SOME IMPLICATIONS OF REMOTE SENSING TECHNOLOGY IN INSECT CONTROL PROGRAMS INCLUDING MOSQUITOES[1]

C. M. BARNES

Biomedical Applications Branch, Medical Sciences Division, Space and Life Sciences Directorate, L. B. Johnson Space Center, Houston, Texas 77058

W. G. CIBULA

Land Applications Group, Earth Resources Laboratory, NASA, National Space Technology Laboratories, Slidell, Louisiana 70458

ABSTRACT. Preliminary investigative work concerning the applications of remote sensing technology to classification of vegetation and terrain which have implied public health and insect control significance has been described. The research concerned definition of mosquito breeding habitat using multiband aerial photography and multispectral sensing from aircraft. Photography is the least expensive remote sensing system yet both methods do an excellent job of defining environment and vegetative habitat. It appears feasible to utilize LANDSAT satellite imagery to classify into broad ecotypes the vegetation sometimes associated with insect development. Research has been limited to one mosquito species *Aedes sollicitans*. It seems likely that other species may be studied using similar technique.

Satellite remote sensing has also been used to define temperature, altitude, and vegetative cover for all of Mexico on a twice daily basis. This program was designed to support studies of the screwworm fly, *Cochliomyia hominovorax*, in that republic. A computer system was designed to accept satellite information, fit it to an insect model and produce imagery indicating best estimates of where the screwworm fly populations can survive and grow based entirely on weather and environmental considerations.

INTRODUCTION

The space agency has been conducting pilot studies concerning the ability of spacecraft and aircraft sensors to observe the earth and collect data considered important in the disciplines of environmental medicine, geographic pathology, ecology, and entomology. About 6 years of basic studies have been completed by the Johnson Space Center staff at Houston, at the Slidell, Louisiana, Earth Resources Laboratory, and by several contractor support groups. During this time, lectures, workshops, and seminars have been held with several groups varying from local medical societies to county, state, national, and international health workers, and environmental scientists. These basic concepts for use of aerospace systems as adjuncts to existing health and insect vector control procedures have been received with cautious enthusiasm. Some have indicated a lack of understanding of this complex discipline due to the "newness" of such concepts. The majority suggest that the use of remote sensing will be particularly appealing to agencies responsible for broad area disease control in developing countries having minimal public health facilities. International health organizations have requested technical assistance and liaison to combat specific problems in country development. Our preliminary evaluation of their requirements makes us realize that while significant progress has been made, we still have an inadequately developed technology. It appears that there is a basic requisite for continuing remote sensing research within the federal government or at university laboratories.

CONCEPTS AND EXPERIENCE IN REMOTE SENSING

Certain unique systems developed by NASA may be able to contribute to im-

[1] Presented at the Chicago meeting, April 1978.

provements in the operating methods of existing health agencies. As an example, 1 epidemiologist has written that NASA's remote sensors give him "new eyes" to see more clearly the big picture of the problems with which he contends (Cline 1971). Indeed, because of aircraft and satellite altitudes, there is an increasing opportunity to accurately see larger geographic areas and to determine how certain physical features (swamps, mountains, rivers, valleys, etc.) contribute toward understanding the environment and the continuance, recession, or control of disease (Fig. 1).

MAPPING. Our experience within a southern Mexico test site indicates some of the difficulties of securing accurate, detailed maps of certain regions of the world. For example, specific villages, important as ground checkpoints, would vary between 1 to 10 kilometers from their actual location as determined by space imagery. Precision in mapping is important for many reasons, but particularly so if one is to use aerial delivery systems for insecticides or pesticides.

Concerning mapping, the World Health Organization has stated that the simple identification of grasslands and the location of their interface with forested areas in inadequately charted areas of Africa can be helpful in understanding the habitat of simians which harbor several important human viral diseases such as yellow fever.

Virologists at the USPHS Communicable Disease Center have commented on the value of remotely sensed fresh water-salt water interfaces seen from space. This zone supports ecologically the development of forest hammocks in Florida and is well known as the habitat of *Culex atratus*, the mosquito vector of a strain of Venezuelan encephalomyelitis virus.

Preliminary work at Houston in the Trinity River basin has led to the theorem that the Landsat satellite images of the area can adequately define salt marsh mosquito *Aedes sollicitans* breeding habitat (Fig. 2). It is now believed that 80% of these mosquitoes are produced in only 10% of the terrain. If this is typical of other river basins of the world where salt marsh mosquitoes may be serious vectors of disease, it appears theoretically possible to control major populations of these mosquitoes with insecticide release over proportionately small areas. The resultant savings in cost for spraying as well as the value of releasing decreased quantities of insecticide to the environment could be quite attractive. In both of these cases, it is obvious that satellites cannot "see" mosquitoes—rather, they can define terrain, geographic features and the vegetative ground cover which has in some cases, been shown to be directly related to breeding habitat. NASA currently has in inventory imagery from many river basins. Some of these river areas undoubtedly contribute to local mosquito problems. It seems important to release such data to health officials of the countries concerned.

COMPUTER ANALYSIS. Of equal importance to the large areas viewed by space systems is the capability for collection and reduction of remotely sensed data by modern analytical methods. Because of the diversity and quantity of detailed information required to assess accurately the vagaries of disease habitat, it is essential that all potentially valuable information be collected, sorted, and presented to the investigator in formats which can aid in diagnosis and/or solution to the problem. Formats vary between the elementary to those of extreme sophistication. Sometimes black-and-white photography or simple computer printouts are adequate for the purpose. Occasionally, a false color coded presentation can separate different data on the same image and do a superb job in explaining the relationships between them. This could mean that the more expensive color procedure may, in the long run, be more cost effective. Examples of information collected and formatted are temperatures (including degree day sums, gross estimates of moisture conditions, altitude, cloud cover, vegetative cover, and terrain characteristics.

For many purposes, not only must the data be synoptic, they must also be collected in real time or within an appropriate time frame allowing responsible officials to develop a compatible disease management strategy. Only within recent years with the advent of modern computers and software has this capability existed. The Johnson Space Center Health Applications staff has demonstrated the current state-of-the-art in at least 1 research and development program (the screwworm data system). Routinely, this system provided 14 kinds of environmental data on a daily basis within 5 days after passage of the satellite. These data consisted of millions of bits of environmental measurements in a geographical region 760,000 square miles in size. The resolution used varied between 1 and 4 km depending on the need for that particular information. The 5-day delay was perfectly adequate for studies of this specific insect vector (*Cochliomyia hominovorax*). A 24-hour turnaround could have been provided if required for the problem (Fig. 3).

WETLANDS INVESTIGATION. Personnel at the Earth Resources Laboratory (ERL) at the NASA National Space Technology Laboratories (formerly the Mississippi Test Facility) are conducting a series of investigations to develop remote-sensing techniques that apply to the study of wetlands. For one of these investigations, a 24-channel multi-spectral scanner was used.

By using computer-determined vegeta-

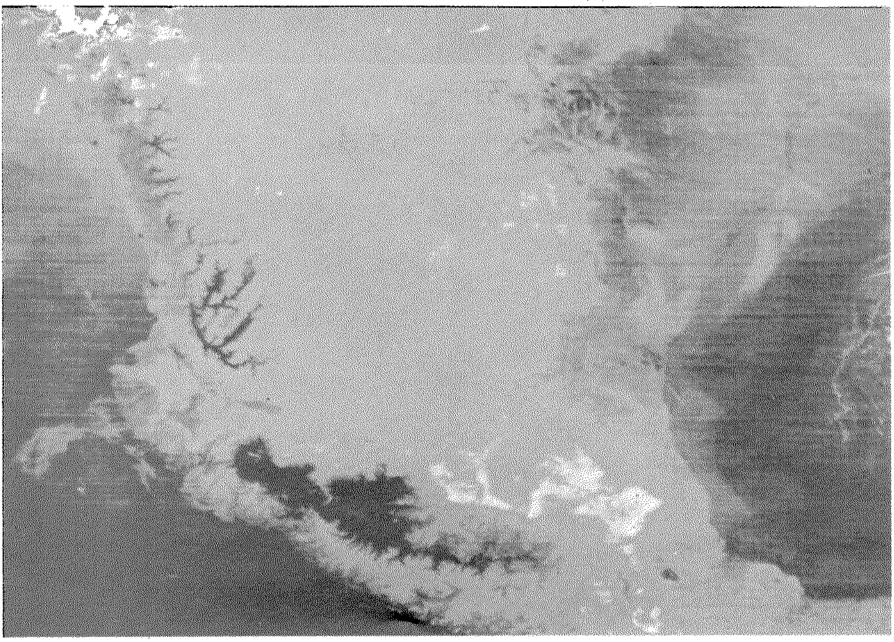

Fig. 1. An Isothermal image of Mexico viewed from 1300 km altitude by ITOS II weather satellite. Note detailed temperature differential of the canyon areas in NW Mexico and Balsas River in central portion. Blue is warmer than highlands which are yellow.

tional classes, known relationships between plant species associations and the egg-laying habitats of the salt marsh mosquito were employed to outline the probable areas where mosquito control would be most effective. For this purpose, vegetational types were analyzed for indications of positive or negative mosquito-breeding terrain.

The study area is part of an older portion of the Mississippi Delta (an extensive alluvial plain having little relief that gradually slopes toward the Gulf of Mexico) and is very near sea level over

Fig. 2. Trinity River basin in Texas as viewed from LANDSAT I. Vegetation is identified as red = pine forest, green = hardwood forest, pink trees standing in water, yellow = wet grass, black = unclassified, and blue = various types of water. Image courtesy Coastal Analysis Team, NASA.

most of its extent. In some regions, elongated-to-circular areas locally known as cheniers that are several feet higher than the surrounding marsh are found. These elevated areas are believed to be either former barrier beaches or outlying fragments of the Gulf Coast.

It is apparent that minor changes in elevation cause major changes in the nature of the plant communities that are present. Penfound and Hathaway (1938) reported: "It should be emphasized also that the transition from one community to another is conditioned by a change in elevation of as little as three inches since four communities may occur on a slope having a fall of less than one foot." This transition is representative of most communities in the study area. Deep water may be covered with the white waterlily (*Nymphaea odorata*). In shallow water immediately behind this, four-square grass (*Eleocharis quadrangulata*) is found; and, in the intertidal area, the wiregrass/blackrush or spikerush (*Spartina patens/Juncus roemerianus*) association is seen. On slightly higher elevations, normally above the intertidal zone, southern wax-myrtle

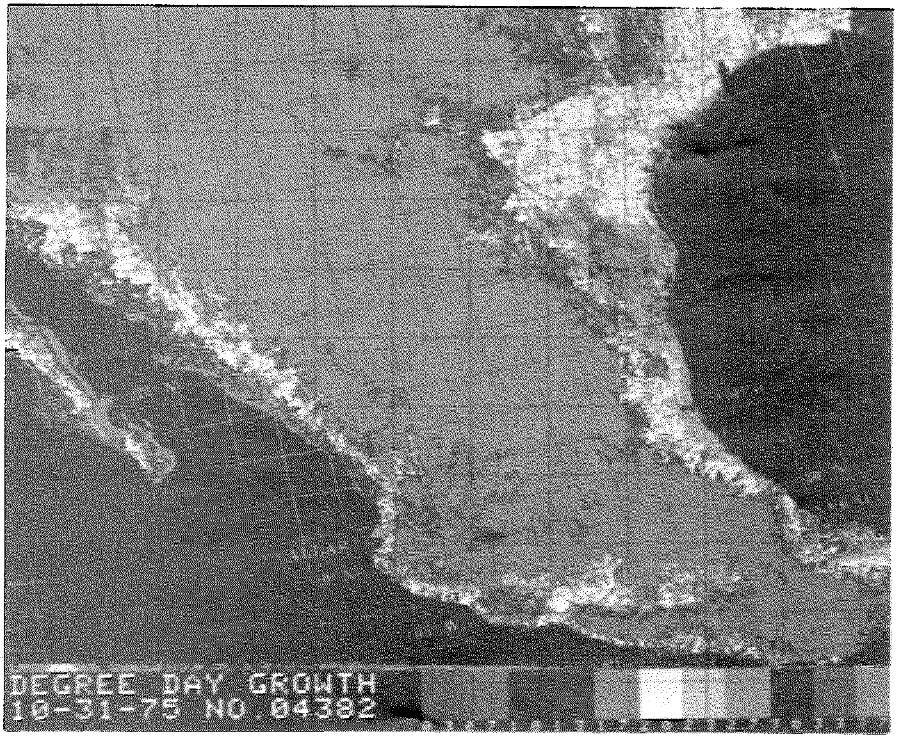

Fig. 3. False color image of Mexico indicating where temperatures have provided sufficient degree days to permit growth of screwworms. Blue indicates declining populations, green = stable growth conditions, tan to red = conditions ideal for an expanding population.

(*Myrica cerifera*) and eastern baccharis (*Baccharis halimifolia*) are found; on still higher ground, stands of slash pine (*Pinus eliotti*) and loblolly pine (*Pinus taeda*) or live oak (*Quercus virginiana*) may be seen.

The presence or absence of certain species associations has been shown to depend in part on the mean water depth present in the marsh. Also, the salinity of the marsh exerts yet another controlling influence on these associations. Therefore, it is evident that inferences can be made about the nature of the environment from the vegetation present. If the ecological niches occupied by other life forms can be determined, it may well be that vegetation can be used as a tool for identifying these other ecological associations. Because the salt marsh mosquito breeds primarily in the intertidal zone, which is occupied by the *Spartina patens*/*Juncus roemerianus* association, these areas can be examined in detail to learn whether differentiation from other plant communities can be accomplished by using remote-sensing techniques.

MULTI-SPECTRAL SCANNER[2] The multispectral scanner system (MSS) used for this study is an airborne imaging spectrometer. In operation, scanning is accomplished by means of a rotating mirror that, combined with the other optical components, has an angle of acceptance of 2 milliradians (0.1146°). The mirror rotates so that the sweep of the spectrometer field of view is perpendicular to the flightpath. The total sweep or scan angle is 80°, consisting of a scan line beginning at 40° to 1 side of vertical and extending to 40° on the other side. As the mirror rotates, the MSS acquires time-coherent spectra, covering the dynamic range from 0.3 to 13 micrometers, from each element. Each scan line consists of 700 elements. The projection on the ground of the 2-milliradian angle of acceptance determines the element size, which obviously is a function of altitude. From an altitude of 1220 meters (4000 feet), an area 2.4 meters (8 feet) in diameter is examined at any one instant; whereas from an altitude of 6100 meters (20,000) feet), an element would be 12 meters (40 feet) in diameter. For each element in each scan line, the reflected or emitted radiation is divided into 24 channels, and the signal developed by each channel is recorded on a tape recorder. Figure 4 is an illustration of the sensor capabilities that are available in the MSS as compared with the range of human vision and with some other more common receptors of data.

The scanner yields a reflectance/emittance spectrum that differs for differing materials and is the basis for classification when using this scheme. These spectra are quantified to allow classification of an unknown element by comparison with the known spectra of a particular element.

VEGETATION CLASSIFICATION. The plant communities were classified by using several computer programs and data reduction techniques. The display used to give the most immediate readout was a character display in which particular alphabetic characters represented particular classification types. Each element was given an alphabetic letter to represent particular vegetation types (Fig. 5).

Color coded products were generated by using an SC 4020 plotter to produce 3 sets of color masks. These masks were then superimposed on an I^2S Mini Adical viewer using red, green, and blue lights, respectively, to illuminate each mask. The display was then photographed and printed. Later, a system was developed which permitted use of 27 different colors resulting in a more accurate classification (Fig. 6).

INTERRELATIONSHIPS BETWEEN VEGETATION AND OTHER ECOLOGICAL FACTORS. A correlation was shown for both salinity and mean water depth with the plant communities that would be present in a marsh having these conditions. During the life cycle of the salt-marsh mosquito

[2] The 24-channel multi-spectral scanner no longer exists. It has been replaced with much simpler systems such as a 5-channel device. The basic principles of operation are the same.

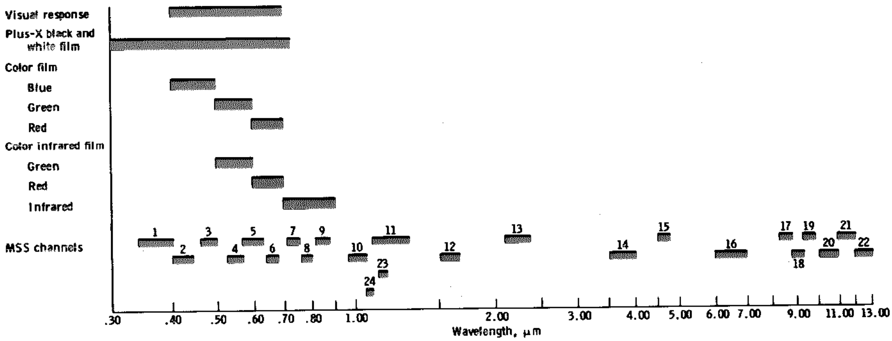

Fig. 4. Spectral characteristics of multispectral sensors.

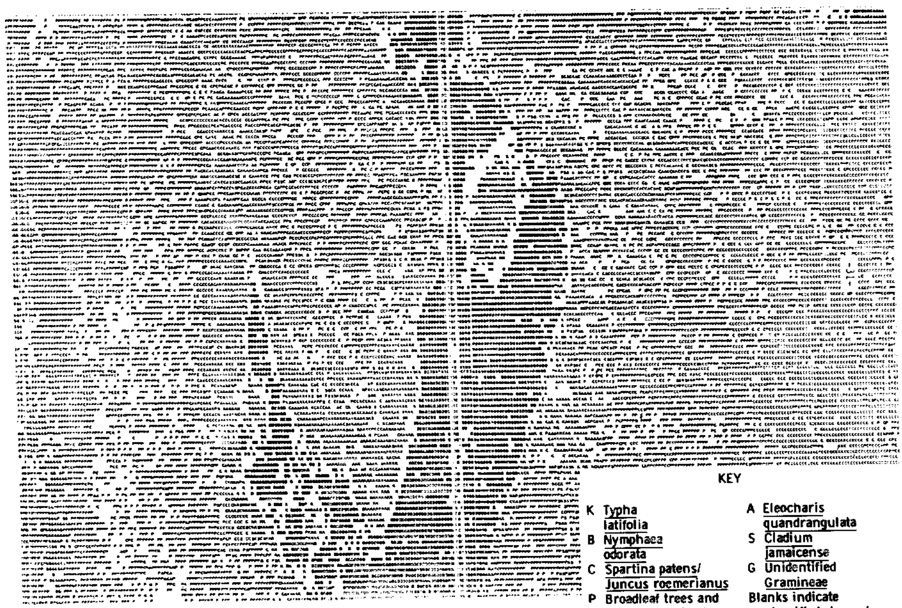

Fig. 5. An example of a character printout in which each letter represents a specific classification.

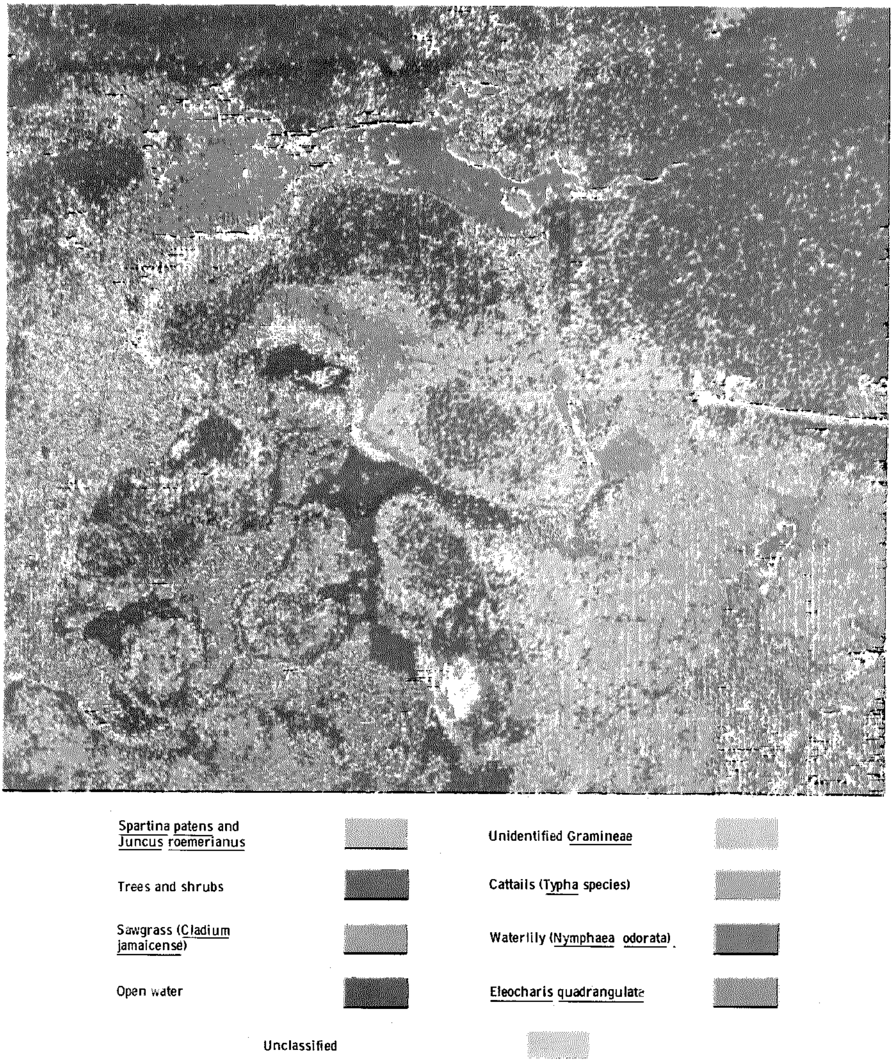

Fig. 6. An example of a multicolor-coded output classifying vegetation by general type.

(*Ae. sollicitans*), the female lays eggs only on soil or leaf litter interstices between plants where there is a periodic removal of water by tidal action. The eggs will not hatch until they are immersed in water. The female of this species of mosquito cannot lay her eggs on land that is primarily covered with water. Conversely, if the eggs are laid in an area where there is no periodic flooding, they will not hatch. Thus, the range for egg laying is restricted to the intertidal area of the marsh that is intermittently flooded with fresh water (Personal communication, Sam Riche, St. Tammany Parish Mosquito Abatement District #2, 1971). By observing the marsh vegetation, it is found that the spikerush/wiregrass association is characteristic of this area. By contrast, stands of cattail, white waterlily, pine and other shrubs, sawgrass, four-square grass, and *Eleocharis microcarpa* are found in areas where the favorable egg-laying habitat does not exist.

By use of the preceding information, the computer is programmed to combine or lump the characters that represent each type of vegetation found in the area that is intermittently flooded with fresh water and to present the total as one character that represents positive mosquito-breeding areas. Likewise, the computer is programmed to add the characters representing other vegetation and to present them as one character representing negative mosquito-breeding areas. The computer output can then be presented (by use of a photographic process to produce the final product) as a color-coded display reflecting positive mosquito-breeding areas in red and negative mosquito-breeding areas in green. Figure 7 is an example of this product. Note that both water and vegetation-covered water are displayed in blue for identifying landmarks; unclassified elements are displayed in white for the same reason. The value of such a display becomes obvious when it is realized that its use may well restrict areas of stern measures for mosquito control to much smaller portions of the map. Savings to be gained are twofold: less expenditure and the confinement of toxic sprays to more restricted areas.

PHOTOGRAPHIC SENSORS. In addition to multispectral electronic sensing, the Johnson Space Center staff has also investigated low altitude aircraft photographic sensors with resolution as small as a few feet. For some activities, these photographic sensors, operated with appropriate filters, can do creditable jobs in environmental analysis. If one can use light aircraft, the cost of precision photography for limited area surveillance is considerably smaller than comparable electronic systems. This can be quite appealing to governmental entities with limited budgets. For example, a photo lab including specialized equipment might cost $10,000 while the electronics for a multi-spectral system might cost several hundred thousand dollars. An example of vegetation differentiation in Louisiana marshland using photographic sensors is given in Fig. 8.

SOME MANAGEMENT PROBLEMS IN THE USE OF REMOTE SENSING

Cited below are some of the problems currently recognized as hindering the rapid development and dissemination of remote sensing technology.

UNDERSTANDING THE TECHNOLOGY: Remote sensing is multidisciplinary in nature utilizing the sciences of physics, electronics, data processing, photography, and systems engineering. The major share of health scientists do not fully understand these disciplines. Training courses, workshops, and demonstration programs must be completed so that public health administrators will be willing to include such adjunct, cost beneficial methods in their armamentarium.

BASIC COSTS OF INSTRUMENTATION AND GROUND TRUTH: Data gathering and processing equipment is not inexpensive. For laboratories without existing computer services and with limited resources, the initial investment required both in hardware and personnel has been found to be a definite constraint. Because the satellite sensor system views large areas and collects many data points, the expense of providing staff, transportation, and communications for the initial large scale ground truth verification of observed data may be almost prohibitive. On the positive side, one might say that never before has one been able to obtain so much data for so little.

DEFINING PRECISE RESEARCH OBJECTIVES: There are many misconceptions concerning remote sensing and how it can be utilized. There are many things that

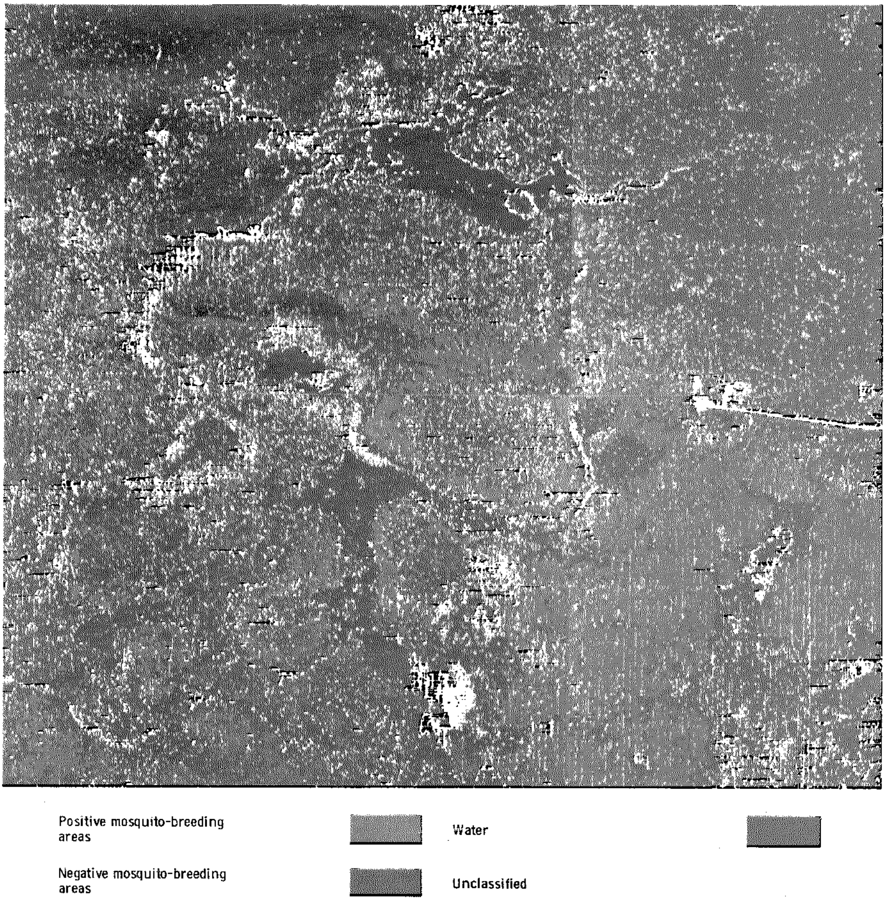

Fig. 7. An example of a color-coded output showing positive and negative mosquito-breeding areas.

Fig. 8. An electronic image from film exposed in the near infrared band. Vegetation is separated into broad categories by this relatively simple photographic procedure.

any new technology cannot do in an effective way. For example, remote sensing will never replace the doctor-patient relationship. On the other hand, it can give the health worker unique information never before available. The systems engineer and other members of the team must work with the health official to determine those objectives which are mandatory, desirable, or can be discarded as wasteful of computer time.

SUMMARY

Preliminary investigative work concerning the applications of remote sensing technology to classification of vegetation and terrain which have implied public health insect control significance has been described. Primary emphasis has been on definition of environmental conditions conducive to the growth and development of insect populations of importance

to human and animal health. Initial activity concerned definition of mosquito breeding habitat using multiband aerial photography and multispectral sensing from aircraft. Photography is believed to be the least expensive and perhaps the most practical remote sensing system for the average mosquito control district. Multispectral electronic sensor systems do an excellent job of defining environment and vegetative habitat. It appears feasible to utilize LANDSAT satellite imagery to classify into broad ecotypes the vegetation sometimes associated with insect development. Research has been limited to one mosquito species, *Ae. sollicitans.* It seems likely that some of the other species, important to health, may be studied using similar techniques.

Satellite remote sensing has also been used to define temperature, altitude, and vegetative cover for all of Mexico on a twice daily basis. This program was designed to support the eradication of the screwworm fly from that republic. A computer system was designed to accept satellite information, fit it to an insect model and produce imagery indicating best estimates of where the screwworm fly can survive and grow based entirely on weather and environmental considerations.

The use of remote sensing in programs of insect eradication and disease vector control is limited only by the imagination of scientific investigators and the willingness of administrators to accept such technology and put it to work for the benefit of all mankind.

References Cited

Cline, Barnett L., 1971. New eyes for epidemiologists. Amer. J. Epidemiol.

Penfound, W. T.; and Hathaway, E. S. 1938. Plant communities in the marshlands of southeastern Louisiana. Ecol. Monographs 8:1–56.

BIBLIOGRAPHY

Anonymous. 1973. Production processing requirements for aircraft electronic sensors. PHO-TR523, Philco-Ford Corp.

Anonymous. 1973. The use of remote sensing in mosquito control, MSC 07644. Health Applications Office, NASA Johnson Space Center, Houston, TX 77058.

Cibula, W. G. 1976. Applications of remotely sensed multi-spectral data to automated analysis of marshland vegetation. NASA Technical Note D-8139.

Correll, D. S. and Johnston, M. C. 1970. Manual of the vascular plants of Texas. Texas Research Foundation, Renner, TX. Vol. 6.

Eppler, W. G., Helmke, C. A. and Evans, R. E. 1971. Table look-up approach to pattern recognition. Proc. 7th Internat. Symposium on Remote Sensing of Environment, Vol. II, Willow Run Laboratories Rept. 10259-1-X, The Univ. of Michigan, Ann Arbor, pp. 1415–1425.

Marill, T. and Green, D. M. 1963. On the effectiveness of receptors in recognition systems. IEEE Transactions on Information Theory, Vol. IT-9: 11–17.

Oosting, H. J. 1956. The study of plant communities. W. H. Freeman & Co., San Francisco.

Penfound, W. T. 1952. Southern swamps and marshes. Botan. Rev. 18:413–446.

Penfound, W. T. and Howard, J. R. 1940. A phytosociological study of an evergreen oak forest in the vicinity of New Orleans, Louisiana. Am. Midland Naturalist 23:165–174.

Rickett, H. W. 1966. Wild flowers of the United States. Vol. II. The southeastern states, W. C. Steere, ed., McGraw-Hill Book Co., New York.

Vines, R. A. 1960. Trees, shrubs, and woody vines of the southwest. The University of Texas Press, Austin.

Viosca, Percy Jr. 1928. Louisiana wet lands and the value of their wild life and fishery resources. Ecology 9:216–229.

Zaitzeff, E. M., Wilson, C. L. and Ebert, D. H. 1970. MSDS: An experimental 24-channel multispectral scanner system. Bendix Technical J. 3:20–32.

Zaitzeff, E. M., Korb, C. L. and Wilson, C. L. 1971. An experimental 24-channel multispectral scanner system. IEEE Transactions on Geoscience Electronics, vol. GE-9:114–120.