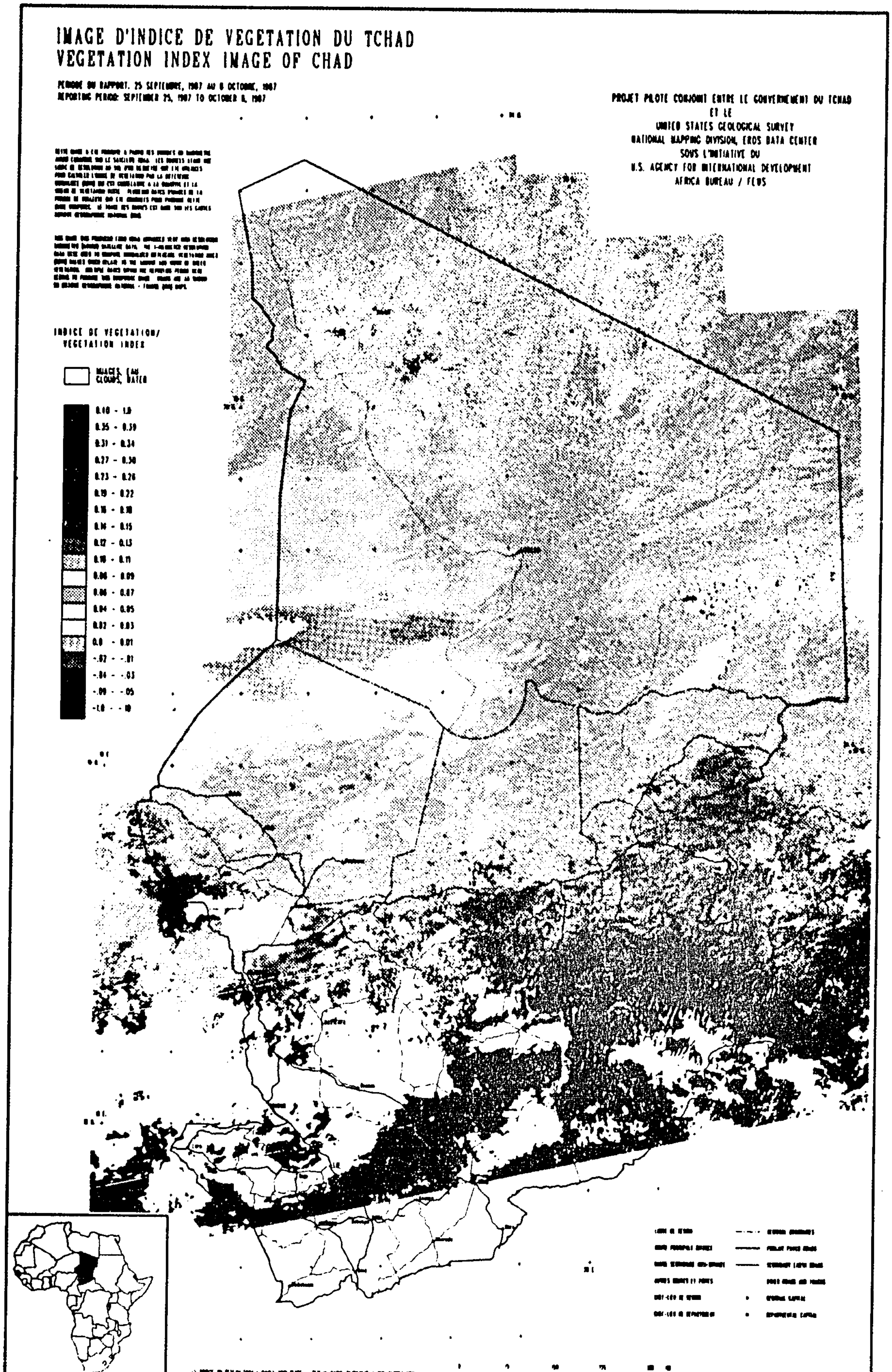

Figure 8. An example of one of the Vegetation Index Maps of Chad, from the period September 25 to October 8, 1987.

4.3.2 The Greenness Maps

Since the intent of the greenness maps was to show the distribution and relative amounts of photosynthetically-active green vegetation, a color legend was developed to depict this information in a way that would be intuitive to the map user. Areas with little or no green vegetation were displayed in shades of orange and yellow. Areas with differing amounts of green vegetation were shown in various shades of green. Those areas with high levels of "greenness" were displayed in darker shades of green. Maximum greenness values were shown as dark blue. Areas obscured by clouds were shown in white. Twenty greenness classes were displayed in color on the greenness maps: one for clouds, eight for non-vegetated areas, and eleven for vegetated areas. The satellite-derived greenness data were thus color-coded and then combined with the map collar information into a single file for plotting on the color ink-jet plotter. The paper map products were laminated for protection.

4.3.3 The Change Maps

The digital processing of map-registered satellite data allowed the generation of difference or change maps (Figure 9). The composite image from

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Figure 9.--Near here.

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the preceding two-week reporting period was digitally subtracted from the current composite image. Areas with no change were shown in yellow, areas with decreases in greenness were displayed in five shades of orange, and areas with increases in greenness were shown in five shades of green. The greater the difference the darker the shade. Again, when present in either image, clouds were shown as white. The color-coded difference image was then combined with the map collar data to form a single plot file. The change maps were also laminated for protection.

4.3.4 The Reference Grid Overlay

A method to identify specific areas of interest upon the maps and communicate this information between EDC and the map users was desired. A grid of "blocks" and "cells" based upon latitude and longitude was devised for Senegal/Gambia and Mauritania. Blocks were one degree by one degree, and numbered consecutively. Cells were ten minutes on a side and numbered 1 through 36 within each block. Thus, any geographic locale within the study area could be uniquely identified, for example: block 15, cell 3. More precise locations within a cell were related with terms like "center", "northwest", etc. The grid and country boundaries were plotted on clear mylar and used as an overlay for the greenness or change maps. Using this grid overlay, areas of interest including the latest greenness information were communicated to the field via telephone and telex.

4.4 Product Deliveries

At least four copies of each map product were delivered to the USAID Mission in each country. An air-express courier (DHL) was used to transport and deliver the maps from EDC to the field. Delivery time was typically 4 to 8 days.

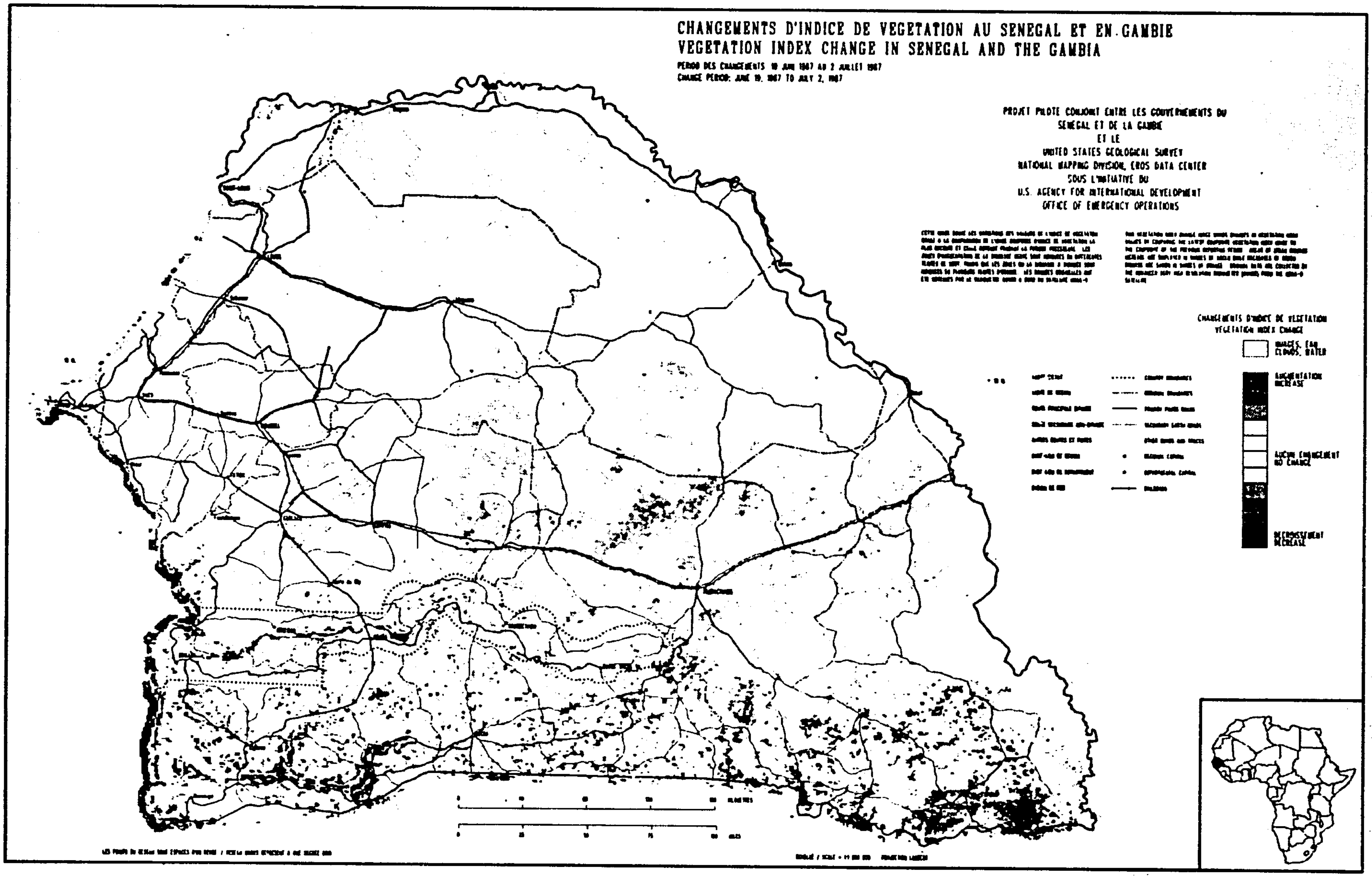

Figure 9. An example of one of the Vegetation Index Change Maps of Senegal/The Gambia. The map indicates changes in greenness values between June 19 and July 2, 1987.

4.5 Training and Technical Assistance

Workshops were offered to USAID mission staff and host country technicians and authorities involved in grasshopper control programs. Two-day workshops were conducted in the Gambia, Mauritania, and Senegal in the June/July timeframe. In September, two additional workshops were given in Senegal to OCLALAV (a regional locust control organization) and to the Department of Agriculture. The workshops introduced the concept of satellite-based vegetation mapping and monitoring, and covered map product characteristics and potential uses and limitations of the products for grasshopper/locust control and other applications.

Technical assistance was provided to the USAID missions, to the crop protection services, and to other interested agencies in the use of the greenness maps. This assistance was limited to Senegal, The Gambia, and Mauritania. It consisted of an in-country expert from the EDC for a total of three months during the Sahelian rainy season, and one expert from EDC for one month to assist with the workshops. The technical assistance team was based in Dakar, Senegal, and was available on an on-call basis for the other two countries. During this period, two trips were made to Mauritania for a total of 20 days, and one trip to The Gambia (5 days). The team also spent a limited period in the field with USAID grasshopper control teams, and participated in collecting field data on vegetation condition, insect populations, and testing the field use of the greenness maps.

5.0 Evaluation of the Pilot Project

The evaluation of the pilot project is based upon the findings of a three-person evaluation team which visited all five participating countries. The team responsibilities were divided such that two evaluators visited Senegal, The Gambia, and Mauritania (the countries that received training and technical assistance), and one evaluator visited Niger and Chad. Collectively, the evaluators conducted interviews with over 70 people in over 20 different agencies. The evaluation focused on characteristics of the greenness maps, on their utility and effectiveness, and on institutional and management considerations.

5.1 Map Product Characteristics

The first set of evaluation criteria dealt with product characteristics, particularly map format, design, information presented, level of detail, and scale.

5.1.1 Map Format and Content

The basic map format and design were considered good. The integration of geographic/locational data with greenness image data was effective in making the product useful. Many users expressed the need for additional geographic/locational detail on the maps. In particular, the addition of more towns and political divisions is needed because various government organizations assess and report vegetation conditions on the basis of political divisions. The maps should include divisions one or possibly two levels below that of the "region" or "prefecture". Other locational features suggested include airports, wells, roads, wadis, and features generally useful for navigation. Furthermore, overlays with land use and soils information would be useful for monitoring greenness within specific land uses.

Users felt the depiction of greenness information outside of the country borders was useful, particularly in the case of Mauritania. It was important to know the position of the green-up wave to the south in order to monitor its progress with respect to the border regions.

5.1.2 Greenness Information

Most users felt the greenness information was well presented with effective use of color to indicate varying greenness intensities. They felt the map information closely reflected actual field conditions. In comparing the maps to reports from agents in the field, the Crop Protection Services in several countries noted good correlations between green vegetation cover and map greenness (Figure 10). These assessments were only qualitative, and

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Figure 10.—Near here.

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several users urged the need to determine a quantitative relation between map greenness (NDVI) and natural/agricultural vegetation parameters.

Several users in Senegal and Mauritania recommended expanding the number of greenness levels or classes in the 1.0 to 2.0 range to increase sensitivity to the lower amounts of vegetation cover.

Biweekly information on changes in greenness as displayed on the Vegetation Index Change maps was used very little. Most users preferred to compare one greenness map to another to assess change, rather than use the "change maps". Changes in greenness from one map cycle to another were often significant, and may have resulted as much from atmospheric and look-angle variations as actual changes in vegetation conditions.

5.1.3 Use of LAC Data for Improved Detail

The one-kilometer resolution of the AVHRR LAC data was considered appropriate for monitoring detailed and intricate patterns of vegetation green-up. This level of detail far exceeded the spatial resolution of existing sources of greenness information provided to users by AGRHYMET. The fact that greenness could be detected within such features as wadis (e.g., in Chad) was considered an important characteristic of the data, particularly for Desert Locust monitoring. This was also considered important for agricultural condition monitoring.

5.1.4 Map Scales

Most users considered the map scales to be adequate for country-wide monitoring needs. However, a number of interviewees within host government agencies recommended larger scales of 1:500,000 and even 1:200,000. These scales are desired for certain regions in some countries, for better navigation in the field, and for improved detail in the greenness information.

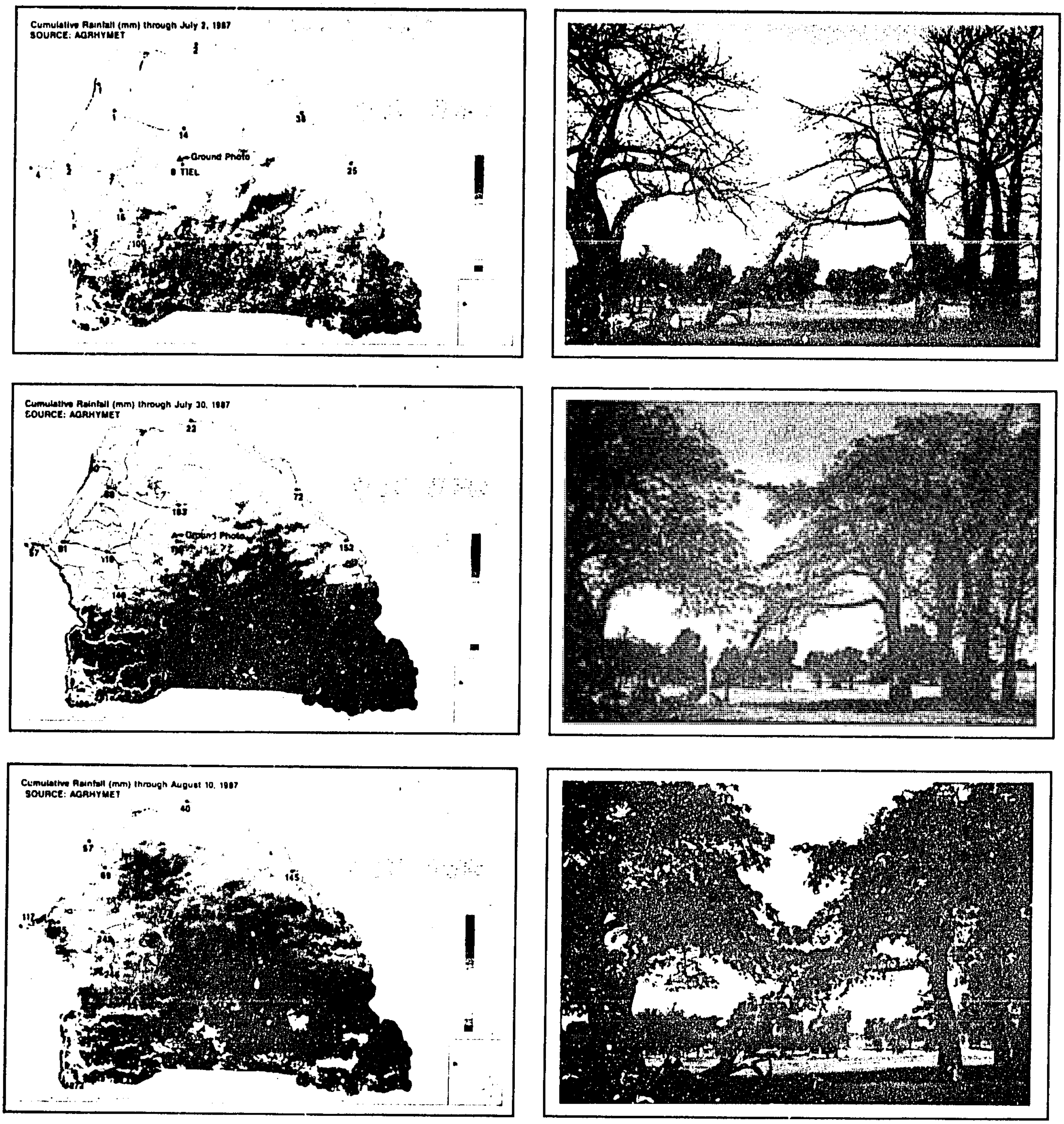

Figure 10. A series of Vegetation Index Maps of Senegal indicating the development of vegetation cover as the rains progress northwards. The adjacent ground photos were taken near Tiel, Senegal. The photo dates of June 22, July 21, and August 3 fall within the three periods represented by the maps. A qualitative comparison between the map greenness values and ground conditions can be made.

It should be noted that these users may not have understood the spatial resolution limitations of the LAC data, and that enlargements of the image data does not create more detail of the information on the maps, but rather makes the maps larger. This does, however, support the need for using AVHRR LAC data as opposed to lower resolution AVHRR GAC or AVHRR data sampled to one-half degree by one degree blocks.

5.1.5 Use of Landsat Imagery

Ten Landsat MSS images were acquired over Senegal and Mauritania to provide more detailed information on vegetation cover and agricultural lands within areas of potential grasshopper infestation. They were also to be used to assess the area of apparent grasshopper damage.

Although the Landsat data provided detailed information on land use and land cover over the selected areas, the data were not effective as a monitoring tool within the campaign due to the lengthy time lag between the satellite overpass of a given area and the delivery of the image products to the field (typically a one-month delay). The data could not be fully evaluated as a means of assessing vegetation damage due to grasshoppers because infestations were not severe enough to cause significant loss of vegetation biomass. Qualitative assessments were made of Landsat imagery acquired in September 1987 over grasshopper infested areas of southeastern Mauritania. In addition to a lack of ground truth for objective assessment, a problem was encountered that indicates that this type of assessment is difficult: variations in vegetation cover and biomass are a result of numerous variables including uneven rainfall distribution, differential grazing intensities, and differences in soil type and topography. Thus, it was not possible without detailed field data to isolate the impacts of grasshoppers on vegetation, biomass, and its corresponding reflectance and "greenness" values on satellite imagery.

The same assessment indicated that Landsat data appear promising for future campaigns as a tool for defining specific sites to be treated once an infestation area has been identified. Landsat imagery has been shown to be effective for mapping land cover and land use in West Africa (Dalsted and others, 1982; Ndiaye, 1980; Sall, 1980; Stancioff and others, 1985; Vanpraet, 1980). Since aerial treatments of grasshopper infested areas often focus on protection of croplands, specific information on crop area and distribution within other land cover types is useful for delineating spray blocks. In southeastern Mauritania, for example, OCLALAV treated four blocks (180,000 ha.) in October, to the south and west of Touil. Neither Landsat imagery nor land use maps were used by the control teams as they delineated the spray blocks. Landsat imagery acquired under this pilot project was used to assess land cover types within the four spray blocks. Although acquired in September 1987, the imagery was not available for analysis until November, well after completion of the aerial treatment. Analysis indicated that only one of the blocks contained areas of significant cropland (about 10 percent of the block area). The other blocks contain less than 1 percent cropland. Furthermore, major areas of cropland occur immediately adjacent to one of the blocks and were not treated (and may not have required it). Thus, very little cropland was actually treated in this particular effort, with most of the treated land being rangeland. The treatment may still have been justified, since treating infested rangelands in Mauritania may have reduced the threat to croplands in Mali from migrations of Senegalese grasshoppers.

Since the land-use patterns do not drastically change from year to year, Landsat coverage every two or three years would allow the CPS to identify agricultural and rangelands in their specific spray blocks and make judgements accordingly. The one-month lag in delivery time would not affect the value of data under these circumstances.

5.2 Product Utility and Effectiveness

This part of the evaluation dealt with the use and effectiveness of the map products/data in support of the grasshopper and locust control activities within the five participating countries. Use of the products by other applications programs was also investigated.

5.2.1 Use Within Grasshopper/Locust Control Programs

Grasshopper and locust control programs in West Africa in 1987 involved numerous organizations. Generally, the Crop Protection Service (CPS) agencies, countries were the operational organizations responsible for carrying out grasshopper and locust control activities. USAID, FAO, and other donors provided financial, technical, and material support of these activities. In support of the overall control program, several copies of the biweekly greenness maps were sent to the USAID missions which, in turn, provided a copy to the CPS's in each country. Other donors, including FAO, had regular access to the greenness maps.

The primary USAID map users were the staff and contractors involved directly in survey and pest control. Nearly everyone found the maps useful for assessment of green-up conditions, and for planning and conducting field and aerial surveys over areas of potential grasshopper and locust infestations. Map use was based on the principle that initial seasonal rainfall triggers both the growth of herbaceous vegetation and the hatching of grasshopper and locust eggs (if they are present in the topsoil). In areas where eggs occur, a good correlation exists between initial green-up and the hatching and development of the Acrididae species. While users recognized that the satellite-derived greenness data could not be used to directly detect infestations, the maps were used to indicate the extent and intensity of vegetation greenness, which is often an indirect indicator of infestations. They served as indicators of environmental conditions favorable to grasshopper/locust development.

Operational use of the maps by USAID and the CPS's varied from country to country. In Niger and Chad, USAID staff used the greenness maps as major sources of information for planning and conducting aerial surveys. In Niger, some green areas identified on the maps were visited and found to contain large populations of gregarious locusts. The CPS of the Government of Niger frequently used the maps for making decisions on whether or not to conduct field surveys. In Chad, the maps were considered to have potential for directing dry season egg-pod surveys, especially in the Sahelian zone. Using information from the maps, the surveys will focus on areas that were green long enough in 1987 for the grasshoppers and locusts to deposit eggs.

In Mauritania, the greenness information was used by both USAID and CPS staff to monitor the green-up situation, as a supplement to weather data, and to confirm field reports on vegetation conditions. The users felt the maps had great potential for grasshopper and locust control, but they did not use the data operationally because the maps arrived too late for the planning of field surveys.

In Senegal, the maps were used by the USAID and CPS control teams to target areas of possible grasshopper infestations, particularly at the beginning of the rainy season. Based on map information, the CPS sent field teams to green areas and avoided wasting time in dry areas (Figure 11). The

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Figure 11.--Near here.

USAID technical assistance team found the maps useful, but strongly recommended shortening the time from data acquisition to product delivery. The survey teams noted good correlation between the maps and ground observations.

In The Gambia, only limited use of the maps was made. First, The Gambia is a very small country in the Sudanian zone which is characterized by more plentiful and regular rainfall than the Sahelian zone. Once the country greened up with the seasonal rains, the maps showed little variation in greenness. Gambian officials did find the maps useful for monitoring the advance of greenness across The Gambia with the first major rains. Secondly, The Gambian CPS has an excellent reporting network which allow the control teams to closely monitor field conditions without the assistance of the maps.

In all five countries, USAID and CPS staff involved in pest control activities recommended continuation of the greenness mapping program. The widespread acceptance of the maps was based largely on the new information contained in the maps, and on their ease of use and understandability. However, nearly all interviewees called for reducing the time of map delivery. They felt this would greatly improve the utility of the product for future campaigns.

5.2.2 Map Use in other Programs

The maps generated considerable interest among a number of agencies with respect to other potential uses, particularly for crop and rangeland condition assessment. The maps were particularly useful in the Sahelian zone, where rainfall is highly erratic over time and space. Here, the maps reflect the complex patterns of green vegetation cover, including the dry pockets so characteristic of this land of marginal rainfall.

Agencies concerned with range management (for example, the Crop Protection Service in Mauritania, and in Senegal, the Direction de l'Elevage [Dept. of Range Management]) were interested in the maps for monitoring and mapping seasonal rangeland conditions in both the Sahelian and Sudanian zones. The maps were considered to provide new and detailed information on green-up and senescence patterns not previously available. Data from the widely scattered weather stations are generally insufficient for assessing rangeland conditions, particularly in the larger Sahelian countries. The CPS of Mauritania found the maps to be indispensible as both a general indicator of rainfall between weather stations, and as a tool for determining location and

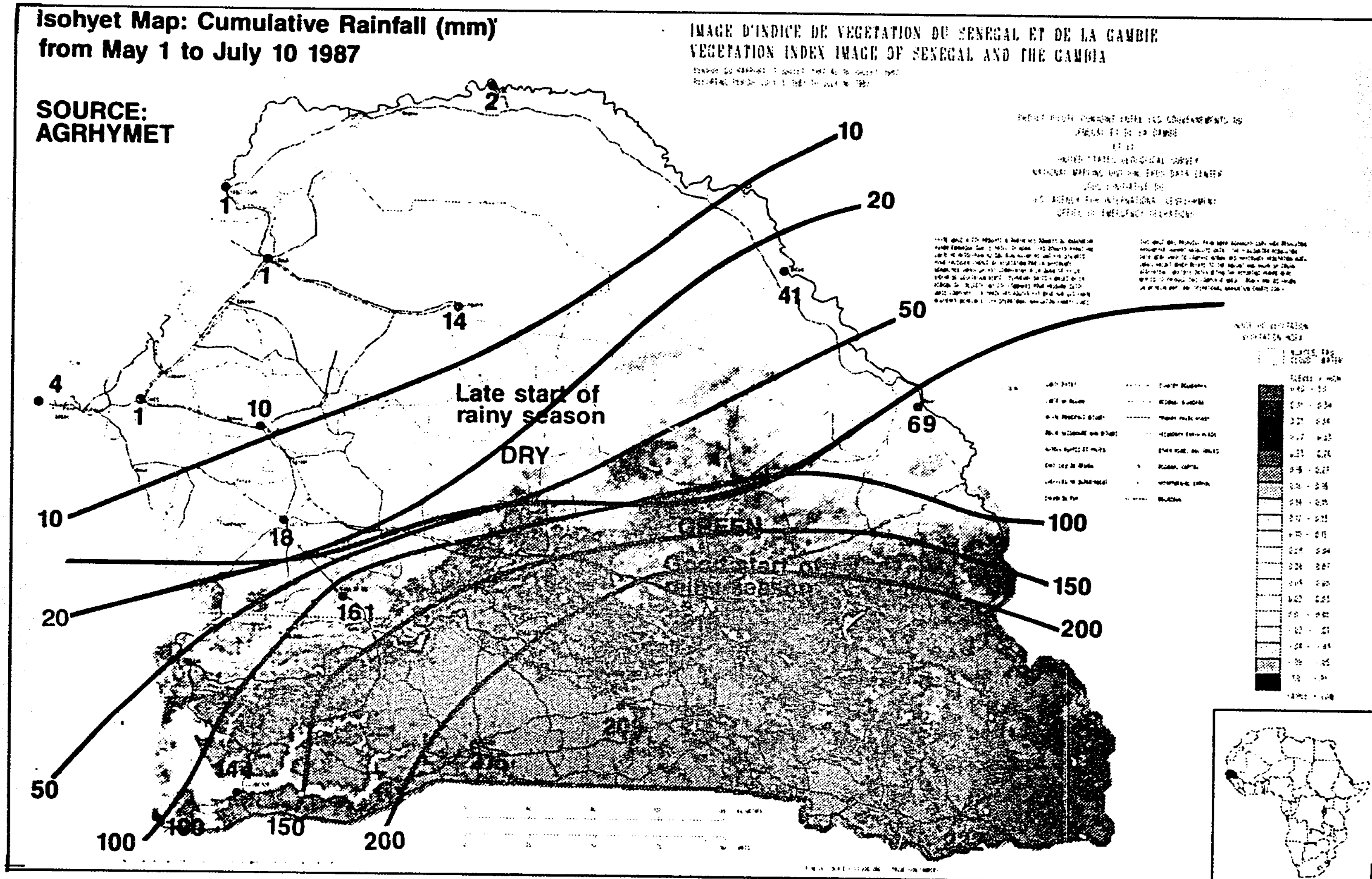

Figure 11. Prior to the regular use of the greenness maps, the Senegal Grasshopper Control Team relied on AGRHYMET rainfall data and Crop Protection Service field reports to estimate the position of the advancing green-up line. The maps provided additional information on the intricate patterns of vegetation green-up, and were used to help direct grasshopper survey missions.

distribution of green pastures. The CPS agency provided a set of maps to the President of Mauritania. He requested that the greenness information be broadcast on the radio in order to make the information quickly available to nomadic populations.

Several agencies (for example, the Direction des Eaux, Forets, et Chasses, Senegal) expressed interest in using the maps to identify grasslands with high fire hazard in order to take actions to prevent widespread burning in the dry season.

The Direction de l'Agriculture (Dept. of Agriculture), Senegal, and AGRHYMET in Mauritania found the maps useful as an additional tool for crop condition assessments, and for the identification of deficit food production areas. Both agencies used the maps as one of several sources of information for preparing weekly and decadal reports on crop condition.

The maps were used within the FEWS/Mauritania program for assessing the general vegetation condition and for indicating rainfall patterns. The maps were considered to be the most valuable source available on vegetation condition. The information was regularly used in the monthly FEWS field reports.

5.2.3 Recommended Improvements in Products and Training

The most universal recommendation was that the products be delivered in a more timely fashion. Timeliness is critical to the operational use of the greenness information. Map delivery should be reduced to five to seven days. A number of users also indicated that a weekly map cycle would be optimum, and that a 10-day cycle would be good. Users would also like to see more copies distributed to each user group. During critical periods, there is a need for frequent telex/telephone summaries of greenness information. More emphasis should be placed on the use of the reference grid overlay.

In the larger Sahelian countries, users called for larger-scale greenness maps of certain regions within each country. In the case of Mauritania, additional coverage is needed to include central and northern Mauritania to monitor scattered green-up in the Saharan zone.

The monitoring period should be extended longer into the winter (dry) season. Ideally, monitoring should occur year-round, or at least from May to the following March.

A better understanding of the relationship of the NDVI greenness values and actual vegetation conditions is needed. Also, further attempts are needed to correlate greenness to rainfall.

Minor deficiencies in map content by adding more locational information including towns and villages, more levels of political divisions, airports, and major wells should be remedied. Adding wadi names would be useful.

A number of users suggested providing thematic resource information in support of the greenness maps (for example, land use). Using a geographic information system approach, resource information could be integrated into the greenness maps, or provided on overlays. This would provide interpreters with improved information on greenness and its relationship to such phenomena as vegetation types, crop condition, and drought. For demonstration purposes, existing soils data for Senegal were entered into a geographic data base (Figure 12). In order to show how this resource information can be used

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Figure 12.—Near here.

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within the context of a grasshopper campaign, certain attributes of the soils data, including soil texture, were identified and plotted to produce a thematic map indicating soils favorable for egg-laying of the Senegalese grasshopper (Figure 13). When used with greenness information, this map could

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Figure 13.—Near here.

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serve as a tool to further narrow down areas being considered for grasshopper surveys.

The training workshops provided to officials and technicians concerning the potential uses and interpretation of the map products were necessary. Nearly all participants felt they were too short. Participants recommend increasing the training to at least one week. Training should stress map interpretation and use.

Some of the USAID staff felt that better coordination and planning of project activities was needed. Each USAID mission should have a greater role in defining project activities and products. USAID should continue to coordinate map distribution to participating organizations.

5.3 Institutional Considerations

The ability to provide LAC-resolution greenness data to Sahelian countries on a synoptic, near real-time, repetitive basis fits well within the objectives of several regional African programs. In particular, this capability appears appropriate to the AGRHYMET Program. The AGRHYMET regional center in Niamey, Niger, serves the CILSS countries by collecting agrometeorological and hydrological data from member countries. It then interprets and disseminates information derived from the data. Future plans are to install an AVHRR reception station for real time reception, and a processing system to analyze and summarize the satellite data for transfer to participating countries. The production and dissemination of greenness products such as the ones prepared by this pilot project would be based, ideally, in a regional center like AGRHYMET where product turn-around time would be shortened. Further, the AGRHYMET program would be enhanced by providing a product for which a high level of interest has been demonstrated.

Use of the greenness maps by the FEWS field personnel indicates the products should be made available to the FEWS field representatives on a regular basis. FEWS field teams have indicated a need for the maps for in-country use in order to focus their data collection and analyses on problem areas within each country. The maps lend themselves to time-series

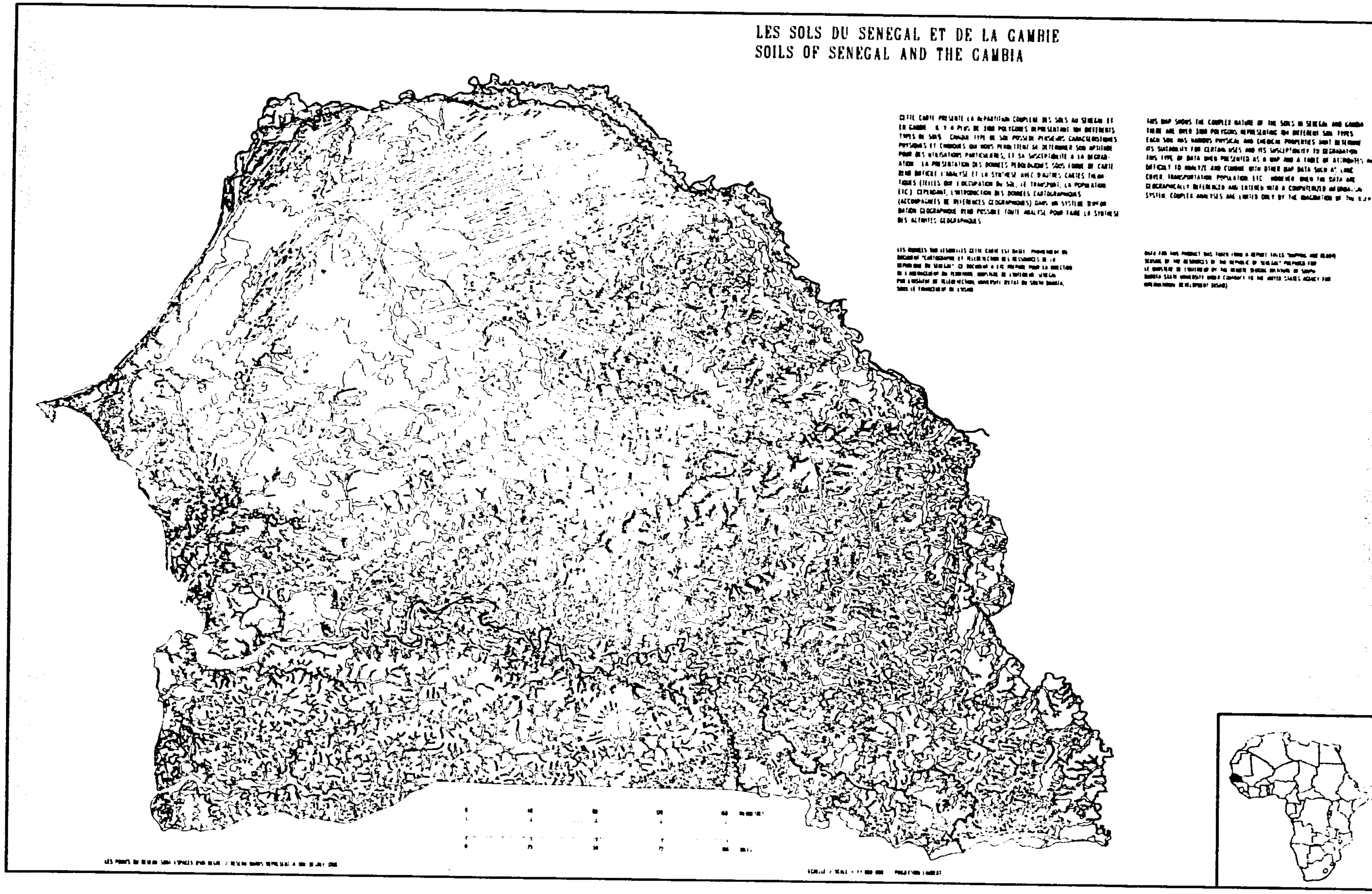

Figure 12. This map shows the soil boundaries of Senegal/The Gambia, and was derived from an existing soils map *(source: Stancioff and others, 1985)*. The data were entered and stored in a GIS, and can serve as a basis for producing a variety of user-oriented thematic maps (see Figure 13).

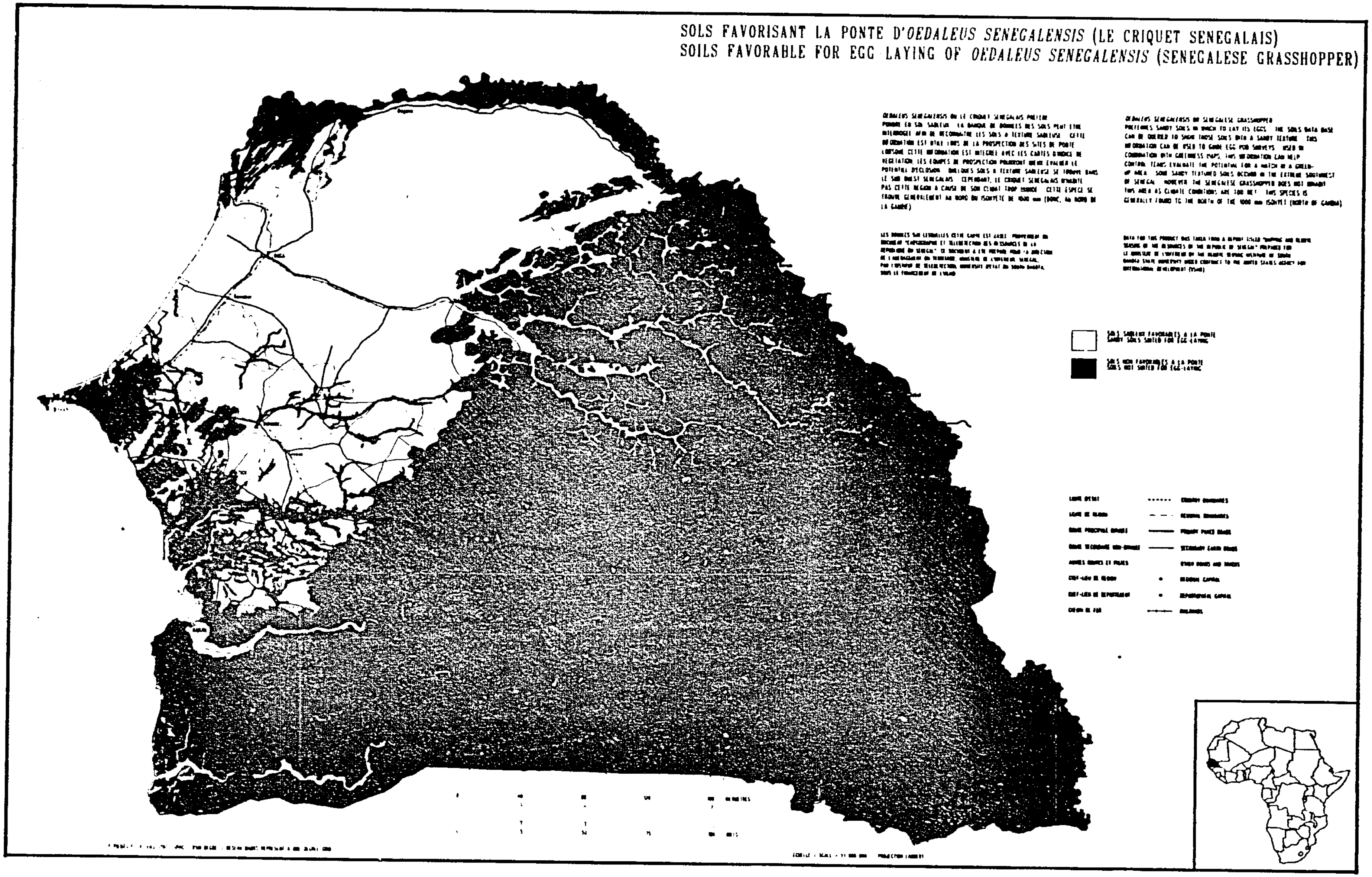

Figure 13. This map is a GIS product from the soils database of Senegal/The Gambia. It indicates soils which are favorable for egg-laying of the Senegalese Grasshopper (white areas). It can be used with the greenness maps to guide survey teams to potential grasshopper breeding areas.

assessments of pastures and crops and can serve as one of the indicators for targeting "at-risk" populations.

USAID is supporting natural resources management in Africa through such regional programs as the Natural Resource Management Systems (NRMS) Project. There is an increasing need for monitoring and management of renewable natural resources in Africa where degradation of soil and vegetation resources is often severe. The greenness maps appear to have major potential for development programs that require a better understanding of environmental problems and needs.

6.0 Conclusions and Recommendations

The greenness maps were well received by both the USAID technical assistance teams and the host country organizations involved in grasshopper and locust control. While the operational use of the maps varied from country to country, nearly all users felt the maps provided new and useful information for use in pest control efforts, and their operational use of the maps would be strengthened if they could be delivered to the users in a more timely fashion.

The information content and format is basically sound, with minor improvements recommended by a number of users. These involve adding more geographic information to the greenness maps, and expanding the map scale for selected regions. Overall, the maps were readily understood and interpretable.

A number of significant applications of the maps were identified in addition to the support of pest control efforts. In particular, the maps have potential for monitoring conditions within rangelands and croplands. The maps were found to be particularly useful in the Sahelian environment where erratic and unevenly distributed rainfall is the rule. The greenness information was a useful indicator of rainfall, though quantitative analyses were not made.

Most users indicated that the greenness mapping program for pest control and other applications should continue, and should move into an operational mode. Follow-on activities should work toward technology transfer to an appropriate regional organization within the Sahel. Expanded coverage to include all Sahelian countries should be considered.

The main recommendations are:

A. Continue the greenness mapping program in the five countries involved in the Pilot Project, with possible expansion to adjacent Sahelian countries.

B. Shorten the map delivery time to a week or less following the production of each map cycle.

C. Add more locational information to the maps for improved interpretability and navigation. Consider expanding the greenness scale, and enlarge the map scale for specific regions within the larger countries.

D. Integrate the maps with other resource data, using geographic information system technologies.

E. Improve coordination of follow-on activities with USAID missions and host government agencies.

F. Future project plans and technology transfer should involve such regional programs as AGRHYMET, NRMS, and FEWS.

G. Document cost-savings of follow-on activities as a result of decisions based upon the greenness maps.

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APPENDIX I

Project Evaluation Results in Senegal

I. BACKGROUND

An evaluation of the USGS/USAID Pilot Project for Seasonal Vegetation Mapping in support of the Grasshopper Control Campaign in Senegal was conducted by Donald G. Orr, U.S. Geological Survey's EROS Data Center and Andrew Stancioff, Dynamac Corporation, from October 26 to November 10, 1987. The evaluation was based upon a series of interviews with representatives of USAID and Senegal government agencies, who had used the seasonal vegetation greenness maps in the grasshopper control program as well as other applications. A list of questions was prepared prior to the evaluation team visit to insure consistency and completeness of the information needed to evaluate the project results. Of particular interest in the evaluation were comments on the product characteristics, utility and effectiveness of the maps, institutional considerations, and management recommendations.

Ten copies of the greenness condition maps derived from composites of NOAA satellite data were provided every two weeks to the USAID Mission in Dakar, Senegal, during the 1987 growing season. The maps were distributed to participating government agencies in Senegal by USAID staff.

II. CONTRIBUTIONS TO THE GRASSHOPPER CONTROL CAMPAIGN

The Grasshopper Control team in Senegal consisted of a number of USAID contractors and representatives from a number of Government of Senegal (GOS) agencies. Overall, the 1987 Grasshopper Campaign seemed to be well organized and effective. Compared to 1986, there were no serious infestations of grasshoppers in Senegal during the 1987 season. Therefore evaluation of the utility of the greenness condition maps for grasshopper control purposes in Senegal was based on how the products were used and correlations to the ground conditions. In Senegal, interviews with 26 people representing 10 agencies were conducted relative to the greenness condition maps. Not all of the individuals were involved in the grasshopper campaign, however.

Dr. Ellis Huddleston, Head Entomologist, 1987 Grasshopper Team, was very supportive of the greenness-condition maps and recommended that they be continued. The Grasshopper Team used the maps to target areas for field surveys and generally found good correlation between the maps and ground observations. Because of delays in delivery of the greenness-condition maps, he felt use of the locator grid to communicate the location of areas of greenness via telephone call from a technical expert at the EROS Data Center was very effective.

III. EVALUATION OF GREENNESS MAPS

A. USAID/Senegal

From the Agriculture Development Office management perspective, it was recommended that any future activities involving generation and distribution of greenness condition maps be coordinated better with the USAID Mission during the planning phases. The 1987 Seasonal Monitoring Pilot Project was initiated hastily and did not allow for adequate preparation for host agency involvement. The USAID Mission management staff were generally supportive of the pilot project and emphasized the importance of establishing the necessary infrastructure, host GOS agency, and long-term applications in other resource areas such as soils, agriculture, forestry, land cover, and water, before the greenness mapping technique can become operational.

The primary involvement in the Pilot Project in support of the 1987 grasshopper campaign by USAID direct-hire staff was to receive and distribute the greenness maps to designated agencies and to provide technical assistance on their uses. However, the vegetation greenness maps were used and evaluated for a number of other applications by USAID staff. The maps were used to monitor the advance of the "green wave" from south to north and to compare greenness conditions with agricultural information received from reporting points throughout Senegal. The maps provided qualitative indications of vegetation state that were useful in correlation to crop planting dates, plant development, estimates of crop yields, crop disease and insect problems and areas of crop stress.

It was felt that the greenness condition maps could have potential application to the FEWS Program, especially in the Sahelian countries. It is important to have timely information on areas of drought and that these areas be monitored in a consistent fashion so food import profiles can be developed more objectively. The maps provide information that can be correlated from country to country and should facilitate regional food assessments.

It was felt that the greenness maps provide a common base for multidisciplinary studies. If other information on soils, vegetation, land use, forest lands, rangelands, transportation, and population were incorporated with vegetation greenness, other applications related to natural resources management appear to be technologically practical.

If the greenness mapping technique is continued and eventually becomes operational, suggested candidate host agencies include: Ministry of Rural Development, AGRHYMET, CRTO, and the Presidency. In the short term, USAID will have to promote the technique and a broader range of applications beyond grasshopper campaign will be needed.

In general, USAID staff were supportive of the pilot project and felt that incorporation of other information on soils, land cover, land use, political boundaries, and other geographic data with the greenness maps would increase their applications. The vegetation greenness maps were relatively easy to understand and correlation to ground conditions was generally good. The 1 km resolution was satisfactory and the scale was considered to be adequate for country-wide coverage. Larger scale (1:200,000) would be preferrable for specific areas.

The major deficiency in the vegetation greenness mapping pilot project was delivery time of the data was not fast enough to target potential grasshopper infestations in real time. The maps were used mostly for after-the-fact confirmation of ground observations. More geographic detail, such as roads, villages, airstrips, rainfall reporting stations, is needed to locate specific areas on the ground and to direct ground survey parties. Additional training, technical assistance, and explanation of the vegetation index color scale would be useful and increase utility of the greenness maps.

Overall, the evaluation of the vegetation greenness maps provided during the pilot project was positive and deficiencies cited are correctable. The potential of the maps for other applications, general understanding of the map content and acceptance exceeded expectations.

B. Government Agencies of Senegal

1. Crop Protection Service (CPS)

The Crop Protection Service was the host agency in the 1987 Grasshopper Campaign. The initial approach in use of the vegetation-greenness condition maps was to target areas of potential grasshopper infestation based upon distribution of green vegetation. The maps were interpreted at CPS headquarters and were considered to be useful as a targeting tool to direct field operations. The greenness maps were well accepted by the Grasshopper Team and were used for both aerial and ground prospecting activities. The locator grid provided with the greenness maps was very helpful in directing field surveys. The maps were considered to be most useful at the beginning of the season when variations in vegetation greenness was very evident on the maps. As the vegetation reached its maximum greenness (the blue class), there was insufficient color differentiation on the maps.

The scale of the vegetation greenness-condition maps was considered to be satisfactory and enlargements of specific problem areas would be very useful.

More locational detail such as villages, roads, airports, rainfall reporting stations (used by CPS and AGRHYMET), etc., was considered important to direct field prospecting. The locator grid provided in the 1987 campaign was useful, but additional local geographic detail recognizable by field agents would improve location of prospect areas.

The major problem with the 1987 vegetation greenness condition maps was late delivery (which averaged about 15 days) after acquisition of the satellite AVHRR data. The length of time between acquisition and delivery of the data reduced their utility in monitoring dynamic processes, such as rainfall and vegetation green-up. A 10-day repeat cycle is preferred because most of their reports are decadal, and the maps are considered to be important for making reports.

The CPS felt the greenness mapping technique should become operational, but does not have funds to commit to it. USAID should promote the operational use of greenness maps, and the Ministry of Rural Development is considered to be a good candidate as the host agency. Should the greenness mapping technique become operational, the data should be correlated with information on land use and vegetation types to increase their utility.

2. Department of Agriculture

Department of Agriculture personnel were very supportive of the project and feel remote sensing applications can be useful for providing information on a variety of their departmental responsibilities. Their most important mission is to estimate agricultural production, and they make weekly reports to the Minister of Rural Development on crop production and crop protection. They used the vegetation greenness maps in making their reports, and the Department of Agriculture needs the vegetation data as soon as possible after acquisition (one week after data acquisition is preferred) so they can determine where food crops are in danger. Department of Agriculture representatives felt the greenness mapping technique should become operational and suggested consideration be given to installation of an AVHRR reception station in Senegal because the AGRHYMET station will not cover western Senegal. They could use data all year to get information critical to rural development.

In regard to the technical characteristics of the products, they felt the map format and classes of greenness were satisfactory. Locational detail down to the arrondissment level is needed because that is the geographic unit used to compile agricultural statistics and make crop production estimates. A scale of 1:500,000 would be better for general use and 1:200,000 would be better for compiling land use. They followed vegetation greenness from south to north through the season and used the greenness information to compare with data from field personnel on crop stage and development. They felt the correlation was very good and would like to have Landsat data also, to increase information on soils, geomorphic features, and land cover.

They felt the greenness mapping should become operational, especially for the Sahelian countries. The AVHRR GAC data could be used for regional coverage and LAC data for individual country coverage. Sahelian country coverage is important to detect deficit food production in the region and allow for planning of exports from other countries that have surpluses.

They felt the ministry for Rural Development would be a good host agency because the Department of Agriculture is also involved in most other projects related to food production.

Additional training will be needed if the greenness mapping technique becomes operational. Department of Agriculture suggested that a few key people from each division be trained for 1 month to 1½ months in the U.S. to remove them from the pressure of work in Dakar. The EROS Data Center specialists and the key Department of Agriculture personnel should cooperate in a series of one-week seminars in Senegal and after that, the key department personnel would provide training for the people down to the field level.

3. OCLALAV

OCLALAV is funded by a number of international donors and has regional responsibilities throughout areas in Africa that have locust problems. The logistics of their field operations is complex, and timely delivery of greenness maps should help considerably in targeting areas to survey by air and on the ground.

OCLALAV representatives expressed interest in the vegetation greenness condition maps, especially in the Sahelian zone countries, for grasshopper and locust campaigns. They would like to have a more quantitative measure of greenness, especially the thresholds for the greenness classes on the maps. Because grasshoppers and locusts prefer certain vegetation types and there is a critical time between green-up and grasshopper hatches, correlation of greenness on the maps and the greenness on the ground is very important. They prefer the 1 km resolution because of the need for spotting small areas of greenness to direct field surveys. The rainy season is the most critical time for preparation of greenness maps but they could use vegetation data all year.

They felt the maps should be continued for the entire Sahel in 1988, and longer. They were mostly interested in Mauritania, but did not receive the maps for that country. If they had received copies of all the maps of Mauritania, they could have evaluated the cost effectiveness of the greenness mapping technique. They did not use the Senegal maps to any extent because there were no serious grasshopper problems. They feel the maps should be delivered within one week of AVHRR data acquisition. They like the locator grid and, in the future, would like enough copies for all the field crews. They feel there is potentially a large number of users of vegetation greenness information in various ministries throughout the

Sahelian countries and if the greenness mapping technique is continued, they would like to have a minimum of three and a maximum of six maps of each country.

4. National Meteorological Services

The AGRHYMET representative at the National Meteorological Services is responsible for providing meteorologic and vegetation data to the crop forecasting and rural development agencies on a regular basis. He received the greenness maps and found them to be more useful than the vegetation index information provided by the AGRHYMET program. The vegetation index information from AGRHYMET was integrated over a 1° x ½° area and the numerical values were furnished by telex. Normally, the data were received late. In the future, AGRHYMENT plans to perform the vegetation index calculation on IBM PC computers and furnish floppy disks to the users.

The representative was supportive of the EDC greenness maps and felt they should be continued. He would like to receive them during the entire year, but the rainy season was critical.

5. Others

a. Canadian Grasshopper Campaign Consultant

Dr. Stanislow Manikowski, a consultant to the Canadian Grasshopper Campaign and employee of FAO/Rome had seen the EDC greenness maps and felt very strongly that they should be continued. He is going to recommend to FAO that these types of data be used for monitoring desert locust habitat. He feels the maps should be produced for all of the Sahelian countries because there are going to be grasshopper and locust outbreaks somewhere in the region every year (i.e., 700,000 hectares are infested in Niger this year). He felt that the EDC greenness maps were the best ones so far and will recommend closer cooperation between FAO and the various grasshopper and locust campaigns.

Within Senegal, Manikowski feels OCLALAV is a potential candidate host agency because they have regional responsibilities and are internationally funded. The entire capability for producing greenness maps will have to be funded and developed by a donor agency.

b. FAO Consultant

Dr. George Popov, a recognized world expert on African grasshoppers and locust, had completed ground surveys on concentrations of grasshoppers in southern Mauritania and Mali and had found a correlation between vegetation greenness and grasshopper populations. He was very interested in the greenness maps and felt that they should be important for targeting areas to survey. He requested the entire series of maps for Mauritania so he could determine correlations between egg-pod concentrations and vegetation type.

c. <u>Ecological Monitoring Center</u>

The Ecological Monitoring Center in Dakar is funded by Denmark and is conducting research on biomass in pastures in the Sahelian zone. They are using remote sensing and ground survey techniques to collect data over 18 sites that are 3 km x 3 km in size. They plan to correlate biomass to greenness and are using well location (bore holes) to integrate all their data to compare it with animal loading at each bore hole.

They can visualize a number of applications for remotely sensed data, including agriculture monitoring, crop forecasting, forestry, range, and hydrology. Currently, they are receiving AVHRR data from the Maspalomas station on floppy disks, and they attempt to composite greenness data over a ten-day cycle to match the AGRHYMET rainfall data. However, delivery of the AVHRR data from the Maspalomas station is a problem.

The Center is assembling processing capabilities, which currently includes an IBM PC XT with a color monitor, a Xerox 4020 color printer, a digitizer, and image display and georectification software developed at the University of Copenhagen. They eventually want to get a mini-computer and ELAS software to develop GIS capability.

IV. RECOMMENDATIONS

The following is a summary of recommendations made during the evaluation study.

A. The greenness mapping technique should be continued and expanded into other applications. In several cases, it was recommended the project be continued for up to 5 years to monitor long-term trends such as areas of degradation, reforestation, agricultural development, etc.

B. Delivery time should be improved.

C. The vegetation greenness information should be incorporated with information on soils, land use, agricultural areas, crop types, forests, rangeland areas and rainfall to increase the applications.

D. In-country data processing capabilities should be considered to improve data utilization and the potential for installation of an AVHRR reception station to cover western Senegal should be investigated.

E. Consideration should be given to adding geographic detail (such as arrondissements) to improve locational information on the maps.

F. Several different Government of Senegal and regional organizations were suggested as candidate host agencies for continuation of the greenness mapping technique operationally. It is apparent that future planning must take into account host agency involvement, infrastructure between user agencies, technological capabilities requirements, training and funding.

G. Requirements for seasonal vegetation monitoring within the FEWS Program, Natural Resources Management Systems, AGRHYMET, etc., especially in Sahelian zone countries should be evaluated relative to commonality of information needs by donor and user agencies.

People Contacted by Evaluation Team

NAME	AGENCY
Mr. Lannon Walker	U.S. Ambassador to Senegal
Ms. Sarah Jane Littlefield	Director, USAID
Mr. George Carner	Deputy Director, USAID
Mr. Wayne Nilsesteun	Chief, ADO, USAID
Mr. Ron Harvey	Deputy Chief, ADO, USAID
Dr. Ellis Huddleston	Leader, Grasshopper Team
Dr. Gil Haycock	Chief, Irrigation Office, USAID
Mr. Moribadjan Keita	ADO, USAID
Mr. Mawa Diop	ADO, USAID
Dr. Francis Can	ADO, USAID
Mr. Olaf Kula	USAID, Contractor
Dr. Mouhamadou Ly	Director, Crop Protection Service
Mr. Robert Nyouki	Head of Surveys, Crop Protection Service
Mr. Dene Ndiaye	Director, AGRHYMET, National Meteological Service
Dr. Yves Prevost	Chief of Party, Ecological Monitoring Service
Mr. Amadou N'Diaye	Director, Ecological Monitoring Service
Dr. Waly N'Diaye	Director, Department of Agriculture
Mr. Abdalla Samba	Project AGRHYMET, Department of Agriculture
Mr. Abdou Diop	Department of Agriculture
Mr. Alidun Dieno	Department of Agriculture
Mr. Abdoulay Diop	Department of Agriculture
Dr. Stanislow Manikowski	Canadian Consultant Grasshopper Campaign

APPENDIX II

Project Evaluation Results in The Gambia

I. BACKGROUND

The evaluation team of Don Orr and Andrew Stancioff spent a day visiting the USAID mission and several government agencies in The Gambia. The evaluation was based on a series of questions asked during interviews with key agency representatives. Appointments for interviews and transportation were arranged by the USAID mission in Banjul.

The vegetation greenness condition maps for use in The Gambia 1987 Grasshopper Control Campaign were provided on a two week cycle; the same as other countries participating in the Pilot Project. Because The Gambia is small and is bordered on three sides by Senegal, the vegetation greenness maps provided included both countries. If vegetation greenness maps are provided in the future, consideration should be given to creating maps that meet individual country requirements.

II. CONTRIBUTION TO THE 1987 GRASSHOPPER CAMPAIGN

The 1987 Grasshopper Campaign in The Gambia was organized and coordinated by the Crop Protection Service. They had a well equipped and coordinated campaign consisting of nine radio reporting stations and field agents who could make decisions on control measures at the local level. There were a few grasshoppers in the natural vegetation during 1987, but they did not pose a threat to crops. Therefore, the vegetation greenness maps were not used appreciably for targeting grasshoppers in The Gambia. In addition, the efficiency of the communications network established by the grasshopper team provided adequate information on the location of grasshoppers before the maps arrived in the country. However, the vegetation greenness condition maps were considered to be useful for other applications.

III. EVALUATION OF THE GREENNESS MAPS

A. Government Agencies of Gambia

1. Crop Protection Service (CPS)

Even though there was no serious threat by grasshoppers in The Gambia during 1987, the CPS representatives were enthusiastic about the potential applications of the vegetation greenness maps. They used the maps regularly in conjunction with land use maps to monitor green-up and dry-down of vegetation in The Gambia.

They think the greenness maps could be very useful, if delivery time was improved, and if the scale of the maps were larger. They would like greenness maps of The Gambia to be 1:250,000 scale. Vegetation greenness maps that have natural vegetation and cultivated agriculture areas delineated on them also would be helpful. They would like to have the maps the entire year because upland rice is not harvested until December. In The Gambia, the rainy season is from the last week in June to the first week in October, so greenness maps from May to November is the most important period.

They also felt additional training and manuals were needed. The locator grid overlay was very useful and, if they had it, additional geographic detail on the maps would not be needed. If the scale was made larger, the CPS felt the program should continue.

2. Water Resources Department

In Banjul, the Water Resources Department is participating in the AGRHYMET project and produces an Agrimeteorological Bulletin for The Gambia every ten days. The bulletin reports rainfall, soil moisture and temperature, evaporation, crop stress conditions etc., and recommends crop planting dates.

The Water Resources Department did not receive any greenness maps for the first month and the remainder of the maps were received about 30 days after the end of the two-week cycle.

The maps were used to monitor greenness in West Africa, especially pockets of drought. The format of the map was considered satisfactory and the 1 km resolution was preferred over the NOAA GAC data. It was suggested the maps be 1:250,000 scale, cover The Gambia only, and should be continued in the future for monitoring vegetation conditions in the country. The two-week cycle is adequate, but delivery time needs to be improved. A soils overlay of the greenness maps would be very useful.

3. Program, Planning, and Monitoring Unit (PPMU)

The PPMU office monitors agricultural production and issues three reports annually. The first report is a crop production forecast and is published in mid-September. The second report is the preliminary estimate of crop production based on field data and is published in November. The final report on production is issued in December.

The greenness maps were used to monitor greenness patterns, but delivery must be much faster if they are to be effective. During 1987, the maps were used by PPMU to verify field reports. They feel the cycle interval for making the maps should be one week instead of the two-week cycle.

The scale and format of the maps are considered to be satisfactory, but maps showing only greenness has limited application for monitoring agricultural production. They need data on cropland areas which cannot be distinguished from forest land on the greenness maps. They currently collect all of their data with field personnel and do not use any photos or maps.

PPMU felt the greenness mapping technique should become operational if the delivery time and other problems were corrected. More training is needed and workshops should be 5-10 days in duration and include interpretation manuals. If the greenness mapping technique becomes operational, it was suggested that users of the greenness maps should meet weekly to compare interpretations and coordinate activities.

B. USAID/Gambia

The Agriculture Development Office (ADO) was interested in the comments made by the Gambian Government Agency personnel relative to the greenness maps. Application of the greenness mapping technique to problems in The Gambia seemed marginal because the country is so small and the communications network is relatively well developed. By the time they receive the greenness maps, they already know what is happening in the country.

It appears that USAID is moving toward technologies involving GIS concepts and natural resource management systems. However, in The Gambia, the technology far exceeds in-country capabilities to operate and maintain such systems and there are serious doubts that they can be effectively applied for some time. The infrastructure is simply not in-place.

IV. RECOMMENDATIONS

The vegetation greenness condition mapping in The Gambia should be continued only if maps are prepared for neighboring countries as well. The utility of greenness mapping in The Gambia for targeting grasshopper infestations appears to be marginal because of the small size of the country and the well developed communications network. However, requirements for other applications appear to justify production of greenness maps.

If the vegetation greenness mapping technique is continued in the future, consideration needs to be given to (1) improving delivery time, (2) enlarging the scale to 1:250,000, (3) incorporating other information, such as land use, vegetation type, soils, etc., into the greenness maps or provided as overlays, and (4) providing more detailed locational information.

Additional training and preparation of an interpretation manual is needed to improve utilization of the greenness maps in the future. Introduction of new technological capabilities in The Gambia must be well planned to allow for development of the necessary infrastructure, training of personnel, and maintenance of equipment.

<u>List of Contacts</u>

NAME	AGENCY
Mr. Ralph Conley	Chief, ADO, USAID/Banjul
Mr. Saikow Jobe	ADO, USAID
Mr. Thomas Hobgood	ADO, USAID
Mr. Bakary Trawally	Director, Crop Protection Service Yundim
Mr. Mounirou Darbo	Water Resources Department Banjul
Mr. Baboucar Gai	Program, Planning, and Monitoring Unit Banjul

APPENDIX III

Project Evaluation Results in Mauritania

I. BACKGROUND

The Orr and Stancioff evaluation team spent a day in Mauritania and interviewed several key officials on uses of the vegetation greenness condition maps during 1987. In Mauritania, the vegetation greenness condition maps covered only the southern portion of the country, northern portion of Senegal and western Mali. This was the region considered to have the greatest potential for grasshopper infestations and is a major agricultural area.

II. CONTRIBUTIONS TO THE GRASSHOPPER CONTROL CAMPAIGN

A few areas in south central and eastern Mauritania were affected by grasshopper infestations and pesticides were applied. The vegetation greenness maps did not arrive in time to be used operationally in the targeting of potential problem areas during the 1987 grasshopper campaign. They were used after-the-fact to compare with ground observations and there was a good correlation between the vegetation greenness map and green vegetation on the ground. In addition, the maps were considered the most reliable indicator of rainfall events because in the Sahelian zone, the rains are very spotty and the distance between rainfall reporting stations is very great.

III. EVALUATION OF THE GREENNESS MAPS

A. Mauritania Government Agencies

1. Crop Protection Service

The Crop Protection Service (CPS) used the maps in the 1987 Grasshopper Campaign and for other applications. One of the most important applications of the greenness maps was to monitor greenness in the pasture areas to advise nomads where to take their herds. This application could save lives of people and animals because the nomads could avoid wandering into non-productive areas. The information about green pasture areas was broadcast over radio Mauritania to the nomadic tribes.

The CPS was also interested in monitoring the vegetation dry down. In areas where adequate rainfall results in large accumulations of grass, there is a high potential for range fires. They advise the Forestry Service about such areas so fire breaks can be prepared.

The third application was to infer rainfall amounts in areas where water management dams have been constructed. Once the dams have water in them, farmers are advised when to plant crops.

The Crop Protection Service made weekly reports to the Minister of Rural Development. Reports were then made to the President of Mauritania. After the President saw the maps, he became very interested and often called to see if new maps had arrived.

In regards to the utility of the greenness maps, CPS found them to be useful because wherever green appeared on the maps they knew it had rained. The greenness maps were considered to be the most reliable indicator of rainfall events because the rainfall data they receive from AGRHYMET contained serious errors.

Three major problems with the greenness maps were noted. The maps always arrived too late to be of use in directing ground operations for grasshopper surveys. CPS personnel felt the scale was too small for survey teams to accurately locate themselves on the ground, and the maps did not show small green areas where the vegetation was sparce.

The following comments were made in regard to improving the utility of the vegetation greenness maps:

a. It would be useful to have greenness maps of northern Mauritania for the late season for locust monitoring.

b. More class intervals between 0.02-0.2 of the greenness scale are needed for better discrimination of greenness in drier areas.

c. More geographic detail including arrondissement, department capitals and provincial boundaries are needed for locational purposes.

d. Increase the scale by a foctor of two in problem areas, otherwise the scale is acceptable.

e. Improve delivery time to 2-3 days.

f. Reduce the processing cycle time to one week because Mauritania has very dynamic ecology.

g. A regional map including Senegal, Mali, and Niger would help monitoring green-up from south to north and distribution of rainfall.

h. The maps should be continued and should increase coverage up to the 23rd parallel to monitor for both grasshoppers and locust.

2. AGRHYMET Office, Nouakchott

The AGRHYMET Office used the maps to monitor greenness, especially where there were no rain gauges, and to monitor biomass development. They advised the grasshopper team on locations of green vegetation.

Their major comments on evaluation of the greenness maps include:

a. Map coverage of Mauritania should be moved further south to include more of Senegal and Mali. It seldom rains in the northern portion of the area included on the 1987 vegetation greenness maps.

b. Class interval from 0.02-0.2 on the vegetation index scale should be expanded.

c. More detailed geographic information is needed. Include arrondissement and provincial boundaries in Mauritania, Mali, and Senegal to monitor advancement of "green wave."

d. The 1 km resolution is acceptable, but maps should be enlarged to a scale of 1:1,000,000 or 1:800,000.

e. Improve delivery time to 2-3 days after each cycle.

f. Cycle should be 10 days to coordinate with other reports produced by AGRHYMET. A 1-week cycle would be better during the rainy season because change is very rapid.

g. The greenness mapping technique should become operational and AGRHYMET should be the host agency.

They would like to combine greenness data with land use, land cover and soils data. The current maps are very useful to monitor rainfall patterns but additional information would improve their use for other applications.

B. USAID/Nouakchott

1. USAID Mission

The USAID mission was very supportive of the greenness maps provided under the Pilot Project for seasonal vegetation mapping and expressed interest in applications beyond the 1987 Grasshopper Campaign. Even though delivery time for receiving the maps during the 1987 pilot project was a problem, the maps appeared to have considerable potential for monitoring vegetation in relation to agriculture production, pastural areas, drought areas and rainfall patterns. Information on vegetation status in southern Mauritania is difficult to acquire because of the size of areas to be monitored, the relatively low population density and the nomadic nature of the indigenous people. An interest was expressed for an in-country processing capability and telecommunications link for transmission of the AVHRR data. Such capabilities would improve delivery of the needed information as well as broaden the applications of the greenness mapping technique. The major uncertainty in developing in-country processing appeared to be the method of funding such a project.

Staff of The Agriculture Development Office felt the vegetation greenness mapping should be continued and the major area for improvement is delivery time. In addition to targeting areas of potential grasshopper infestations, several other applications important to Mauritania should be investigated.

2. USAID/FEWS Mauritania

The FEWS representative in Nouakchott was provided copies of the greenness maps during the 1987 pilot project. The maps were considered to be the best information on vegetation greenness and rainfall patterns available and were used regularly to prepare FEWS reports.

Because of the utility of the maps in the FEWS program, it was felt that FEWS should participate in part of the funding for continuation of the project. Multiple donors should pay for a ground processing system so they can process and plot data to satisfy a number of applications.

The timeliness needs to be improved but FEWS can use the data as it currently is provided. The format should remain the same for at least another year. Important characteristics of the maps are their ease of use and understandability.

IV. RECOMMENDATIONS

The following are recommendations made during the pilot project evaluation.

A. The vegetation greenness maps should be continued operationally in the future.

B. A regional map covering Mauritania, Senegal, Mali, and Niger should be considered in order to assist in monitoring greenup from south to north.

C. Consideration should be given to preparation of greenness maps for northern Mauritania to monitor desert locust habitat.

D. Delivery time should be improved so the maps are available in-country 2-3 days after the data processing cycle. The cycle time should be changed from 2 weeks to 1 week because of the dynamic changes that occur in Mauritania.

E. Geographic detail including arrondissement, department capitals and provincial boundaries should be added to the maps.

F. The greenness index scale should be expanded for better vegetation discrimination in drier areas.

G. Consideration should be given to developing an in-country processing capability to improve data availability and to broaden the applications of the data.

List of Contacts

NAME	AGENCY
Mr. John Vincent	DCM, U.S. Embassy, Mauritania
Mr. Arthur Lezin	Director, USAID/Nouakchott Acting Chief, ADO, USAID
Dr. Walter W. Boehm	Deputy Director, USAID/Nouakchott
Mr. Bill Thomas	Contractor, USAID
Mr. Jeff Coupe	FEWS, USAID
Mr. Galledou Tahara	Director, Crop Protection Service
Dr. Nsomlie Magema	Chief Council to FAO
Mr. Ibrahima N'Bass	AGRHYMET, Nouakchott
Mr. Diakite Yacoube	AGRHYMET

Appendix IV

Project Evaluation Results in Niger

I. Situation Report

The initial request for greenness maps was made in August because of a potentially serious locust outbreak. The OFDA Disaster Consultant, Charles Kelly, initiated the request through the USAID/Niger mission. Dayton Maxwell was the designated mission contact.

Two sets of maps were provided to USAID. A 1:2,500,000-scale national map, and a 1:1,000,000-scale map covering the Air/Temensa Region were sent to Niamey every two weeks. The greenness maps were distributed to the following organizations:

- Famine Early Warning System (FEWS)
- Government of Niger (GON) Protection des Vegetaux (Crop Protection Service - CPS)
- United Nations, FAO
- USAID/Niger Grasshopper Project

The main uses of the maps in Niger were for grasshopper and locust programs. Due to the late start of the Niger program, little effort was devoted to the exploration of additional uses of the products.

USAID, particularly Charles Kelly, was the catalyst that got the greenness maps into the Niger grasshopper and locust control programs. Kelly demonstrated the use of the maps to both the CPS and FAO. The CPS became users of the greenness maps following Kelly's demonstration of their interpretation and utility.

The CPS has the responsibility for operational grasshopper and locust control in Niger. The USAID mission does not actually get of information used by the CPS for determining plans of action were situation reports sent in by field staff. USAID also used the CPS situation reports to track grasshopper and locust problems. FAO also contributed intelligence that was used by USAID and CPS for assessing the severity of grasshopper and locust infestations. The FAO was considered to be the most reliable source of information in Niger. In addition to CPS and FAO reports, USAID would make field trips and visit the Department heads in order to find out what was going on.

USAID provided significant logistical support in the 1987 campaign. Specific support included the greenness maps, an Aerial Operations Manager for the control program, a helicopter for reconnaissance overflights, and funding for aerial surveillance using chartered fixed wing aircraft.

The main operational use of the greenness maps was for locust problems in the Air Mountains/Tamesna region. While the maps were not received in Niger in time for the initial field effort, interpretations of greenness conditions were made in the U.S. by Gary Eilerts of Price, Williams, and Associates. Eilerts was very familiar with the Niger situation and the information requirements of the grasshopper and locust campaign. As a result, he received the maps directly from EROS and telexed geographic coordinates of potential problem areas quickly to the field. Some green areas on the map, identified by Eilerts, were found to have locust populations in the gregarious stage. Once the maps began arriving in Niger, they were used to identify green areas for field inspection. Based on their confidence in the maps, USAID justified aerial reconnaissance flights to inspect apparent problem areas.

While the maps were used to locate locust populations, locust movement in Niger was extremely rapid and the insects departed before spraying was possible. The swarms originating in the country moved quickly to Morocco.

The Niger grasshopper and locust season is dependent upon the arrival of the rains. Typically, the season goes from mid-May through early-October. Due to poorer rains, the 1987 season went from early-June through September. The locust season begins later and runs through late-October or early-November.

II. EVALUATION OF GREENNESS MAPS

A. U.S. Agency for International Development

USAID staff had an overall positive assessment of the utility of the greenness maps for grasshopper and locust control programs. The AID grasshopper project staff found that the maps were useful for identifying green-up areas and looking for changes in greenness between reporting periods. However, some project staff had difficulty using the maps because of underdeveloped map reading skills.

While there was initial skepticism of the value of the 1:2,500,000-scale country-wide maps, the mission was amazed at the power of the maps for convincing people of the situation in the field. They increased people's awareness of the severity of the problem. The country maps became a valuable public relations tool.

There is ample evidence to support the value of the maps. Specific examples include:

- The maps save money. One fixed wing charter flight into the Tamesna Region costs nearly $7000 more than the cost of one month of maps.

- The maps provide a means to reduce the amount of aerial reconnaissance and allow more efficient use of ground surveys.

- The maps were used to identify green areas in Temensa. Aerial inspection of selected sites identified using the maps were confirmed to have locusts.

There is no question that the 1-kilometer resolution is worthwhile. It is possible to interpret vegetation conditions in drainages and locate specific land features more accurately than with coarser resolution data.

The key mission concern about the maps is that they arrived very late. For the maps to have utility, delivery must be improved. DHL is too slow in Niger. Because of the delivery route, DHL takes about 10 days. It goes to Paris, Abidjan, then Niamey. Mission suggests that EROS try regular international mail which goes to Niamey directly from Paris. Delivery time for international mail is approximately 6 days.

A second mission concern was that the NDVI classes were not as sensitive as the information presentation scheme used with the Ambroziak Color Coordinate System. The mission has not conducted tests to verify this opinion. It likely reflects confidence and familiarity in greenness products provided for several years to the USAID mission.

Training and technical assistance is crucial in order to increase map utility in Niger. USAID use of the maps was limited because few on the staff knew how to use or interpret the maps.

USAID is very interested in the role that AGRHYMET could play in the project. They would like to see EROS pursue increased use of AGRHYMET.

The Mission is not sure they could pay for the maps. They would prefer that USAID/Washington fund the program. If mission funds were to be used, training would be a necessary part of the package.

B. Government of Niger

Mr. Mouddour, head of the CPS, endorses the greenness mapping program and hopes that the maps will be available again in 1988. His office is responsible for controlling all pests in Niger. They are the key agency designated to provide spraying for grasshopper and locust control. He said he found the maps to be quite useful for making decisions on whether to conduct field work.

The 1:2,500,000-scale national maps gave a useful perspective on the rainfall situation and vegetation conditions. When rural officials contacted Niamey CPS with reports of serious problems, the country-wide maps were used by decision makers to quickly verify field reports.

The CPS believes that training is the key to the program. A manual that guides users in map interpretation would be very helpful.

C. Others

The FAO believed that the greenness maps were well made and had value in the locust campaign. There was not, however, confidence in the interpretations made from the maps due to a lack of understanding of the NDVI information.

The FAO's major criticism of the maps was timeliness. They believe that the added expense needed to deliver the maps within 7 days is warranted.

The FAO would like to see the program continue in 1988 and expanded to cover other countries in the region. Training and the provision of knowledgeable experts must be a component of the program.

III. RECOMMENDATIONS

All greenness map users concluded that the maps would be beneficial in Niger if provided operationally. The ideal program should not cost more than $50,000 to $60,000 per country for 5-6 months of services. At this cost, the maps would be cost effective and result in a reduction of other costs associated with helicopter rental, aerial surveys, and ground surveys. However, program specifications should be changed. Recommended program changes include:

- Decrease map delivery time.

- Produce 2-3 copies of the 1:2,500,000-scale maps that can be used in Niamey by GON decision makers.

- Produce 1:500,000-scale maps that cover the entire southern third of Niger. This would require four separate maps. These could be prepared with less category detail so that the maps could be blueprinted. For field activities, map scales of 1:500,000 would be more useful than the 1:1,000,000-scale maps. Aerial navigation is usually done with the larger scale maps.

  The CPS would like to see the maps include the addition of a grid overlay that corresponds to the reporting grid they use to communicate with field personnel. The use of the grid would help guide staff to areas that need spraying.

- Provide a training and technical assistance program. The program should include awareness training for decision makers, detailed training of technicians, and have an expert available for consultation. A single short course is not enough. Technical assistance through an on-site expert is needed to answer questions during the growing season. Local geographic organizations such as Agrhymet in Niger have staff that could serve this need. Regionalized training is a good idea. Agrhymet is a good candidate for providing regional technical assistance. CRTO is also a candidate, but it is doubtful that it would be successful. All training and outside technical assistance must be given in French.

- Provide more copies of the maps so that more copies can be sent to GON agencies.

An ideal program would routinely provide national maps, but still permit production of customized products as the need arises. In addition, there are other products that would be useful including:

- Coordinates of green areas.

- Telex summaries of changes in greenness. These would need to be interpreted by someone familiar with grasshopper project needs.

While map delivery is slow, DHL is not the only problem. DHL can get materials to Niamey in 7 days. The problem may be related to shipping materials in map tubes. USAID recommends sending a telex to the country informing USAID of shipment. USAID staff can then go to the airport and look for the maps, potentially eliminating airport delays.

There is also a need to study the relationships between NDVI and field conditions so that map users have a better understanding of the meaning or NDVI categories.

USAID endorses the continuation of the project in 1988. They stress the need to eventually transfer responsibilities to AGRHYMET. The program should be continued in a way that does not disrupt AGRHYMET's AVHRR plans. AGRHYMET hopes to have an operational capability by mid-1988. The ideal mission plan includes a continuation of the project in 1988 with EROS support and a strong organizational link to AGRHYMET. EROS could transfer the capabilities to produce the maps to AGRHYMET in a phased program beginning in 1988.

IV. OTHER APPLICATIONS

Most people contacted recommended other Niger programs that may benefit from the greenness maps.

USAID/Niger is involved in a multi-year project entitled Niger Integrated Livestock Pilot Project (NILPP). The project is being conducted with the GON Livestock Service. Much of the work is being done by New Mexico State University. The goal of the project is to look at developing dry-weight biomass production estimates using field data correlated to aerial photo derived information. A current problem in the project is that the recurring costs of aerial photography is prohibitive so they plan to look at the use of either Landsat or SPOT imagery. The ultimate goal of the project is to map the country into classes similar to range sites. The range sites would then serve as the biomass production monitoring units. A significant database is being developed for the project. The USAID project manager hopes that AGRHYMET will have the data analysis capabilities needed for an operational program. He is especially hopeful that the information can be integrated into a GIS so that the data can be used in a variety of applications. There is real potential for using the greenness maps for monitoring activities in this project. A quick comparison of the NMSU field data (KG/hectare) to greenness maps covering approximately the same period (September 24) shows significant similarity in measured biomass amounts to greenness patterns. The GON ultimately plans to establish a network of field agents to carry out field data collection. The project is scheduled to continue another 18 months.

The Direction de la Meteorologie Nationale is the Niger AGRHYMET cell. They are responsible for the preparation of agrometeorological bulletins describing rainfall and drought conditions. The group was not on the distribution list for the greenness maps, but had a chance to work with some of the maps and saw much value. The believe the maps could be used to track the ITCZ and green-wave movement. They have used the 1 by 1/2 degree greenness index information provided by NOAA. While the NOAA information was useful, it lacked the detail needed for other applications. The LAC-based maps would be very useful in the preparation of their decadal Agrometeorological Bulletins. They also believe the maps should be provided to the GON ministerial group assembled to review and summarize land conditions. The group includes representatives of the Ministries of Agriculture, Animal Production, Plans, and Interior.

The CPS recommends that the maps be provided to the GON Livestock Service. They should also be considered for use in a planned early warning system that is proposed by FAO and UNDP.

FEWS use of the maps was limited. The FEWS program in Niger concentrates on public health and nutrition problems rather than vegetation condition assessment. Their soil use of the greenness maps was to verify other sources of information. The FEWS Public Health Advisor (PHA) believes that the GON Meteorological Service should routinely receive the maps since they are responsible for preparation of agrometeorological bulletins.

List of Contacts

U.S. Agency for International Development
Dayton Maxwell, Agricultural Development Officer
Dennis Panther, General Development Officer
Flynn Fuller, Project Officer, Grasshoppers
Kevin Mullallay, Deputy Agricultural Development Officer
Mark Madland, Project Officer, Integrated Livestock Project
Julie Reid, Project Assistant, Grasshoppers
Mahamane Kondo, Project Assistant, Grasshoppers
Shawn Baker, Tulane University, FEWS Public Health Advisor

Goverment of Niger
Ismael Mouddour, Directeur, Protection des Vegetaux
Alio Maidoukia, Agrometeorologiste, Direction de la Meteorologie Nationale

Others
Lene Poulsen, Niger Project Officer, United Nations FAO
Mr. Germeaux, Consultant, Grasshopper and Locust Campaign, United Nations, FAO
Jelle Hielkema, Remote Sensing Officer, United Nations FAO
Gustavo Necco, Director of Training, World Meteorological Organization
Burkina Faso Agrhymet Representative
Sudan World Meteorological Organization Representative
Egypt World Meteorological Organization Representative

Appendix V

Project Evaluation Results in Chad

I. SITUATION REPORT

Greenness maps were produced for Chad starting in late-August for use in locust control programs. They were provided under the sponsorship of the Famine Early Warning System (FEWS). The Chad greenness map set included a 1:2,500,000-scale national map and a 1:1,500,000-scale map covering the east-central region of Chad. The contact in USAID for the greenness map program was Kurt Fuller, Agricultural Development Officer. Fuller supervised the distribution and use of the maps within the FAO, the Ministry of Agriculture, Chief of Field Operations, and the USAID/Chad mission.

Reports of locust outbreaks in eastern Chad caused considerable alarm. The locusts were feared to become a continental problem if they transformed into a gregarious state. There was hope that the control campaign, with proper resources, could eradicate the threat before populations reached major proportions. Unfortunately, the locusts in their eastern Chad recession area transformed into the dangerous condition.

The key organizations involved in locust and grasshopper control in Chad are USAID, FAO, and the Government of Chad (GOC) Ministry of Agriculture. Operational assistance responsibilities to the GOC are divided between the United States and France. The United States is responsible for the eastern half of the country while the French work in the west. The FAO was responsible for coordinating control through the Ministry of Agriculture.

FAO provided a helicopter for use in reconnaissance, but it was frequently ineffective because it was not permitted to fly in some parts of the country. In addition, the pilot did not have sufficient information to direct the aerial surveys, so use of the helicopter was not always productive. Among the reasons for requesting the greenness maps was the travel restrictions and need for direction. The maps allowed the development of plans for directing field survey parties.

Surveillance was done using both field crews and aerial reconnaissance. Prospecting was commonly done by checking up on field reports. The problem areas were too large for routine surveillance so officials had to rely on reports. An additional problem is that travel is restricted in much of the country. Mines laid in eastern Chad during the Libyan occupation create dangerous field travel conditions.

Interpretations of the greenness maps was carried out by Kurt Fuller. He would identify green areas and the MOA would then direct field staff to those areas. Fuller had confidence in his ability to interpret the maps. He felt that patterns were usually, but not always, reliable. The biggest problem he had was that the field parties were not always able to locate the correct areas due to poor map reading skills.

USAID and the MOA would like to try to use the 1987 maps for planning 1988 campaign strategies. They need a July, 1987 map so that they can develop a better understanding of field conditions during the early stages of the grasshopper and locust infestations.

There is no consensus as to the potential severity of the 1988 grasshopper and locust control program. The USAID entomology consultant thought that the grasshopper situation should not be as severe as 1987. He felt it should certainly start slower than the past year. With early ground spraying in 1988, grasshopper populations should be controllable. Others felt that there was a good change for continued problems. The maps would be useful in 1988 in order to effectively initiate and carry out a surveillance program. Fuller would have preferred to have participated in the program from the beginning. The extra information would have been beneficial. A 1988 control program would certainly be more effective if the maps are provided beginning early in the campaign.

II. Evaluation of Greenness Maps

A. U.S. Agency for International Development

The overall conclusion of the USAID staff, who had used the greenness maps, was that they were a beneficial tool for locust control activities. While the greenness maps came later than desired, they were still useful. The mission realizes that their late request for maps was a big reason why the program got off to a slow start. The greenness maps would have been more useful if they had been provided throughout the growing season.

The USAID mission did not request the country-wide greenness maps. They only needed the larger-scale map (1:1,500,000) covering the eastern portion of Chad. This series was needed for locust control. The scale of the maps used in the field is 1:200,000.

Timely delivery of the greenness maps was a problem. The first maps arrived almost one month beyond the date of the AVHRR data used in the maps. After that, the maps arrived on a regular two-week interval, but the data were approximately two-weeks old at the time of arrival. While the maps were very late, too late for some applications, they were still used to gain a perspective of the general situation.

Specific comments concerning the characteristics and utility of the greenness maps include:

- The maps have more potential value in locust control rather than in grasshopper programs.

- The map format was good and the plastic lamination was useful since the maps were taken in the field and were handled extensively.

- The two week composite period was adequate. It should not be lengthened or the information would be too old.

The October 10 maps were not distributed because of apparent imagery problems. Rather than risk having the GOC make incorrect interpretations, USAID decided to withhold the set.

B. Government of Chad

Chad had a difficult year in trying to handle its grasshopper and locust problems. There was very little money available for control activities and the little there was, was frequently wasted because nobody knew where to go. Field parties were operating with little direction. The greenness maps finally provided the GOC with a chance to focus their efforts in areas that had a higher likelihood of having problems. The Director of Agriculture quickly saw the value of the maps and personally carried copies to Abeche for use by the field staff. The maps, with the assistance of Kurt Fuller, were used to direct field parties in the Abeche area. There is much value in the maps and the Ministry of Agriculture plans to keep using them if they are available in 1988.

C. Others

The FAO grasshopper and locust consultant was initially a skeptic of the greenness map program. He has used satellite imagery before and did not believe that the greenness maps would be useful. After receiving the first sets of maps, he changed his mind and became an aggressive advocate of the program. He then pushed MOA staff to use the maps.

The greenness maps were an excellent addition to the grasshopper and locust campaign. While the FAO did not have copies for use in the field, they were viewed as a great tool in the hands of the field staff. An initial FAO comparison of areas with serious infestations to the greenness maps showed strong correlation.

The map design was very good and does not need significant modification. The addition of more towns and the names of selected wadis would be useful.

The value of the maps for grasshopper control is less than in the locust campaign. Once an area greens up, green vegetation is everywhere and it is difficult to pinpoint problem areas. At this point, it would be good to know the location of the crop and pasture lands. If this was known, it would be possible to place priorities in areas where the risk to croplands would be greatest.

III. RECOMMENDATIONS

USAID, FAO, and GOC greenness map users endorse the program. The greenness maps were beneficial and will be helpful if they are provided in 1988. They were a tool whose utility was quickly demonstrated. The major reason for using the maps is for making objective decisions instead of relying on hearsay from the field. If the program is continued, USAID should continue to be the program coordinator. They can insure that the maps will be quickly and fairly distributed.

Mission staff believe there is enough potential information in the greenness maps in the grasshopper and locust control program to justify program continuation. They are unsure of the value in other programs. They doubt that the maps would be useful for crop production assessments, but think the maps would be useful for livestock management activities. There is some concern, however, that the level of management is too low to effectively use the available information.

The scale of the 1987 maps was acceptable. However, the field teams typically use 1:200,000-scale maps, so if the greenness maps are at that scale, they would be easier to use. This is viewed as a desirable rather than mandatory option.

Recommendations for program improvements include:

0 Reduce delivery time. The absolute latest acceptable delivery of maps to N'Djamena is two weeks. Five days would be optimal. DHL delivery depends on when you hit the Paris-N'Djamena flights. There are only two flights per week so a day late can cause a four day delay in delivery. The key to timely delivery, therefore, is to schedule map shipments to arrive in Paris a day before the N'Djamena flights.

- Consider using telex transfer of information during critical periods as a means for rapid transfer of information.

- Training in map use would be very helpful. Most users did not understand the meaning of the categories on the maps. Some level of training is needed to help understand uses and interpretation of the greenness maps. The training does not need to be too elaborate or long. It would be best to train field staff so that they can use the maps effectively for field prospecting and control.

- Provide maps from May through October.

- There is a need to have a better understanding of the meaning of the NDVI categories. For example, what NDVI level is associated with emerging vegetation?

The ideal maps would provide information describing the condition of vegetation by land use conditions. Grasshoppers prefer grasses over crops (millet and sorghum), so it would be good to know the location of grasslands.

Higher resolution Landsat images would also be a useful tool for the locust and grasshopper campaign. The false-natural color images show the landscape in the same appearance as it is when viewing from an aircraft. The drainage detail, in particular, is excellent. Scenes covering key areas would be most useful for both aerial and field activities.

While there is interest in having AGRHYMET provide the greenness maps, there is concern that they may not be able to meet users demands. The mission is very concerned about the services provided to Chad by AGRHYMET. The Centre has been slow in providing technical assistance to Chad. The organization's management is poor and they are not good at delivering scheduled services. Chad seems to be a low priority for AGRHYMET, which has created disappointment in the country.

IV. OTHER

The MOA Director of Agriculture would like the maps to be provided to all of the directors in the Ministry. He believes they would definitely see applications in many of their programs.

There are several potential users of the greenness maps, including the Ministry of Livestock, and Plant Protection Service. Both groups could use the maps for monitoring of crop and pasture land conditions. There is interest in Chad in influencing the movement of livestock to areas with better pasture conditions. The Ministry of Livestock should be encouraged to investigate use of the maps for this application.

The full set of maps are now being used to determine priorities and strategies for next year's program. The areas that had grasshopper sittings, and the areas sprayed, are being plotted on the greenness maps. They plan to use the plotted information to determine areas that were not inspected this year, but have conditions appropriate for grasshoppers and locusts. These areas will be the first inspected in 1988. In addition, the MOA is planning an egg pod survey in December, 1987. The maps will be used for prioritizing survey areas. It is hoped that this year's survey will be more effective than the previous year when they had to randomly determine where to inspect.

List of Contacts

U.S. Agency for International Development
Bernard Wilder, USAID/Chad Representative
Kurt Fuller, Agricultural Development Officer
Leroy Jackson, Program Development Officer
Les McBride, Food for Peace Officer
Haroun Kabadi, Assistant Agricultural Development Officer
Habib Khouly, Entomologist, Locust and Grasshopper Campaign
Charlotte Sharpe, Tulane University/FEWS

Government of Chad
Ngaro Millet Michel, Director of Agriculture, Ministry of Agriculture

Other
John Egelele, FAO Consultant on Locusts and Grasshoppers, Emergency Program