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RESEARCH ON ENHANCING THE UTILIZATION OF DIGITAL MULTISPECTRAL DATA AND GEOGRAPHIC INFORMATION SYSTEMS IN GLOBAL HABITABILITY STUDIES

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Edward A. Martinko, Ph.D.
Principal Investigator
Assistant Scientist, Space Technology Center

James W. Merchant, Ph.D.
Co-Investigator
Senior Remote Sensing Specialist
Space Technology Center

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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2291 Irving Hill Drive-Campus West Lawrence, Kansas 66045

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RESEARCH ON ENHANCING THE UTILIZATION OF DIGITAL MULTISPECTRAL DATA AND GEOGRAPHIC INFORMATION SYSTEMS IN GLOBAL HABITABILITY STUDIES

INTRODUCTION

The University of Kansas Applied Remote Sensing (KARS) Program is engaged in a continuing long term research and development effort designed to reveal and facilitate new applications of remote sensing technology for decision-makers in governmental agencies and private firms. Now in its twelfth year, this program is developing the concepts and procedures for utilization of products prepared from the data gathered by various remote sensors (e.g., multispectral scanners, cameras) mounted in low and high altitude aircraft and spacecraft. Increasingly, KARS staff are developing mechanisms for integrating remotely sensed data with other data in automated geographic information systems (GIS). KARS staff conduct both basic research and applied research projects. Applied research projects are designed to address specific problems faced by officials in governmental agencies (municipal, county, multi-county, state and federal) and in business and industry. The interaction between the KARS Program and agency and industry personnel as they jointly work on cooperative projects insures the continued relevance of the program and maximizes the extent to which remote sensing/GIS technologies address actual issues, problems and needs.

The key objectives of the KARS Program may be summarized as follows:

- Research and develop new modes of analyzing Multispectral Scanner, Aerial Camera, Thermal Scanner, and Radar data, singly or in concert, in order that more effective use can be made of such systems.
- Merge data derived from remote sensing with data derived from conventional sources in geographic information systems to facilitate better environmental planning and resources management.
- Stimulate the application of the products of remote sensing systems to significant problems of resource management and environmental quality now being addressed in NASA's Global Habitability directive.
- Apply remote sensing techniques and analysis and geographic information systems technology to the solution of significant concerns of state and local officials and private industry.
- Participate cooperatively on remote sensing projects with public agencies and private firms.

- Effect the transfer of applicable remote sensing technology to governmental agencies and private firms at all levels as a by-product of projects conducted in the KARS Program.
- Assist personnel within public agencies and industry in the evaluation of the capabilities of the rapidly changing remote sensing systems and the benefits which might be achieved through their utilization.
- Guide, assist and stimulate faculty, staff and students in the utilization of information from the Earth Resources Satellite (Landsat) and Aircraft Programs of NASA in research, education and public service activities carried out at the University of Kansas.

THE KANSAS APPLIED REMOTE SENSING (KARS) PROGRAM

The Kansas Applied Remote Sensing (KARS) Program was established by the National Aeronautics and Space Administration (NASA) in 1972 to conduct applied research on techniques which will enable public agencies and private industry to better utilize available satellite and airborne remote sensing systems. The KARS Program is a research program of the University of Kansas Space Technology Center administered through the University of Kansas Center for Research, Inc. The Program draws upon the remote sensing expertise and facilities of the University of Kansas accumulated as a result of over 19 years of research in remote sensing conducted at the University (Appendix I).

The Space Technology Center (STC) was founded in 1972 by the National Aeronautics and Space Administration and the State of Kansas to enhance research and education in space-related science and technology through multidisciplinary research efforts. STC was established as part of a NASA plan to set up a network of advanced facilities across the nation. Recognizing that important University research is sometimes impeded because specialized researchers do not have the facilities to work together, NASA sought to build centers where such interaction not only would be possible, but would be encouraged.

The goal of the Space Technology Center is to enhance research and education in space science and technology and contribute to the economic growth of the nation. To achieve this goal, the Center fosters multidisciplinary research in the sciences, humanities, engineering and business and transfers the results to the public.

The KU Space Technology Center is the last of 27 interdisciplinary centers that were built across the nation as part of NASA's $44 million investment program. Its 77,000 square-foot design is planned to encourage communication between researchers and to adapt easily to the growing interests of faculty and students and the changing priorities of the space program. More than 30 KU faculty and 105 staff and students, representing every school of the University, work at the Center to explore areas that are related to the space program.

The KARS Program possesses a full range of remote sensing, mapping, geographic information system, and related capabilities (Table 1). Projects undertaken by the KARS Program with public agencies or private clients are designed to identify and facilitate the manner in which remote sensing/geographic information systems technology can be employed to aid in decision-making, policy formulation, planning and in meeting other responsibilities and objectives. The KARS Program has provided assistance and services to more than 40 agencies and firms in Kansas, Missouri and other states in the Great Plains/Rocky Mountain region. Contractual applied remote sensing projects have been carried out for the National Aeronautics and Space Administration, U.S. Fish and Wildlife Service, U.S. Office of Surface Mining, USDA/Soil Conservation Service, U.S. Environmental Protection Agency, U.S. National Park Service, Missouri River Basin Commission, Kansas Fish and Game Commission, Mid-America Regional Council and Farmland Industries, Inc. (Appendix VII). Projects have involved research designed to enhance utilization of remotely sensed data in land use/land cover inventory, monitoring land use change, wildlife habitat evaluation, mapping of irrigated lands, surface mined lands inventory, recreational area planning, soil conservation needs assessment, aquatic vegetation mapping, rangeland condition evaluation, urban area analysis, and education and training (Table 2). In addition, KARS staff have provided remote sensing consulting services to the Government of India under the auspices of UNESCO, the State of Wyoming, the State of Tennessee, and the State of Chihuahua, Mexico.

One measure of the KARS Program's success in working with state agencies and other users in Kansas is the establishment of the Kansas Commission on Applied Remote Sensing. The Commission, comprised of representatives of all state agencies that have utilized Landsat or other remote sensing data, is

Table 1. CAPABILITIES AND SERVICES OF THE KARS PROGRAM

- Interpretation of remotely sensed data (in digital or image format) in support of land use/land cover, environmental, planning, agricultural and natural resources inventories and analyses.

- Geocoding, geographic informaation system design and production; statistical analysis, design of sampling surveys, areal statistical data summaries;

- Field investigation either in support of remote sensing data collection or independently designed to meet specific agency or client requirements;

- Aerial photography in support of KARS research and applications projects;

- Map production using state-of-the-art cartographic techniques including negative scribing, color separation and computer graphics. Production of printed maps in color or black and white, transparent overlays, precision scale matching;

- Analysis of trends, projections, spatial modeling, monitoring of change on a seasonal (e.g., range burning, harvesting) or annual basis (e.g., land use, wildlife habitat);

- Location and acquisition of remote sensing data, flight mission design;

- Instruction in remote sensing techniques, interpretation and applications; short courses, workshops, seminars; technology transfer.

Table 2. MAJOR KARS PROGRAM RESEARCH AND APPLICATIONS AREAS

Land use/land cover inventory, change detection and mapping
Irrigated lands inventories
Water resources management
Wildlife habitat evaluation
Strip mined lands assessment
Crop and rangeland resource inventory and evaluation
Integrated natural resources inventories
Geographic information system design, construction, and application
Thematic mapping
Technology transfer/remote sensing education

actively engaged in examining alternatives for making greater operational use of the KARS Program to serve Kansas State government (Appendix II). The Kansas Legislature, in 1983, awarded the KARS Program funds to work more operationally with Kansas agencies and established a fee fund to facilitate such work.

The KARS Program has published the quarterly KARS Newsletter since 1972. Now funded by the Kansas Commission on Applied Remote Sensing, the Newsletter is designed to foster the application of remote sensing data and to provide a forum for communication on remote sensing related matters. Current circulation is approximately 2,000. Readers include employees of local, state, regional, and federal agencies, research centers, colleges and universities, and private firms. Most readers reside in the Midwest and Western U.S., but Newsletters are mailed throughout the United States, and to several other nations. Many new projects have developed from this medium.

As a means of facilitating KARS' responses to continual requests for information about the Program, a descriptive brochure has been designed, printed and distributed to all recipients of the KARS Newsletter (Appendix I). The brochure summarizes the facilities, equipment and staff of the Program and describes the capabilities and services of the KARS Program. The brochure has proved to be an invaluable introduction to the Program that provides an attractive "calling card" for distribution at meetings, workshops, agency visits and use in answering phone and mail queries.

The KARS Program has sponsored over 25 workshops, conferences, short courses and seminars on applied remote sensing. Since 1972 the KARS Program has provided training for over 900 agency personnel and other users from throughout the U.S. Training, briefings and technology transfer activities have been conducted both in Lawrence and at other locations. KARS staff have provided briefings, workshops, and seminars for legislators, public agencies, professional organizations, industry and other users in Kansas, Missouri, Wyoming, Tennessee, Mexico, and India.

PRINCIPAL KARS PROGRAM PERSONNEL

The KARS Program has assembled a unique staff of individuals who have over 40 years combined experience, broad contacts, and specialized expertise in applied remote sensing, mapping, and natural resources. The KARS Program is administered by Dr. Edward A. Martinko. Dr. James Merchant and Ms. Loyola

Caron are senior personnel of the Program. Other faculty in the University participate in specific projects. The KARS staff is comprised of specialists having expertise in ecology, forestry, wildlife biology, geography, computer science, environmental studies and natural resources management. Three of the principals have worked for state government and, therefore, have first-hand knowledge of the needs and problems experienced by such agencies.

The Director of the KARS Program is Dr. Edward A. Martinko. Dr. Martinko is an Assistant Scientist in the Space Technology Center and is also Director and Assistant Professor of Environmental Studies at the University of Kansas. He has over 15 years' experience in the areas of ecology and remote sensing of biological resources, nine years of which he has been associated with the KARS Program. He is also Director of the Kansas Biological Survey, an agency of the State of Kansas responsible for the inventory and study of plants and animals in Kansas. He is a co-founder of the Kansas Interagency Task Force on Applied Remote Sensing and is intimately familiar with the functions and needs of state government and industry. He has first-hand familiarity with public agencies and other users in the states of Kansas, Colorado, Missouri and Texas, and has been a consultant to the government of Chihuahua, Mexico. Dr. Martinko's recent work has focused on remote sensing applications in integrated pest management, noxious weed inventory and wildlife habitat assessment.

James W. Merchant, Senior Remote Sensing Applications Specialist with the KARS Program, has been engaged in basic and applied research in remote sensing since 1971, ten years of which he has been associated with the KARS Program. He has also served as a Natural Resources Planner with the Baltimore (Maryland) Regional Planning Council and Research Assistant in microwave remote sensing with the University of Kansas' Remote Sensing Laboratory. He holds a B.A. in Geography from Towson State University, Towson, Maryland, an M.A. and Ph.D. in Geography from the University of Kansas. He is currently working with Kansas and federal agencies on projects involving the application of remote sensing and geographic information systems to resources problems in the areas of water resources management, rangeland inventory and evaluation and land use analysis. He is Executive Director of the Kansas Commission on Applied Remote Sensing. Dr. Merchant is personally acquainted with users and remote sensing specialists throughout the U.S. He has participated in the

National Conference of State Legislatures' Natural Resource Information System (NCSL/NRIS) Task Force meetings and NCSL briefings for state government officials in Kansas, Wyoming and Tennessee, and has been a consultant to the government of Chihuahua, Mexico.

Loyola M. Caron, Remote Sensing Specialist with the KARS Program, has a unique background in natural resource information systems (NRIS) technology, remote sensing, wildlife management and forestry. She holds a B.S. in wildlife biology and an M.S. in forestry, with emphasis on remote sensing of natural resources, from the University of Minnesota. Prior to joining the KARS Program staff, she was Staff Associate with the National Conference of State Legislatures' Natural Resource Information Systems Project in Denver. This program provided technical assistance to state legislators on Landsat and NRIS technology. During her two years with the Conference, she participated in state legislative committee briefings throughout the U.S. designed to inform legislators about Landsat and NRIS capabilities and limitations; represented state needs in the national "Five Agency" effort to develop a national land classification system for vegetation, landforms, soils and water; assisted in a performance audit for the Arizona Resource Information System, with special emphasis on examining state agency information needs; and was responsible for preparation of a bi-monthly newsletter and various other publications about Landsat/NRIS technologies and their use by state legislators and agencies. She has also worked for North Dakota's Regional Evnironmental Assessment Program (REAP), an experimental effort by the State of North Dakota to implement NRIS technology in an attempt to better plan for and manage development of its resources. In this capacity she served as the earth sciences research coordinator responsible for collecting natural science data for a statewide automated data base. Ms. Caron also acted as liaison between state agencies and REAP computer personnel to determine optimum strategies for meeting agency needs.

Projects requiring specialized scientific expertise are staffed by graduate students and faculty from the specific academic disciplines involved. Personnel from the various firms and agencies are involved in their own projects at no cost to NASA.

FACILITIES

KARS Program offices and laboratories are located in the University of Kansas Space Technology Center. The program has complete facilities for processing and interpretation of remote sensing data in both image and digital formats, state-of-the-art cartographic production, statistical analysis, and geographic data base production. Graphic arts, photographic processing and support services are provided within the Space Technology Center.

The KARS Program's Image Interpretation Laboratory is furnished with a complete range of equipment for viewing and analyzing imagery, and for transferring image data to base maps of various scales. Included are a Bausch and Lomb Zoom Transfer Scope, five Richards Light Tables with Bausch and Lomb Zoom 240 stereoscopes, a Saltzman Reducing/Enlarging Projector, a MacBeth Color Spot Densitometer, an Old Delft Scanning Stereoscope, and a complete assemblage of other manual image interpretation aids.

Aerial photography in support of KARS projects is acquired from a Cessna 180 Skywagon accessible to KARS staff. Both a multispectral cluster of four Hasselblad 500EL 70mm format cameras and a Fairchild nine-inch format cartographic camera are available for photographic missions.

Custom designed cartographic and graphic products are prepared by KARS staff using negative scribing and photo-mechanical techniques. Production of color graphic and color separations are standard procedures. Printing services are available. KARS staff also have access to Tektronix computer graphics systems, computer mapping software, and both flatbed and drum plotters.

A current file of Landsat, Skylab and aerial imagery is maintained by the KARS Program for the use of project personnel and user agencies. The Landsat file contains a combination of selected black and white and FCC imagery for various dates since the earliest Landsat in mid-1972. Over 130 prints and 1,100 transparencies are included in the file. The imagery is catalogued by path and row and date and includes complete coverage of Kansas. Aerial photography holdings include over 170 rolls of film.

An extensive map collection is maintained by the KARS Program. This collection contains a variety of maps of Kansas and surrounding areas. Included are state base maps, topographic sheets, county maps, general regional maps, thematic maps and image mosaics.

The KARS Program also maintains a substantial reference library for both in-house and agency use. This material includes reports, articles, periodicals, manuals and textbooks pertinent to remote sensing and selected applications areas.

Analysis of digital remote sensing data, digitizing and other computer-assisted data processing operations are supported by facilities of the KARS Digital Data Analysis Laboratory. The KARS stand-alone Digital Image Processing System provides KARS with a full range of capabilities in computer enhancement and classification of digital Landsat data, as well as other remotely sensed data. The system also supports computer graphics, geographic information system, statistical, cartographic, and integrated natural resources analysis.

The KARS Digital Image Processing System has as its host a Digital Equipment Corporation LSI-11/23+ central processing unit, a microcomputer implementation of minicomputer technology. The computer has one million bytes of main memory, a Sky Computers SKYMNK arithmetic pipeline processor, an 80-megabyte CDC 9762 disc pack drive with Emulex SC01B2 controller, a Kennedy 9100 75-inch-per-second vacuum-column tape drive, and serial input/output ports for as many as eight user terminals.

There are two color image displays connected to the system. The first, a Digital Graphic CBX-400 display, is used with the ERDAS software package as described below. The CBX has a spatial resolution of 256 by 240 pixels in a 4-bit-per-gun RGB mode, and a spatial resolution of 512 by 480 in a 16-color lookup-table mode. The ERDAS software uses the low-resolution mode for imagery and the high-resolution mode for GIS applications. KARS hopes to upgrade the device to a CBX-800, which can display 256 colors in high-resolution-mode--normally adequate for imagery. The CBX is actually a self-contained Cromemco Z-80 microcomputer. It includes a joystick for cursor control and a high-speed parallel interface to the 11/23. The second display, a Terak 8510/a-8600 HDX microcomputer, is used with other KARS software. The 8510/a includes a DEC 11/2 processor, 64K bytes of memory, an 8-inch dual density floppy disc drive, keyboard and monochrome CRT display with graphics capability at a 320-by-240 pixel resolution. It can function as a stand-alone computer running DEC's RT-11 operating system. The 8600 HDX display integrated with the 8510/a includes an Intel 8086 processor and video refresh memory and display circuitry capable of 640-by-480 pixel resolution. The 8600 HDX can display 64 simultaneous colors from a palette of 512.

Graphics output can be performed on a Versatec 8222-F 22-inch electrostatic printer/plotter with 200 point-per-inch raster resolution. An Anadex 9501A dot-matrix graphic printer is dedicated to ERDAS applications. Spatial input is provided by an Altec AC90SM intelligent digitizer with a 60 by 42-inch backlit tablet.

Other peripheral devices include two desktop personal computers. An Intertec Superbrain is used as an intelligent terminal and as an operator console and data preprocessor for the Altec digitizer. A Zenith Z-100 personal computer is used for word processing and small-scale data base applications. Various CRT and hardcopy terminals are also connected to the KARS system.

KARS also has access to the University of Kansas central computer system, a Honeywell Level 66 DPS-3E computer. The KARS instructional image processing package, developed for special short courses but also used in regular University classes, runs on the central system.

The KARS 11/23+ runs under the RSX-11M operating system (version 4.1). KARS programming has been done using the DEC FORTRAN-77 (version 5.0) compiler.

The software capabilities of the KARS program have been substantially enhanced by the recent acquisition of a second ERDAS software package from the Earth Resources Data Analysis Systems organization in Atlanta, GA. The software runs on the IBM-PC AT computer system. This system provides KARS staff with a capability to conduct off-site data processing and analysis.

The ERDAS software is a powerful and general package of image processing and GIS programs. Capabilities include a grid-cell oriented GIS system adapted from the Harvard IMGRID package, a set of programs for analysis of Landsat or other image data, programs for modification or annotation of a displayed image or map, programs for various sorts of hard copy output, utility programs including magnetic tape input and output routines, a demonstration facility and X-Y tablet digitizing capabilities.

PROPOSED PROJECTS FOR 1986-87

During 1986-87, the KARS program will continue to build upon long-term research efforts oriented towards enhancement and development of new technologies for using remote sensing in the inventory and evaluation of land use and renewable resources (both natural and agricultural). These research efforts will directly address needs and objectives of NASA's Land-Related Global Habitability Program as well as the needs of and interests of public agencies and private firms. The KARS Program will place particular emphasis on two major areas:

1. Development of Intelligent Algorithms to Improve Automated Classification of Digital Multispectral Data; and
2. Integrating and Merging Digital Multispectral Data with Ancillary Data in Spatial Models.

These areas and the specific contexts in which they will be addressed are discussed in the following pages. Our 1986-87 research will build upon ongoing work of the KARS Program through the following projects:

1. Employing Geographic Reasoning and Spatial Logic in Analysis of Digital Multispectral Data.

The study of global habitability will require the preparation of a myriad of small scale (i.e., 1:250,000 - 1:5,000,000) thematic maps. Initial assessment of science issues which need to be addressed in the study of global habitability indicates that among others, maps depicting land use, biotic communities and ecological regions will be required (NASA, 1983). Such maps will need to be prepared for large areas (perhaps the entire Earth), and will need to be periodically updated in order to monitor and evaluate change in the environment, its causes and effects.

Landsat provides both the spatial and multi-temporal coverage required for such mapping. Most remote sensing specialists would agree that computer-based techniques have been rather successfully employed to classify and map land cover from Landsat Multispectral Scanner (MSS) and, more recently, Thematic Mapper (TM) digital data. In a rather typical outcome of computer classification, on a pixel by pixel basis, land cover can be identified quite accurately where such distinctions can be made based upon spectral characteristics of the cover.

Production of the types of thematic maps cited above, however, will require the development of new techniques of data analysis, ones that employ, not only spectral characteristics of the data, but also spatial, structural and contextual attributes. The importance of this task has been recognized in NASA's review of research needs related to the study of land-related global habitability (NASA, 1983, p II.5-11).

Spatial/contextual algorithms are required for several reasons:

1. to help distinguish between land cover types which have similar spectral characteristics, but which may, in fact, be quite different. Such cover types (e.g., irrigated alfalfa and watered urban lawns) would be indistinguishable using conventional spectrally-based algorithms;
2. to aid in the generalization of classifications in order that small-scale maps can accurately represent the full resolution (i.e., each pixel visible) products from which they were derived; and
3. to aid in the preparation of maps which portray integrated or syntetic regions (e.g., regions of land use or eco-regions which are comprised of complexes of land cover).

"Employing Geographic Reasoning and Spatial Logic in Analysis of Digital Multispectral Data," is a KARS project designed to develop new techniques to improve classifications through the analysis of context (i.e., relationships between and among classified pixels). These techniques cn be important for the production of maps depicting land use, biotic communities and ecological regions required for the study of global habitability.

2. Development of Models for Assessing Biological Productivity of the Land: The Use of Digital Multispectral Data and Spatial Modeling Techniques.

Fundamental to the study of global habitability is an understanding of biological productivity and its relationships to global energy balance and to biogeochemical and hydrological cycles. Biological productivity, however, not only requires the study of the primary productivity of plant communities but also the secondary productivity provided by animal communities. Knowledge of the composition, and the spatial and temporal distribution of plant and animal communities associated with land surface cover changes is therefore of central importance for developing models of biological productivity.

Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) digital data in conjunction with computer-based techniques have been utilized successfully in the classification and mapping of changes in land use and land cover. The ability to employ digital multispectral data to portray the spatial and temporal distribution of land surface features is essential for establishing a basis for modeling and assessing biological productivity on a regional or ecosystem basis.

NASA's Global Habitability Program reviews the importance of these and other related research needs (NASA, 1983, p II, 5-7) as a basis for an understanding of the complex processes that offer habitability. Specifically, studies of the biological productivity of land require:

1. investigation of integrated ecosystems in order to understand the interactions of land surface cover with life support processes;
2. the assessment of the extent and spatial distributions of biomass and productivity associated with land surface features;
3. the collection and analysis of remote sensing and ground data to determine normal variations within and among years;
4. the development of models which characterize natural vs. man-induced surface cover variation to predict spatial and temporal changes in productivities.

"Development of Models for Assessing the Biological Productivity of the Land" is a KARS project designed to utilize digital multispectral data to classify land surface cover as a basis for developing models of biological productivity. Ground data on plant and animal community composition and distribution will be utilized in the biological productivity models for assessment of spatial and temporal productivity changes.

3. Merging Remotely Sensed Data with Ancillary Data: A Geographic Information Systems Approach to Resources Management.

Environmental management and policy decisions must, almost always, be based upon examination and analysis of the interplay of many different factors which may bear upon a particular issue. Decisions concerning conservation of high quality groundwater, for example, must be based upon evaluation of a spectrum of institutional, political, economic and environmental data. These data are usually geographically-referenced (i.e., data tied to specific locations on the Earth's surface). Geographically-referenced data may be considered data that can be mapped. Automated geographic information systems (GIS) enable one to rapidly store, manipulate, compare and display geographically-referenced data. Once stored, such data can be automatically extracted, reconfigured, updated, analyzed, mapped in a format and at a scale designed to meet a specific need, and used for many types of decision-making. Geographic information systems provide decision-making with a capability to analyze complex spatial interrelationships between variables.

Approximately two-thirds of Kansas water supplies are derived from groundwater sources. The aquifers containing these waters vary appreciably in lateral extent, saturated thickness, specific yield, depth to water and geological composition. The present quality of the groundwaters also varies markedly. About 8 percent of public water supplies derived from groundwater contain concentrations of hazardous substances that exceed State primary drinking water standards. The Kansas Department of Health and Environment (KDHE) believes that most of these excesses are due to natual causes, but that some could possibly have been caused by man. The potential exists for additional contamination of groundwater supplies as municipal, industrial, and agricultural activities become more intense and cover a greater portion of the area overlying aquifers. The purpose of this project will be to develop techniques for using remote sensing and GIS technology to assess, monitor, manage, regulate and forecase groundwater conditions. The project will be funded 75% by the Kansas Department of Health and Environment and 25% by NASA. It is expected that system use will generate suggestions for refinement and augmentation, unforeseen applications, administrative support for the technology and demand for additional capabilities related to other areas of global habitability.

EMPLOYING GEOGRAPHIC REASONING AND SPATIAL LOGIC IN ANALYSIS OF DIGITAL MULTISPECTRAL DATA

James W. Merchant

Introduction

Remotely sensed data are commonly used to aid in classification and mapping of landscape regions (e.g., ecoregions, land use regions). Visual image interpreters routinely employ spatial cues evident in a scene to aid in data stratification, classification and mapping. Such cues may include parcel size, parcel shape, pattern, texture, context and associations of cover types. Optimal visual image interpretation requires the use of geographic reasoning and spatial logic. "Geographic reasoning" is defined as the systematic application of geographic knowledge, understanding and expectations in the analysis of data acquired via remote sensing for the purpose of accomplishing a specific objective or set of objectives. "Spatial logic" is defined as the formal expression and systematic application of decision rules which are formulated to assist in the attainment of a particular analytic objective (e.g., preparation of a 1:250,000 scale land use map portraying classes X, Y, and Z) and are based upon characteristics and relationships evident in a particular landscape as depicted in a particular set of remotely sensed data. Spatial logic is developed as the image analyst transforms observations, understandings and geographic knowledge of the landscape into decision rules which can be applied in data analysis to segment that landscape into regions of interest. Such rules typically require consideration of both spectral <u>and</u> spatial properties of the landscape, and may require inference and deduction.

Algorithms currently used to classify multispectral scanner data are founded, almost exclusively, upon spectral pattern recognition techniques. Spectrally-based classification algorithms have been found to be rather effective in distinguishing many types of "land cover" classes (e.g., corn, wheat, water) which are more or less spectrally homogeneous. They have been less successfully employed to identify classes which, although of vital interest to (map) users, are not separable on the basis of spectral characteristics alone (e.g., land use classes). Most work on digital land cover/land use classification and mapping has focused on the Landsat MSS. Previous research has often been mathematically sophisticated, but appears less profound in its application of "geographic reasoning" and "spatial logic." This research is directed towards defining and testing algorithms and strategies, founded upon geographic reasoning and spatial logic, which will enable production of better thematic maps from digital multispectral data.

Production of many types of thematic (e.g., land use, ecoregion) maps will require the development of new techniques of data analysis, ones that employ not only spectral characteristics of the data, but also spatial, structural and contextual attributes. Spatial/contextual algorithms are required:

1. To help distinguish between land cover types which have similar spectral characteristics, but which may, in fact, be quite different. Such cover types (e.g., irrigated alfalfa and watered urban lawns) would be inseparable using conventional spectrally-based algorithms;
2. To aid in the cartographic generalization of classifications in order that small-scale maps can accurately represent the full resolution (i.e., each pixel visible) products from which they were derived; and
3. To aid in the preparation of maps which portray integrated or synthetic regions (e.g., regions of land use or ecoregions which are comprised of complexes of land cover). The definition of such regions depends upon analysis of the spatial distributions and characteristics of cover types.

It is proposed that significant improvement in automated detection and interpretation of landscape regions could take place if software were to emulate important aspects of visual image analysis. Such "intelligent" software would employ "geographic reasoning." In work completed to date, a strategy for employing geographic reasoning in classification of Landsat Thematic Mapper digital data has been proposed. Thematic Mapper data are initially stratified into water, vegetated and non-vegetated pixels. A region-growing algorithm is then used to define "fields" of similar land cover composition. Fields are characterized by size and neighborhood attributes. Hierarchical clustering has been employed to test the hypothesis that the diversity, field sizes and spatial interspersion of land cover types are useful discriminants of landscape regions. The hypothesis has been shown to be valid (Appendix III).

A major focus of future research will be upon implementation of these results. A geographic information system (GIS) will be used to provide a spatial "frame of reference" for guiding digital image segmentation and classification. The GIS, which includes elements of the local transportation network, digital terrain data and hydrology, will be employed during the classification process rather than, as is often the case, in post-processing. Successful application of a GIS in this mode demands explicit expression of the logic of image interpretation. Artificial intelligence concepts will direct the formulation of image analysis strategies.

In this research, a layered classification strategy will be employed. In the layered technique a classifier logically filters the unknown through a sequence of decisions, each of which may be dependent on the outcome of previous decisions. Classification will be guided by artificial intelligence concepts. Landscape regions will be defined via both analysis of spectral data and via reasoning based upon antecedent conditions, expert knowledge and ancillary (e.g., field) data.

The "intelligent" classifier will be capable of geographic calibration. In other words, the data analyst will be able to "tune" it to a particular environment, thus allowing regional interpretation of locally derived quantitative relationships between surface phenomena and indices (e.g., greenness and brightness indices) computed from satellite data. Calibration will be accomplished by establishing, for specific geographic regions, a known "baseline" from which change can be measured and against which surface conditions can be calibrated. The "baseline" will include both data (e.g., digital elevation data) <u>and</u> geographic expert knowledge expressed as logical rules.

Ancillary data and "a priori" knowledge, it is suggested, could be useful in at least two ways:

(a) Existing maps, both digital (e.g., USGS Digital Line Graphs) and conventional, known to be accurate, could provide a spatial "starting point" to begin structural analysis of the landscape (e.g., to "guide" region-growing). Existing road and railroad networks and drainage systems might provide a structural framework within which to grow "fields." Knowledge of former land use might be employed to help assign probabilities of likely current land use in digital classification (e.g., a CBD is unlikely to change to bare cropland, a golf course is unlikely to change to pasture).

(b) Ancillary data will be used, as well, to assign probabilities of correct classification. Digital terrain data, for example, could be employed to derive slope and local relief. It might be determined that cropland is not likely to occur on steep slopes or in hilly areas. Floodplains, known to be almost all cropland, might be defined topographically.

The geographic window (Figure 1) concept will also require further consideration. Statistics in the hierarchical clustering study were computed over such a window. The hierarchical clustering experiments demonstrated that a set of statistics which characterized land cover composition and spatial structure of the landscape can be used to discriminate regions of land use and land cover (Appendix III). These statistics were computed, however, for geographic windows (sample sites) demarcated visually. The sites were of (variable) sizes known to capture the "character" of each respective land use class sampled.

In order to implement any of the positive results found in the hierarchical clustering experiment, statistics must be computed for an area - a window. Intuitively, it is believed that the geographic window is a better concept than the geometric window. If, for example, it is desirable to measure field size or shape, then one does not want to use a window that "cuts" fields into sectors, as a geometric window would.

The key to successful implementation of the geographic window may lie in development of a technique to "focus" the field-of-view of the window. That is, rather than let the window vary in size according to the character of a single field, the dimension of the window might be allowed to vary by evaluation of the characteristics of several neighboring fields. Such statistics (e.g., mean field size, spatial complexity index) might be generated and used to select a window size that would likely generate meaningful statistics.

The window problem is related to the outcome of region-growing. Further research on region-growing (using a GIS to guide segmentation as outlined above) is required. It may be that different decisions made in this regard would enable the geographic window, even as it stands, to perform better.

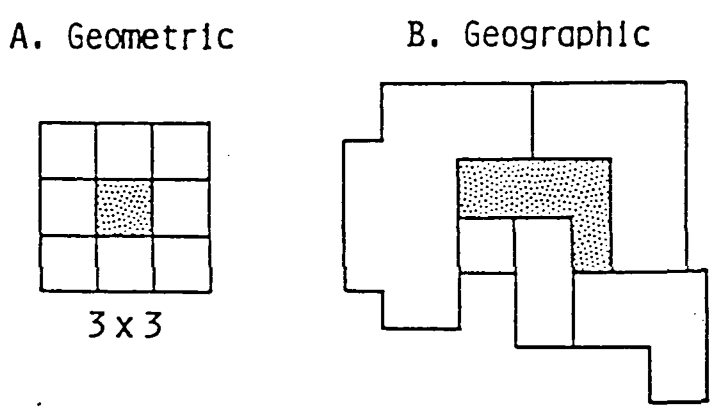

Figure 1. A geometric window is comprised of a pixel and its neighboring pixels. A geographic window is comprised of a field and its neighboring fields.

Summary

Future research will be concentrated in six areas:

1. Experiments directed towards better definition of optimal spatial and contextual measures/variables and weighting schemes;
2. Experiments directed towards better definition of region-growing/geographic window relationships and the effects these may have on the use of a geographic window in a classification algorithm;
3. Efforts to improve the internal logic of and implement an operational classification algorithm;
4. Examination of additional spatial, textural and contextual measures;
5. Examination of the potential applicability of alternative means of image segmentation and classification (e.g., conventional per-pixel classification); and
6. Comparative analyses of other airborne and spacecraft-borne multispectral systems having different spatial resolutions (e.g., AVRIS, SPOT).

DEVELOPMENT OF MODELS FOR ASSESSING BIOLOGICAL PRODUCTIVITY OF THE LAND: THE USE OF DIGITAL MULTISPECTRAL DATA AND SPATIAL MODELING TECHNIQUES

Introduction

Assessing the biological productivity of the land is of central importance in understanding habitability. Productivity, however, changes both spatially and temporally and therefore must be monitored on a continuing basis. The synoptic view produced by remote sensing devices provides the mechanism for monitoring and assessing changes in biological productivity on a regional or ecosystem basis. The focus of this research effort is to determine those factors that influence the long term ability of the land to support given levels of biological productivity.

While the major biological variable of interest in biological productivity is the primary productivity of an ecological system, the secondary productivity of animals is also important for the habitability of a region or an ecosystem. Since animals are an important factor in shaping plant communities which are responsible for primary production, knowledge of the composition of animal communities is therefore important. Mapping areas which are suitable for the occurrence of a species but where it is not known to exist can, for example, be useful to: (1) choose suitable sites for introduction or reintroduction of species (KARS successfully chose release sites for pronghorn antelope in Kansas using MSS imagery (Martinko, 1981)); (2) predict the expansion of exotic species; (3) suggest areas where search for a species might be fruitful; and (4) uncover species distribution problems in need of study.

The potential for existing satellite imagery in mapping and evaluating animal habitat is relatively limited. However the usefulness of digital MSS imagery has already been demonstrated in various projects (e.g. Thompson et al., 1980; Isaacson and Leckenby, 1981). The rapidly improving capabilities of GIS technology in spatial analysis and the use of ancillary data are, however, far from being fully explored. Furthermore, other types of multispectral data will almost certainly prove to be better than the MSS in habitat studies, due to higher resolution, broader spectral ranges, and higher band specificity. The use of multispectral data and GIS technology in this area seems to be quite promising.

Because most estimates of biological productivity are estimates of potential rather than actual biological productivity, a basic prerequisite for accurate models of actual productivity is the development of a suitable land cover classification. We will compare various approaches to this problem and experiment with different linear data transformations, spectral classification algorithms, and spatial reclassification filters. Since we are using this project as a model for future large scale studies, the cost of the various techniques used will be considered along with accuracy. In spite of the intensity of research in this area during the past decade, the development of processing algorithms and methodologies for extracting land cover information from remotely sensed data, and the study of associated costs, are still major goals of NASA's global habitability program.

Cost and availability considerations make the use of remotely sensed data in operational projects still very appealing. With this in mind, we will compare the results obtainable with various types of multispectral data in land cover mapping.

In summary, the major goals of this project are to:

(1) Experiment with various approaches to spectral/spatial land surface classification in order to implement an accurate and cost efficient model.

(2) Compare the performance of various types of multispectral data in land cover mapping as a basis for studies of biological productivity.

(3) Develop and evaluate spectral/spatial/temporal models of biological productivity of the land based on Landsat imagery and ancillary ground data on plant and animal communities.

(4) Develop a model to classify and map animal communities based on the results of (3).

In work completed to date an initial study area located in northeastern Kansas was utilized. The area is dominated by forests, rangeland and cropland. One TM scene obtained on September 3, 1982, and a MSS scene obtained by Landsat-4 on the same date, as well as a MSS winter image, were used in this project. Large scale aerial photography were used along with ground surveys to check the results of the analysis. A mixed spectral/contextual land cover classification approach was used along with a geographic information system to improve the final land cover map. This spatial/spectral approach to land cover classifications resulted in an accurate and effective model for habitat evaluation (Appendix IV).

The approach described above was designed to map areas that are suitable for the occurrence of a particular species where it does not now exist, namely the location of potential release sites for the ruffed grouse (Bonasa umbellus). Future research will concentrate on the generalization of the results of this initial effort to other species and experimentation with different approaches to mapping communities and species distributions based on point samples of community composition and species abundance.

On completion of the land cover mapping and animal community mapping, temporal and spatial models of biological productivity will be developed utilizing a synthesis of the remote sensing data and procedures from theprevious research along with ground based measurements or primary and secondary productivity. These models will integrate the ground based measurements, the remote sensing data and ancillary data into a regional estimate of biological productivity. It should be emphasized that the development of these models is an end product of the research efforts described herein and will incorporate the findings of each element. The outcome of this effort should provide a basis for an improved understanding of the spatial and temporal dynamics of biological productivity in terrestrial ecosystems.

In the sections that follow, we will give a short description of the research plan, along with a summary of the background information on which we are basing this work.

Research Plan

During the last few years research on land cover classification techniques has been very intensive. However, we are still far from being able to select the optimal approach to follow in a specific application. Actually, comparisons among the numerous available techniques are relatively scarce, and the situation is considerably complicated by the lack of standardization at all levels in this new area. In order to select the land cover classification approach best suited to a particular community, species or ecosystem, we will have to experiment with various techniques. Accuracy, cost, and time considerations will be the basis for our comparisons and selection criteria. The multitude of combinations of methods available make it impossible to explore all them in the time available for this project. We have selected the ones we are using based on the nature of the area in which we will be working, software availability, and the published results of previous work.

In a project in which various classification approaches are tried and compared, it is of special importance to use a practical and precise method to evaluate the accuracy of the obtained products. Various recent papers discuss the problems associated with accuracy assessment (e.g. Hay, 1979; Rosenfield et al., 1982; Dozier and Strahler, 1983). A number of ground truth points will be selected by stratified random sampling (Cochran 1977) in order to get a good representation of the various zones of the study area. The ground cover at this site will be identified using large scale aerial photographs and, when necessary, field checked. The identity of this cover will be kept on file for automatic comparison with the results of the various analyses. Percentage confusion tables including confidence limits will be generated. An arcsin transformation will be performed to correct for non-normality of the percentile data (Sokal and Rohlf, 1981). To compare statistically the obtained confusion tables, Hotelling's T^2 will be used for global comparisons, and Bomferroni's multivariate tests for multiple comparisons, as suggested by Merembeck and Turner (1979).

Mapping Animal Habitat and Communities

The importance of digital multispectral imagery in wild species habitat studies has already been proven by work done in the last few years (for an overview see Best, 1981). However, most of these studies are simply involved in the identification of habitat elements, such as vegetation. This is a necessary step, but it is unfortunate that so few works try to quantitatively relate these elements to the actual needs or preferences of the individual animal species (but see Thompson et al., 1980). In this part of our work we will try to develop models to allow us to map the habitats of species in an area, based on Landsat imagery and ancillary data. These maps should also include an evaluation of the habitat "quality" for each species. This model will only be successful in cases where the habitat limiting variables can be directly or indirectly detected and measured on the imagery and/or easily included as digital ancillary data.

Because of the amount of data available for the study area, initial effort will focus on the passerine bird community. Ground data on the breeding bird fauna of the study area will be collected using a point count technique (Blondel, 1981). About one hundred sampling sites will be randomly distributed throughout the various habitat types present. Data will consist of a relative measure of bird abundance. Only the species that are relatively common will be included in the analysis, to make the samples more representative. The counts will be carried out early during the breeding season (late May and June) in order to increase the count accuracy. To reduce temporal bias only early morning counts made on days with good weather will be included (Verner, in publication).

Two approaches to evaluate and map the habitat of the individual bird species will be followed:

(1) Each habitat type identified in the previous land cover classification will be rated in accordance with the pooled information of all the sampling points within its boundaries. This method assumes that the habitat types selected in the classification process are relevant in the distribution of the sampled species.

(2) The second approach searches for a direct relationship between the species distribution and abundance and the spectral image values. In order to establish this relationship we will experiment with three methods: (1) a stepwise multiple linear regression will be performed using various bands and ancillary digital information as dependent variables; (2) a maximum likelihood classifier will be employed to separate habitat from non-habitat using the bird survey points as training sites; (3) a K-nearest neighbor classifier will also be used with the same training sites.

The results of habitat mapping for individual bird species is examplified by the work done on ruffed grouse (Appendix IV). This approach to habitat mapping will provide the framework for the evaluation of the habitat of other species and the development of a model to predict the distribution of the various communities present in an area based on Landsat imagery and ancillary digital information. We have not found a bibliography dedicated to this subject. Community classification and mapping has great scientific interest and can be an important tool in planning and managing protected areas. Two different approaches to the design of the model will be tried:

(1) The first approach will be based on the potential distributions predicted by the most successful of the species distribution predictive models described in the previous section. Each pixel will be characterized by the predicted presence/absence of each of the studied bird species. Several clustering algorithms will be used to identify faunistically distinct units, which will then be mapped. This approach is similar to the one used by various authors (e.g., Simpson, 1964; Schall and Pianka, 1977) to identify zoogeographical units in large scale studies. An extension of this approach will be the inclusion of information on the predicted species abundances in

the cluster analysis. Obviously, the successfulness of this community mapping is dependent on the accuracy of the distribution/abundance digital maps constructed. The use of many species may compensate for part of the noise introduced by incorrect predictions of the distribution and/or abundance of some of the species. In order to reduce computing time, pixels with similar faunistical composition will be grouped in homogeneous units, which will then be submitted to the clustering algorithms.

(2) The second method will be initiated by clustering the sampled points based on the presence and/or abundance of the studied species. Each cluster of sampled points will then be considered as a training set in a land cover classification based on the Landsat imagery and ancillary digital maps, such as "habitat homogeneity," "habitat unit size," etc. The same classification methods referred to previously for land cover mapping will be tried here. Another clustering operation will group the bird species according to their habitat preferences.

The spatial relationship between the bird communities mapped and the land cover may suggest which habitats are recognized as distinct by the birds and even what variables are most important in controlling their distribution. Future work will concentrate on further refining the models and habitat mapping procedures as a basis for the development of spatial and temporal models of biological productivity on a regional basis.

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MERGING REMOTELY SENSED DATA WITH ANCILLARY DATA:
A GEOGRAPHIC INFORMATION SYSTEMS APPROACH
TO RESOURCES MANAGEMENT

Environmental management and policy decisions must, almost always, be based upon examination and analysis of the interplay of many different factors which may bear upon a particular issue. Decisions concerning conservation of high quality groundwater, for example, must be based upon evaluation of a spectrum of institutional, political, economic and environmental data. These data are usually geographically-referenced (i.e., data tied to specific locations on the Earth's surface). Geographically-referenced data may be considered data that can be mapped. Automated geographic information systems enable one to rapidly store, manipulate, compare and display geographically-referenced data. Once stored, such data can be automatically extracted, reconfigured, updated, analyzed, mapped in a format and at a scale designed to meet a specific need, and used for many types of decision-making. Geographic information systems provide decision-makers with a capability to analyze complex spatial interrelationships between variables.

The objective of this project is to design optimal techniques for interfacing remotely sensed data with other geographically-referenced data in automated geographic information systems. This prototype, funded chiefly through the Kansas Department of Health and Environment, will focus on development of GIS techniques for assessing, monitoring, managing, regulating and forecasting groundwater conditions.

Approximately two-thirds of Kansas water supplies are derived from groundwater sources. The aquifers containing these waters vary appreciably in lateral extent, saturated thickness, specific yield, depth to water and geological composition. The present quality of the groundwaters also varies markedly. Temporal variations in quality can occur in response to changes in recharge, amount of pumping and the introduction of substances by man's activities. About 8 percent of public water supplies derived from groundwater contain concentrations of hazardous substances that exceed State primary drinking water standards. The Kansas Department of Health and Environment (KDHE) believes that most of these excesses are due to natural causes, but that some could possibly have been caused by agricultural practices. In a few cases, past pollution by oilfield brines has adversely affected public water supplies. The potential exists for additional contamination of groundwater supplies as municipal, industrial, and agricultural activities become more intense and cover a greater portion of the area overlying aquifers.

Water resources scientists will be involved in identifying the information components of the geographic information system, will aid in the design of strategies, models and algorithms for analyzing date (e.g., the National Water Well Association's DRASTIC). and will have access to the system in order to gain experience in using the GIS for routine decision-making. Such utilization is essential if water managers are to better define mechanisms and methods for employing GIS capabilities in management activities. The feedback stemming from "hands on" experience will aid in "fine-tuning" system design, in more accurately establishing cost-benefit relationships and in better defining applications. A geographic information system, employing the ERDAS IBM PC-AT GIS, will be established to enable water resources managers to better address resources management issues pertaining to groundwater and surface water quality, irrigation, and municipal water supply.

The study area selected for the prototype GIS includes all of Harvey County, the easternmost townships of Reno County, and the northern-most townships of Sedgwick County, Kansas. This region was chosen because it includes a portion of major aquifer (the Equus Beds) that, in terms of groundwater sources, probably supplies the largest number of people in Kansas for an area equivalent to that of an average county. The Wichita well field (municipal water supply) and a major portion of the Equus Beds Groundwater Management Destrict (irrigation water district) is included within the study boundary. A region of sand dunes probably receiving greater than normal surface recharge is in the northwestern part of the study area. A section of the alluvial aquifer of the Arkansas River is in the southwest, while limestone aquifers yielding supplies of water adequate for only domestic or stock purposes are in the east. Oil has been produced for many years from the Burrton and other smaller oil fields. Oilfield brine associated with this activity has polluted the surface and intermediate levels of the aquifer around Burrton; this pollution is being monitored by the Groundwater Management District and the Department of Health and Environment.

Additional support for selection of this area for the system prototype is the relatively large amount of remotely-sensed groundwater-related and land-use data that exists. An important example is that the soils survey of Harvey County has been digitized by the Kansas Applied Remote Sensing Program.

The proposed project will encompass 10 major Tasks, though Task 10 is not covered by funds currently available. The Tasks are as follows:

1. Define KDHE needs for a geographic information system (GIS);
2. Identify existing sources and files of geohydrology, water quality, water supply, waste sources, soils and land use data;
3. Identify existing digital data/computer capability which could be employed in a GIS (work through Kansas Commission on Applied Remote Sensing, Kansas Geological Survey, and Kansas Water Data Control Committee);
4. Identify hardware/software and data that would need to be acquired;
5. Identify types of information needing calculation and associations among different types of data necessary for decisions concerning groundwater quality protection (e.g., environmental performance zoning);
6. Identify existing data analysis models that could be used to process and display desired information;
7. Modify existing models or develop new models to address KDHE requirements;
8. Develop and test prototype GIS for an area representative of groundwater supplies important to large numbers of individuals and that has different existing and potential water pollution problems (Harvey, eastern Reno, and northern Sedgwick counties, within Groundwater Management District No. 2 and including the water well field of Wichita);
9. Recommend mode of system implementation, integration, and institutionalization.
10. Provide on-site training (workshop).

Although designed for water resouces management, it is important to note that other users may access the GIS for applications ranging from urban planning and land appraisal to soil erosion hazard assessment and wildlife habitat evaluation. It is expected that system use will generate suggestions for refinement and augmentation, unforeseen applications, administrative support for the technology and demand for additional capabilities.

APPENDIX I

APPENDIX II

APPENDIX II: The Kansas Commission Applied Remote Sensing

In July 1982 the Kansas Legislature established the Kansas Interagency Task Force on Applied Remote Sensing. Major objectives of that Task Force were to provide policy direction for the KARS Program, the enhance interagency communication, and to assess alternatives for greater and more operational utilization of remote sensing/geographic information systems technologies on a statewide basis. The Task Force presented a Final Report on its accomplishments, studies and deliberations to the Governor and the Kansas Legislature in December 1983. A major recommendation of the Task Force was that a permanent Commission on Applied Remote Sensing be formed to foster the use of remote sensing and related geographic information systems technologies. House Bill 2670 (now KSA 74-7701) establishing the Kansas Commission on Applied Remote Sensing was signed into law by Governor John Carlin in April 1984. The duties of the Commission are to:

- Assist users in assessing the capabilities, costs, and alternatives for employing remote sensing or related geographic information systems technologies;
- Serve as a forum and mechanism for interagency communication, coordination and cooperation for the use of remote sensing and geographic information systems technologies;
- Advise the KARS Program regarding the data and informational needs of Commission members, and aid the KARS Program in identifying and prioritizing projects which are of greatest import to the State;
- Disseminate information regarding new developments and capabilities pertaining to remote sensing and geographic information systems;
- Prepare and present to the Governor and Legislature on or before May 31, 1986, a report and any recommendations regarding the need for an integrated, comprehensive Kansas resources information center; and
- Prepare and present annual reports to the Governor and Legislature, and recommend funding levels for the KARS Program and the Commission in the subsequent fiscal year; and make recommendations to each regular session of the Legislature and to the Governor concerning necessary or advisable legislation relating to issues of statewide importance concerning remote sensing or geographic information systems technologies.

Twelve state agencies, the Governor's Office, both houses of the Legislature, county governments, and the groundwater management districts are represented on the Commission. Federal and local agencies and private firms are invited and encouraged to participate in Commission activities.

The work of the Kansas Commission on Applied Remote Sensing is currently supported by a state allocation to the KARS Program of approximately $55,000. This funding was originally appropriated to KARS to help it support the work of the Interagency Task Force and to provide a fundamental level of services to state agencies. The National Aeronautics and Space Administration (NASA) also contributed funds which helped subsidize these activities; NASA funds are no longer available. The Commission has requested funding for FY 87 in the amount of $98,000, this amount to supplement KARS' current $50,000 allocation.

The Commission has recommended augmentation of KARS funds to support three major programs. These are:

1. Support for the Kansas Commission on Applied Remote Sensing. Funds would provide administrative and technical support for quarterly meetings of the Commission. This support would include both staff and material expenses such as:
    1. Preparation, duplication and mailing of the agenda, reports, handouts, minutes for quarterly meetings;
    2. Technical and secretarial support for the chairperson and executive director;
    3. Travel for KARS staff to Commission meetings;
    4. Preparation of materials for legislative and agency briefings;
    5. Publication and distribution of a newsletter designed to enhance awareness of the services and technologies available;
    6. Preparation of the annual report of the Commission; and
    7. An Executive Director (.25 EFT) to carry out day-to-day administrative and technical tasks of the Commission.
2. Services to Kansas. Funds would cover the following services:
    1. Consulting with Kansas agencies, Kansas firms and individuals requesting information;
    2. Proposal preparation for agencies;
    3. Training, workshops, shortcourses for Kansans;
    4. Affiliation with the National Cartographic Information Center to foster the availability of data on maps and remote sensing data needed by Kansas agencies; and

5. Maintenance of KARS image collections, maps and digital data for use by Kansas agencies, firms and individuals.

3. Initiation of a land information system. A land information system would contain information regarding vegetation, agricultural land use, and urbanization. Such data do not exist, but are needed for water resources management environmental pollution assessment, conservation needs evaluation, wildlife management and other purposes. Kansas agencies, the Legislature and private individuals would find such data invaluable.

   The Commission has requested funds for KARS to initiate production of such a data base. The data base would be capable of producing maps and statistical data formatted to the needs of a specific user. KARS would assist agencies in using these data to make management and policy decisions more effectively and at lower overall cost.

4. A Study of the Need for a Kansas Resources Information Center. The Commission is charged, under KSA 74-7701, to prepare and present to the Governor and Legislature on or before May 31, 1986, recommendations regarding the need for an integrated, comprehensive Kansas resources Information Center. In 1985 the Commission began this evaluation.

   The Kansas Interagency Task Force on Applied Remote Sensing had considered, in a preliminary fashion, the need for a broadly focused state information center. Such a center would retain and expand all of the current capabilities of the KARS Program. In addition, it could be charged with inventorying, cataloging and coordinating data about Kansas maintained by state, local and regional agencies, federal agencies, some private firms and institutions of higher education. The center could provide clearinghouse and referral services; spatial data analysis capabilities; geographic data base development for state users; remote sensing data/imagery interpretation; training and briefings; and development and/or implementation of new high technologies. A resources information center could facilitate enormous tasks such as a statewide reappraisal, water resources planning, soil errosion assessment, and monitoring of prime agricultural land use change.

APPENDIX III

EMPLOYING GEOGRAPHIC REASONING IN LANDSCAPE MAPPING

James W. Merchant
Kansas Applied Remote Sensing Program
University of Kansas
Space Technology Center
Lawrence, Kansas 66045

ABSTRACT

"Geographic reasoning" is defined as the systematic application of geographic knowledge and understandings in the analysis of data acquired via remote sensing. Visual image interpreters routinely use geographic reasoning in preparing maps of land use and ecoregions. A strategy for employing such reasoning in classification of Landsat Thematic Mapper digital data is proposed. An experiment is designed to test the proposed strategy on a Kansas site. Thematic Mapper data are initially stratified into water, vegetated and non-vegetated pixels. A region-growing algorithm is then used to define "fields" of similar land cover composition. Fields are characterized by size and neighborhood attributes. Hierarchical clustering is employed to test the hypothesis that the diversity, field sizes and spatial interspersion of land cover types are useful discriminants of landscape regions. The hypothesis is shown valid. A major focus of current research is upon implementation of these results.

INTRODUCTION

Classification of landscapes and mapping of landscape regions (e.g., ecoregions, land use regions) are important foci of study in geography and other earth sciences (Spence and Taylor, 1970; Gardiner and Gregory, 1977). The concept of the geographic region is based upon the premise that there are identifiable physical and/or cultural landscape elements which serve to characterize an area and differentiate it from surrounding areas. Remotely sensed data are commonly used to aid in classification and mapping of landscape regions.

Conventional computer-assisted classification of digital multispectral scanner data may be considered monothetic in that it is usually based upon essentially one type of variable - spectral reflectance (though this variable may be comprised of individual measurements taken in several spectral bands). Spectrally-based classification algorithms have been found to be effective in distinguishing many types of "land cover" (e.g., grass, coniferous forest, water). They have been less successfully employed to identify and map landscape regions (Merchant, 1984a, b). Classification of ecoregions and land use requires a polythetic procedure (Spence and Taylor, 1970). Land cover composition, which can often be estimated via multispectral classification, is an important variable, but it alone does not permit differentiation among, or demarcation of, such regions. Other variables must be employed. Bailey, _et al._, (1978) observe that "the relationship between components of landscape and physical and biological process is almost always through spatial pattern or structure rather than through composition alone."

Landscape regions are comprised of mosaics of individual parcels or "patches" of land cover. Forman and Godron (1981) propose that "the structure of a landscape is primarily a series of patches surrounded by a matrix . . . the numbers of patches of each patch origin [natural or cultural], biotic patch type, size and shape determine in part the landscape structure. However, the spatial configuration among the patches present may be just as important as the numbers." Landscape structure is infrequently random (Grigg, 1965; Forman and Godron, 1981). Randomness implies that each event has an equal probability of occurrence. Landscapes, particularly those resulting from human decisions, are likely to reflect some spatial order.

The spatial character of the landscape may arise from a variety of phenomena and processes. In the "natural" environment where man is not a significant factor, spatial structure may reflect the pattern of vegetation communities and/or soils which tend to develop in a particular mosaic pattern under a given set of geologic, topographic (e.g., elevation, slope, aspect, drainage) and climatic circumstances. Where man is a significant organism in the environment, the spatial character of the surface will be related to segmentation of the landscape resulting from land ownership, land use (including settlement, cropping, grazing, and mineral extraction practices), transportation and energy resource development, and urbanization. In most instances, these phenomena will still reflect, to a substantial extent, the natural environment (e.g., soils, slope, drainage, relief, climate), since the environment imposes some constraints (at least economic) on the practical use of the land.

Visual image interpreters routinely employ spatial cues evident in a scene to aid in data stratification, classification and mapping. Such cues may include parcel size, parcel shape, pattern, texture, context and associations of cover types. Optimal visual image interpretation requires a systematic, logical approach to data analysis, and usually employs deductive reasoning and inference. Visual image interpretation requires the use of geographic reasoning and spatial logic. "Geographic reasoning" is defined as the systematic application of geographic knowledge, understandings and expectations in the analysis of data acquired via remote sensing for the purpose of accomplishing a specific objective or set of objectives. "Spatial logic" is defined as the formal expression and systematic application of decision rules which are formulated to assist in the attainment of a particular analytic objective (e.g., preparation of a 1:250,000 scale land use map portraying classes X, Y and Z) and are based upon characteristics and relationships evident in a particular landscape as depicted in a particular set of remotely sensed data. Spatial logic is developed as the image analyst transforms observations, understandings and geographic knowledge of the landscape into decision rules which can be applied in data analysis to segment that landscape into regions of interest. Such rules typically require consideration of both spectral <u>and</u> spatial properties of the landscape, and may require inference and deduction.

This research is directed towards examining means for applying such reasoning in the classification of digital multispectral data. The research has two specific objectives:

1. To formulate and test a data analysis strategy, founded upon spatial logic and emulating some aspects of visual image interpretation, which can be employed to prepare maps of landscape regions from digital multispectral data; and
2. To evaluate the utility of Landsat Thematic Mapper (TM) data for this application.

DEVELOPMENT OF A DATA ANALYSIS STRATEGY

A data analysis strategy, founded upon geographic reasoning and spatial logic, was formulated. The strategy, described at length previously (Merchant 1984 a, b), is here only summarized.

It was observed that visual image interpreters creating land use maps appear to rely on analysis of the spatial distributions of rather generalized land cover types in order to demarcate regions of land use. For example, an image interpreter can identify "cropland" without first having to identify corn, wheat, oats and soybeans. Cropland can be defined on the basis of the size, shape and spatial arrangement of "fields" (parcels, "patches") of "crop-like" stuff, bare soil and other less frequently occurring cover types (e.g., water, trees).

It was proposed that a greenness/brightness data transformation be used initially to stratify the data into, what might be termed, "least common denominator" cover classes - water, organic (vegetated) and inorganic (non-water, non-vegetation) pixels. A "region-growing" technique would then be employed to define "fields" of similar cover composition within each stratum. Fields would be subsequently characterized in a more refined manner (e.g., crop-like, grass-like). Such cover classes should comprise the fundamental constituents of all land use classes, should have "physical significance," and should be readily and consistently identifiable by any data analyst.

Having "mapped" the distribution of fundamental cover types, the task would then be to "classify" land use on the basis of differences in the spatial structure of the landscape so depicted. Three properties of the landscape would be employed, initially, in an attempt to differentiate landscape regions:

1. Fundamental cover composition;
2. Cover diversity (i.e., the number and types of cover per unit area); and
3. Cover interspersion (i.e., parcel size, arrangement and context).

These three variables, selected from a broad range of possible measures of landscape structure, were thought to characterize important elements of spatial structure employed by visual image interpreters in the definition of land use regions. A complex supervised iterative contextual classification algorithm was developed to assign final land use/land cover labels to each field.

INITIAL EXPERIMENTS

The strategy outlined above was tested on a 640 x 480-pixel scene selected from a Landsat TM image acquired September 3, 1982 (ID 40049-16273). The study area includes the City of Topeka, Kansas, and vicinity. The success of classification was evaluated with respect to (1) contemporary aerial photography and (2) a conventional supervised multispectral classification of the same data set carried out by other researchers.

Initial classification results were unsatisfactory. Several adjustments and retrials resulted in little improvement. Consequently, it was decided to examine class statistics to determine if problems lay within the logic of the proposed strategy or were within the complex final classification algorithm employed.

HIERARCHICAL CLUSTERING OF SAMPLE DATA

It was hypothesized that the problems experienced in classification were related to the complex manner in which the classification was implemented, rather than to the logic of the overall proposed strategy. An experiment was conducted to test this hypothesis. The experiment had two major objectives:

1. To determine if the proposed measures of cover composition, field size and interspersion, computed for the landscape defined by the data processing carried out heretofore, could be used to discriminate between land use classes; and
2. To determine if all measures were of equal value and to identify useful measures.

If the measures were shown to be valid and useful, then one might assume that the problems experienced with the classification program were likely due to the complexity of implementation rather than to basic flaws in spatial logic.

Forty samples of twelve land use/land cover classes were selected (Table 1). Each of the forty samples was characterized by a set of eleven statistical variables which were designed to characterize land cover composition, field size attributes and land cover interspersion (Table 2).

Various combinations of the eleven variable sets were entered into a hierarchical clustering program. Hierarchical clustering (HC) is a tool used to cluster together (or link) objects of interest according to selected measures of their similarity (or, if desired, their dissimilarity) (Davis, 1973; Mather, 1976). The intent of clustering was to determine whether any of the statistics computed served as useful discriminants for separating samples of different classes, and, if so, which served as the best discriminants.

RESULTS

A 40-sample x 40-sample error matrix was constructed for each HC run. The error matrix portrays linkages between all samples at the twelve-cluster level. A perfectly accurate twelve-cluster linkage would have resulted in all samples of a single land use class being linked with one another and no linkages between different land use classes (Figure 1).*

A relative accuracy (RA) score was computed for each of the twelve classes and for each run. The within-class relative accuracy score was computed as:

$$\frac{\text{actual within-class links achieved}}{\text{maximum within-class links possible}}$$

The overall score for the entire run was computed as:

$$\frac{\text{actual "correct" within-class links achieved over all classes}}{\text{maximum within-class links possible}}$$

*Note that, since the error matrices are symmetrical, only one-half of the matrix is shown.

TABLE 1. LAND USE/LAND COVER CLASSES

	Class	Number of Sample Sites (Sample Numbers)
1.	Residential - Urban Core	4 (1-4)
2.	Residential - Older	4 (5-8)
3.	Residential - Newer	4 (9-12)
4.	Central Business District	3 (13-15)
5.	Secondary/Neighborhood Business Districts	4 (16-19)
6.	Industrial	2 (20-21)
7.	Institutional	3 (22-24)
8.	Urban Open Land	3 (25-27)
9.	Cropland and Pasture - Upland	4 (28-31)
10.	Cropland and Pasture - Floodplain	4 (32-35)
11.	Rangeland	3 (36-38)
12.	Woodland	2 (39-40)

TABLE 2. VARIABLES COMPUTED FOR EACH SAMPLE

1. The relative frequency of occurrence (RF) of each of the nine cover types of which any sample is comprised (expressed as the percent of the total pixels in the sample):

   (1) Water
   (2) Dark Inorganic Material
   (3) Medium-Dark Inorganic Material
   (4) Medium Inorganic Material
   (5) Medium-Bright Inorganic Material
   (6) Bright Inorganic Material
   (7) Crop-like Material
   (8) Tree-like Material
   (9) Grass-like Material;

2. The relative frequency of occurrence of Water, Inorganic Material (the sum of cover classes 2-6) and Organic Material (the sum of cover classes 7-9);
3. The mean field size of each cover type present in a sample;
4. The mean field sizes of Water, Inorganic and Organic Material;
5. The standard deviation of field sizes of each cover type present;
6. The standard deviation of field sizes of Water, Inorganic and Organic Material;
7. The modal field size of each cover type present;
8. The modal field size of Water, Inorganic and Organic Material;
9. The percent of the sample in each of nine field size categories:
10. The mean, standard deviation and modal field size for all fields in the sample; and
11. An index of spatial complexity (interspersion) for the entire sample (SCI), where

$$SCI = \frac{\text{fields}}{\text{pixels}} * 100$$

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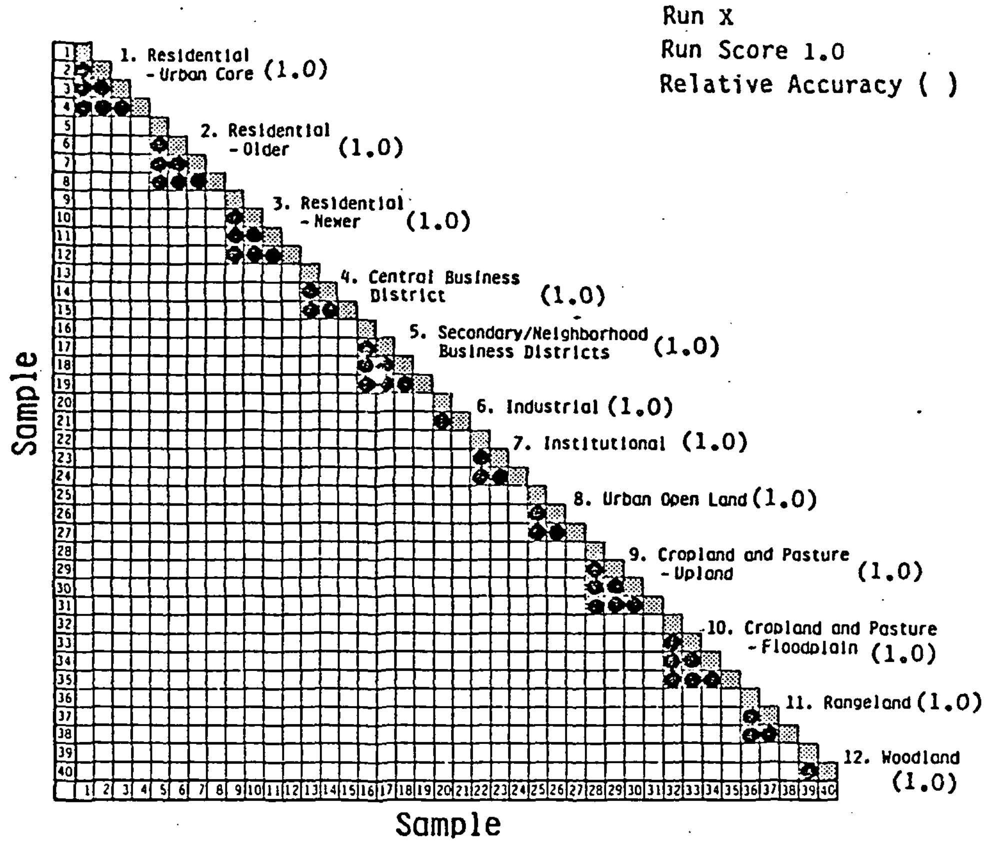

Figure 1. Example of an error matrix portraying perfect linkage between all samples within each land use class and no confusion between classes. Linkage indicated by •.

In either case, the score ranges from 0 (indicating no "correct" links) to 1.0 (indicating that all samples of a given class were linked perfectly). Note, however, that this score cannot be interpreted as percent correct. A class that has a score of 1.0 may still have links with other different classes. That is, all samples of a given class may have been linked together (giving an RA score of 1.0) but all may have also been linked, in a particular run, to samples of a completely different class. Such "confusion" is graphically portrayed on the error matrices. The RA scores and error matrices provided a guide to interpretation and comparison of the results of each run.

Because of limited space, only the best outcome of hierarchical clustering is discussed in detail below. Complete results are presented in Merchant (1984b).

The most satisfactory result (Run 7) was obtained by clustering on four variables:

(1) The relative frequency of occurrence (RF) of each of the nine cover types of which any sample could be comprised;
(2) The mean field size of each cover type present in a sample;
(3) The standard deviation of field sizes of each cover type present; and
(4) The modal field size of each cover type present.

Analysis of the error matrix for Run 7 produced an overall RA score of 0.56, a substantial improvement over other runs (Figure 2). This was attributed to the addition of one or more of the field size descriptors. Subsequent addition of the spatial complexity index (SCI) and percent of the sample in each of nine field size categories (PCF) to the variable set produced no discernible increase in success of clustering.

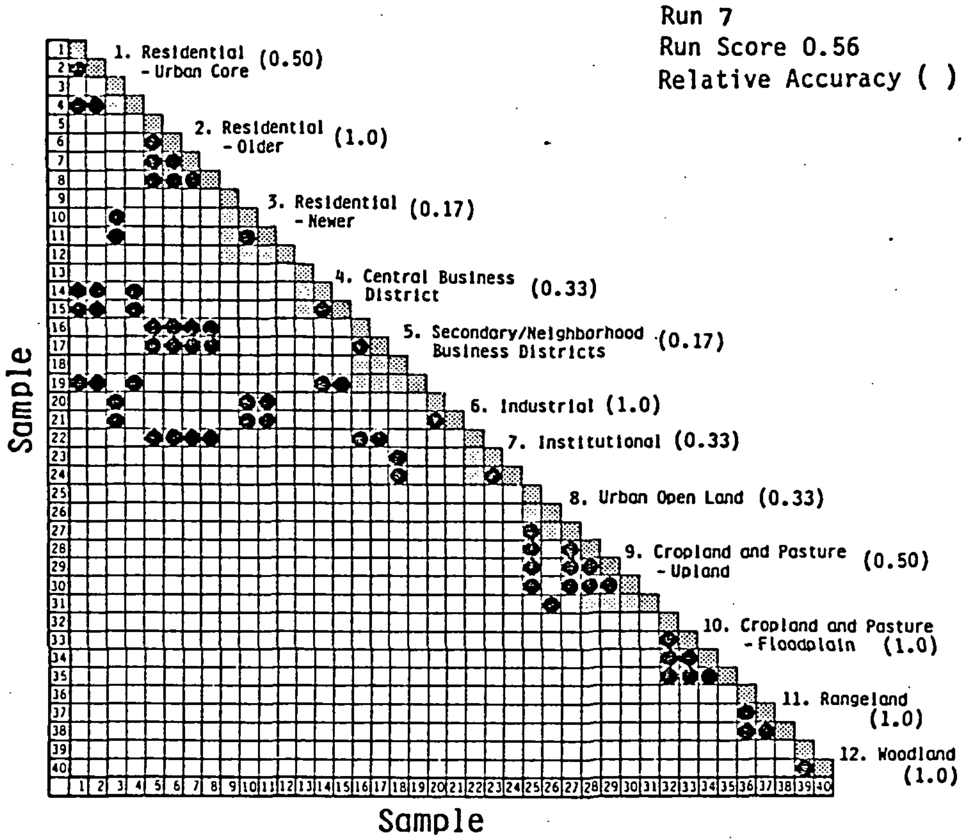

FIGURE 2. Error matrix for best HC run.

The result of Run 7 was compared with the result of the next best run, Run 2 (which was based on the RF alone). The success of within-class linkage was noted to have improved in Classes 2, 5 and 10, but decreased in Classes 3 and 4.

Rural classes were generally quite well-defined. All samples of Classes 10, 11 and 12 (Cropland and Pasture-Floodplain, Rangeland and Woodland, respectively) were linked with one another, and were linked with no other classes. The confusion between Class 10 and Sample 18, Class 5 (White Lakes Mall), which was present in Run 2, was absent in Run 7. Field size apparently aided in sorting these classes. It was noted that confusion between Classes 9 and 10, observed in other HC runs, was also resolved favorably.

Class 6 (Industrial) was perfectly defined in Run 2, but was confused in Run 7 with Sample 3 (Class 1) and Samples 10 and 11 (Class 3). This confusion of industrial and residential land uses was believed to be an artifact of the 3-to-1 weighting applied to field size attributes. It was noted that the SCI, properly weighted, might have been used to help segregate these samples at least to the extent of separating industrial from residential land uses (Table 3).

TABLE 3. RELATIONSHIPS BETWEEN REGIONAL SPATIAL COMPLEXITY INDEX (SCI) (NUMBER OF SAMPLES) AND LAND USE/LAND COVER

Land Use/Land Cover Classes	Spatial Complexity Index (SCI)				Mean SCI
	1-10	11-20	21-30	31-40	
1. Residential - Urban Core	***	*			6
2. Residential - Older			**	**	31
3. Residential - Newer		***	*		21
4. Central Business District	***				3
5. Secondary/Neighborhood Business Districts	**	*		*	16
6. Industrial	**				10
7. Institutional	**		*		12
8. Urban Open Land			***		24
9. Cropland and Pasture - Upland	*	***			13
10. Cropland and Pasture - Floodplain	***	*			10
11. Rangeland	***				3
12. Woodland	**				6

Note: $SCI = \frac{\text{fields}}{\text{pixels}} * 100$

SCI = 100 = maximum interspersion; as SCI approaches 0 it indicates decreasing interspersion

Overall, urban classes (Classes 1-8) and rural classes (Classes 9-12) were well distinguished from one another. Only Classes 8 and 9 (Urban Open Land and Cropland and Pasture-Upland, respectively) were confused. In terms of RF and field size, these might be considered "transitional" classes. It was observed, again, that even this confusion might have been reduced by use of a properly weighted SCI.

The results of the hierarchical clustering experiments may be summarized as follows:

1. The results showed that the relative frequency of occurrence of each of the nine cover types of which a sample could be comprised and field size statistics could be profitably employed to separate land use/land cover samples into a logical classification.
2. Two other variables tested were shown to have little value. These were:
   (a) the percent of the sample in each of nine field size categories; and
   (b) the spatial complexity index (SCI) of the sample site.

3. Classification wherein cover was labeled only as Water, Inorganic and Organic material was not as successful as classification wherein cover was broken into nine types.
4. Rural and urban land use/land cover classes were well-separated from one another in the best run. Most confusion between classes was logical and explainable.
5. There was evidence that results might be improved if field size, RF and SCI variables were more equitably weighted.
6. Comparison of the results of these experiments with conventional spectral classifications of the study area produced from TM and MSS data shows that the addition of spatial information aids in definition of land use and in separation of certain land use classes.

It should be noted that all of these findings reflect the manner in which fields were defined (i.e., through greenness-brightness transformations and region-growing) and labeled, the decisions that were made during these steps of analysis (e.g., thresholds selected), and the way in which spatial structure and cover composition were measured (e.g., RF, $\bar{x}$ field size, SCI). They also reflect the manner in which hierarchical clustering was conducted. Nevertheless, it seems clear that the type and diversity of cover and field size are important variables that can be employed to help classify and identify landscape regions in digital TM data.

CONCLUSIONS

A case has been made for the more rigorous application of geographic reasoning and spatial logic in analysis of digital remotely sensed data. A strategy for mapping landscape regions, founded upon spatial logic, has been proposed and tested. The strategy was judged to be valid, but full implementation will require additional effort.

The major conclusions of this research to date are as follows:

1. Spatial logic and geographic reasoning provide useful frameworks for formulation of digital data analysis strategies;
2. Greenness and brightness data transformations and region-growing are useful for defining landscape structure in a cogent manner;
3. Several measures of the landscape structure so-defined are effective for classification of land use. These include:
   (a) the relative frequency of occurrence of land cover types;
   (b) the mean field size for each cover type that occurs; and
   (c) the standard deviation of the field sizes of each cover type that occurs;
4. Other measures of landscape structure, such as the spatial complexity index, may be useful discriminants if weighted appropriately; and
5. The results of the hierarchical clustering experiments suggest that the overall approach to data analysis proposed is valid. The failure of the contextual classification algorithm to perform successfully is believed to stem from the internal complexity and logic of the program and not from the spatial logic which guided the overall strategy. Further research is warranted.

ACKNOWLEDGMENTS

The constructive critiques and helpful suggestions of T. H. Lee Williams and George F. Jenks have been important contributions to this research. Tshow Chu and Chien-Chung Chan provided expert and innovative software development. The financial support of the National Aeronautics and Space Administration (Grant NGL 17-004-024) is gratefully acknowledged.

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APPENDIX IV

USING LANDSAT TM IMAGERY AND SPATIAL MODELING IN AUTOMATIC HABITAT EVALUATION AND RELEASE SITE SELECTION FOR THE RUFFED GROUSE (GALLIFORMES: TETRAONIDAE)*

Jorge M. Palmeirim

Kansas Applied Remote Sensing Program,
and Museum of Natural History
University of Kansas, Lawrence, Kansas 66045, U.S.A.
and
Departamento de Zoologia, Faculdade de Ciencias
Universidade de Lisboa, 1200 Lisboa, Portugal

ABSTRACT

Thematic Mapper (TM) imagery was integrated in a Geographic Information System (GIS) to develop automated models to evaluate and map ruffed grouse habitat, and select potential release sites for that species in northeastern Kansas (U.S.A.). Forest cover was mapped from a TM image using a mixed spectral/contextual approach. The high resolution of the TM imagery allowed a detailed mapping of forest edge, a critical element of potential grouse habitat in this region. Forest areas were then evaluated as potential ruffed grouse habitat by a spatial model using the following elements: (1) woodlot size, (2) woodlot interconnection, (3) amount of forest edge, (4) distance to woodlot edge, and (5) forest type. Another model generated a map of release site suitability based on the regional amount and quality of appropriate habitat. The results obtained were evaluated by wildlife management professionals familiar with the grouse and the local habitat conditions. It was concluded that the techniques employed have substantial potential as tools in grouse management.

1. INTRODUCTION

The low ground resolution of the Multispectral Scanner (MSS) (79x79m) has been a major factor limiting the use of its imagery in habitat studies. Nevertheless many papers have been published on the subject in the last few years showing a wide range of applications when a high ground resolution is not critical (for an overview see Palmeirim, in prep.). In particular the usefulness of MSS Landsat imagery in the selection of sites for reintroduction of locally extinct species has been demonstrated by various projects. Wild turkeys (*Meleagris gallopavo*) were released at sites selected using an MSS-based land cover classification (Katibah and Graves, 1978); monitoring the rates of conversion of rangeland to agricultural land using MSS imagery

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assisted in the choice of release sites of pronghorn antelope (Antilocapra americana) in Kansas (Martinko, 1978). The higher resolution of the Thematic Mapper (TM) (30x30m) considerably increased the potential to use satellite-borne sensors in wildlife studies.

Most of the previous work focussed upon simple identification of habitat elements, such as vegetation. In spite of the usefulness of that work, it is unfortunate that so little effort has been expended in relating these elements to the actual needs or preferences of the individual animal species (but see Thompson, et al., 1980; Lyon, 1983). In this project I attempted to do this using TM imagery to generate a vegetation map, and GIS models based on the biology of the ruffed grouse (Bonasa umbellus) were used to manipulate the vegetation map. An automated model was developed to evaluate the quality of the identified vegetation types as habitat for the ruffed grouse. This model generated a habitat suitability map which was then used in another model that selected potential sites for reintroduction of the grouse.

The ruffed grouse is a forest species with a wide range in North America. Due to its importance as a game bird various agencies have been reestablishing the grouse in areas where it became extinct in historical times, or even introducing it outside its historic range (Gullion, 1984). The Kansas Fish and Game Commission is currently attempting to restore this species in wooded areas in northeastern Kansas. Throughout most of its range the grouse depends heavily on aspen (Populus tremuloides, P. grandidentata) for food and cover (Gullion and Svoboda, 1972). However, in the southern part of its range, in the absence of aspen, the grouse seems to be mostly dependent on understory growth of shrubs, vines, and herbs for those requirements (Hale et al., 1982). Not surprisingly it is believed that in these regions it was, prior to settlement by Europeans and widespread extinctions, limited to ecotones and early successional areas (Hunyadi, 1984). Since Kansas is on the southern edge of the historical range of ruffed grouse these are the habitats where it is most likely to thrive in the state.

The study area is located around the intersection of Douglas, Leavenworth and Jefferson counties, just north of Lawrence, Kansas. It includes 52 km (240x240 TM pixels) of intermixed rangeland, cropland, deciduous forest and old fields.

2. MATERIALS AND METHODS

Since many wildlife biologists have little knowledge of image processing methods, the objectives of the various operational methods carried out in this project are explained in general terms. A textbook on image processing (e.g. Schowengerdt, 1983) may be consulted for additional details regarding some of the techniques used.

All the image processing in this project was done on a Honeywell 66 DPS-3E computer. The photographic image products were generated using a Video Display Interface (VDI), installed on a Digital Equipment Corporation PDP-11/23, and a Terak 8510/23 Graphics Computer System.

2.1 SPECTRAL LAND COVER CLASSIFICATION

An automatic supervised spectral classification was first performed. The image was subdivided into various cover types, according to their spectral characteristics. A series of training areas of known cover was select-

Image Processing System (KUTIPS) program package (Williams et al., 1983).

Two separate land cover maps were generated using the same training statistics but different classification algorithms. The Maximum Likelihood Classifier produced the map with the highest overall accuracy, but the Minimum Distance Classifier was more successful in mapping wooded areas. To take advantage of this situation the two forest classes of the Minimum Distance map were digitally overlayed onto the Maximum Likelihood image. The Map Analysis Package (MAP) (Tomlin, 1980) was used to merge the two classified images. The final land cover map used was therefore a combination of the results of both classifications.

2.2 CONTEXTUAL LAND COVER CLASSIFICATION

The contextual information in an image can be used to improve the accuracy of pixel identification (e.g. Gurney and Townshend, 1983). Contextual information was incorporated in the land cover classification following a simple and computationally inexpensive approach. Pixels that could not be assigned with acceptable certainty to any of the cover classes based on their spectral characteristics alone were submitted to the spatial classifier; each of these pixels was assigned to the majority cover in its immediate neighborhood.

Two approaches were used to spatially classify pixels, depending on the homogeneity of its neighborhood: (1) if at least five of the eight neighbors in a 3x3 pixel neighborhood of a particular pixel belonged to a single cover class the pixel was assigned to that class; (2) the identity of the remaining unclassified pixels was determined by a larger (5x5 pixel) neighborhood. However, since a pixel adjacent to an unclassified pixel provides a better clue to its identity than a pixel located further away, the individual contributions were proportional to the distance from the pixel being classified. This contextual classification was performed using a modified version of neighborhood functions available in the MAP package.

2.3 HABITAT AND RELEASE SITE EVALUATION

Extensive processing of the land cover map was needed to generate the habitat and release site maps. All the operations were performed using unmodified functions available in the MAP software. Although MAP is an interactive package, the large number of operations needed for each model made it advantageous to lay out sequences of commands in files; the commands were then executed automatically in the set sequence. This approach resulted in considerable time savings due to the need to make modifications in the models during their development. Implementing the same model in other areas and/or including minor modifications also becomes simpler and more accurate. Flowcharts and printouts of these command files are available from the author.

3. RESULTS AND DISCUSSION

3.1 LAND COVER CLASSIFICATION

The seven class land cover map generated included rangeland, old fields, standing crop, bare soil, water, and two types of deciduous forest. Since the ruffed grouse is a forest species I made a particular effort to optimize the mapping of these latter cover types. A comparison of the results obtained with aerial photography and field checks showed that the generated map (Fig. 1) accurately represents the distribution of forest in the study area. Small clumps of trees, the wider tree rows, and the intricate contours of the irregular woodlots characteristic of this area were evident. The gray area on the classified image (Fig. 1) indicates forest appearing younger, mostly on south-facing slopes, and black represents the remaining forest. The composition and structure of the forest on the south-facing slopes differs considerably from that of other exposures. This seems to be at least partially related to their age (Fitch and McGregor, 1956, include a description and history of some of the forest lots in the study area). The degree of confusion between the two types of forest on the classified map is hard to estimate, because no absolute criteria were established to separate them on the ground.

3.2 HABITAT EVALUATION

When visually classifying ruffed grouse habitat suitability using aerial photographs, the experienced wildlife biologist would make a series of more or less subjective decisions. The models used attempt to process the imagery making similar judgements. This is a particularly hard task because it is often not possible to state absolute rules for those judgements. In the following pages I will illustrate the various "decision steps" made, and explain their biological significance in the context of ruffed grouse habitat.

Woodlot size and interconnection

The wooded areas were first isolated from the land cover map; other habitats were considered as not fulfilling the minimal ruffed grouse habitat requirements. The analysis will not be seriously affected if grouse use these habitats since this will only happen along forest edges. Although all forested areas can potentially be grouse habitat the high resolution of the TM imagery (30x30m) allows the mapping of very small clumps of trees, many of which are too small to be used by the grouse. Isolated forest pixels were therefore eliminated. Of the remaining woodlots some are still too small, unless they are located close to other woodlots. Forest patches separated from other forest patches by more than 300 meters were eliminated unless they had an area of 4 ha or more (Fig. 2). This area was chosen because one pair of grouse per 4 ha is about the highest possible density under most conditions (Gullion and Svoboda, 1972). Fig. 2 still includes some woodlots smaller than 4 ha; this is because they are close enough to other forest patches to be considered connected to them. This figure also shows that there is a high level of interconnection among the woodlots and that small patches of forest are important in the interconnection of the larger woodlots.

Edge effects

The most important limitation of a habitat evaluation model based on Landsat imagery is that it can only include variables that can be directly detected and measured on the imagery or easily included as digital ancillary data. In the case of ruffed grouse habitat in Kansas, the inability of Landsat images to detect the structure of the forest understory is a serious limitation because in the southern part of its range the grouse seems to be mostly dependent on the understory (Hale et al., 1982). The imagery is, however, particularly suited for modeling using spatial components of the habitat and closely correlated variables. Forest edges are a good example - they can be accurately mapped and are closely associated with a denser understory. Overgrazing has destroyed much of the forest undergrowth in northeastern Kansas. This factor is likely to have been a major cause for the disappearance of the ruffed grouse in the state (Goss, 1891). Presently, dense undergrowth occurs mostly along edges, where growing conditions are more favorable and regeneration faster. Forest edges are therefore the most important single element in this habitat evaluation. TM imagery is well suited for this project because it allows an accurate mapping of the forested areas, and its comparatively high resolution portrays the detail of the woodlot edges. Using imagery with a poorer resolution, such as MSS, would result in a considerable loss of detail in these edges, which are so critical for the grouse. Forest clearings are often good habitat for the ruffed grouse in this area since they usually create an edge effect that generates a denser understory in the forest in their vicinity. However, very small clearings are probably not important habitat, and the likelihood that they are the result of a misclassification of the Landsat data is comparatively high. To avoid a major influence on the final habitat evaluation the smallest clearings were eliminated. Fig. 3 shows the results of this operation. The appropriateness of this step is however quite debatable because, while it eliminates undesirable image noise, it also causes the loss of some habitat information. Since the final result of the model was acceptable, this step was retained in the analysis.

Since forest edges are most likely the best habitat for the grouse in this area, the edge pixels were given the highest ratings on a scale of 0 (no habitat, lightest on Fig. 4) through 5 ("best" habitat, darkest on Fig. 4). In the map on Fig. 4 the relative quality of each pixel is proportional to its location in relation to the forest edge. Rating 5 was given to the actual edge pixels, 3 to pixels between 30 and 90 meters away from the edge, 2 to the pixels between 90 and 180 meters, and 1 to the innermost forest. Non-forest pixels were assigned a rating of 0. The scale is arbitrary and is designed to reflect relative probability of habitat quality: the probability of a pixel being suitable as habitat for the grouse is higher when located near an edge than in the innermost part of a woodlot. Further studies are needed to select an optimal rating scale.

Forest type

The preferred types of forest for the ruffed grouse seem to vary seasonally, even though grouse seem to use all types of hardwood forest (Bump, et al., 1947; Gudlin and Dimmick, 1984). Overall, the grouse seems to prefer second growth hardwood forest over climax forest, particularly for brood cover (Bump et al., 1947). Although preferences shown in other areas may not hold in the study area, the ratings of the areas of younger forest (Fig. 1) were increased slightly, by adding one unit to the previously assigned ratings (Fig. 5). The suitability scale now varied between 0 and 6, the highest value corresponding to second growth forest edge pixels.

Final habitat suitability map

Habitat suitability is better measured by an average of quality over an area than by the ratings assigned to individual pixels as in Fig. 5. The quality of each pixel as potential habitat for the grouse is not only a function of its characteristics but also of the forest pixels in its neighborhood. The rating of each pixel was, consequently, substituted by the average rating of the forest located within a circle of about 30 ha centered on the pixel (Fig. 6). Although the size of the scanning area is not critical, (because the technique is deriving a relative not absolute quality rating), the choice of 30 ha as the scanning area is based on the fact that this is a reasonable size for the home range of a male grouse (Gudlin and Dimmick, 1984; Woolf, et al., 1984). The cell ratings on this image can, thus, be considered a measure of the relative quality of home range of a bird that used the area within a circle of 30 ha centered on each cell. However, since nonforested pixels were excluded from these calculations, the actual averaged area may be much less than the 30 ha scanning circle. Notice on this figure that the highest ratings have been assigned to small and/or irregularly shaped woodlots due to the greater importance of edges in those lots. The lowest probability habitat suitability ratings were assigned to the innermost areas of the larger lots.

The road network was digitized and superimposed on the habitat suitability and following maps (Figs. 6, 7, 8, and 9) to make them easier to use. The signal of the roads on the original imagery was deleted to avoid confusion with the road overlay.

The suitability map on Fig. 6 is needed for the process of selection of release sites, but it can also have other applications in a grouse management project. For example, it can be used to help in the choice of sites to place man made drumming logs, since the areas with darker tones are more likely to become grouse territories.

3.3 RELEASE SITE SELECTION

Despite its usefulness the habitat suitability map generated (Fig. 6) still leaves open the question of where the release points should be located. One could select these points using the habitat suitability map by visually choosing areas including large amounts of good habitat. To locate the best candidate sites automatically the rating of each forest cell was made proportional to the amount and quality of the forest habitat within a circle having a diameter of 1800 meters centered on the pixel (Fig. 7). The choice of diameter is a compromise between the need to sample a considerable amount of habitat and the advantages of keeping a small scanning radius. The use of a larger radius could result in suggested release sites located far from patches of good habitat; the spatial correlation between the generated "release sites" map and the "habitat suitability" map is inversely proportional to the length of the radius used. The 1800 meter diameter was chosen to reflect known dispersion patterns of grouse away from release sites (Gudlin and Dimmick, 1984).

Before performing the scanning operation the values on the scanned map (Fig. 6) were squared. The squaring operation was designed to increase the relative contribution of the best habitat types in generating the "release sites" map (Fig. 7). The rating scale ranged then from 0 (lowest, no habitat) to 36 (highest, best habitat). The values of all the pixels within the scanned area were then averaged; the value obtained was assigned to the center pixel.

The "release sites" map is intended to be an aid in the location of sites to release grouse. The suitability of the areas having the highest ranks should be field checked first. Grouse can then be released either on these high ranking areas or in neighboring areas of good habitat (as suggested by the "habitat suitability" map and field checks).

In the choice of release sites there are usually two main considerations: (1) site quality, which was discussed above and is dependent on the habitat suitability around the potential site (Fig. 7), and (2) convenience, a component most often dependent on the accessibility of the site. A very good site may not be used because it is too costly to reach. In this study area the dense road network and the absence of common obstacles such as large water bodies and rough terrain make the access to all areas fairly easy. However I include here, as an example, a simple extension of the release site selection model that takes in consideration convenience.

The convenience of a release site decreases with the distance from a road. Since it is much easier to move in some land cover types than in others, it would not be appropriate to evaluate convenience with a simple distance measure; the difficulty of moving in the various cover types should also be included. I estimated that it is about three times harder to walk through the forest than through the other major cover types. Fig. 8 shows four levels of relative difficulty in reaching the various parts of the study area, taking into consideration the differences in mobility. Fig. 9 is a combination of Fig. 8 with the release sites map (Fig. 7); it combines the quality of release sites with their convenience. For sake of clarity only the higher ranking areas are shown in Fig. 7. The darkest tones represent very good quality and very good convenience (accessibility) ratings; the lighter tone also represents very good quality but lower convenience rating.

3.4 VALIDITY OF THE MODELS

A serious problem with the models presented here is the difficulty in testing their validity. Even if grouse are released and the species becomes established in the study area, it will take several years before its distribution and density will become a useful indication of habitat suitability. However, the experimental results obtained were evaluated by wildlife management professionals familiar with both the grouse and the local habitat conditions. It was concluded that the techniques employed have substantial potential as tools in grouse management. Field checks also support the utility of these TM imagery based models and they will soon be implemented operationally in a much larger area, which will help in their evaluation.

4. CONCLUSIONS

TM imagery proved to be appropriate for this project, in which accurate forest classification and detailed woodlot edge mapping were needed. The MAP package was an invaluable GIS tool. The many available general use commands when combined allow the implementation of complex image operations. MAP was used in this project not only to implement the models, but also to improve the spectral land cover classification, introducing contextual information in the final land cover map. The package also allowed the inclusion of roads as a reference system on the final maps generated. Various versions of the MAP package are now available, including one for microcomputers (pMAP, Spatial Information Systems) making this technology quite accessible.

The models implemented in this paper were designed to be used in northeastern Kansas. It was assumed that most good ruffed grouse habitat lies along the forest edges. The models are, therefore, applicable only where this assumption is met, as in the many areas lacking aspen along much of the southern range of the species. Model adjustments can be made to adapt the model to different areas. For example, the suitability rating of the non-edge forest, very low in this study area, can be increased if the model is applied to areas where the forest has a more dense understory.

This is one of the first attempts to combine Landsat imagery and spatial modeling in wildlife biology. However, the need for habitat models is great and many models based on habitat variables obtained in the field are now available (for the ruffed grouse see Cade and Sousa, 1985). These models have the advantage of basing their predictions on variables that describe habitat with more detail than TM imagery. The limited capability of satellite-borne sensors to provide information on certain important habitat components restricts the range of situations were the approach described in this paper can be successfully implemented. However, when applicable, models based on digital satellite imagery can be implemented quickly and inexpensively over large geographical areas. Because some of the variables employed (e.g. density of understory) are not directly detectable but are inferred from other variables (e.g. distance to edge), the various suitability maps generated in this project cannot be called absolute maps. The rating assigned to a pixel on these maps is intended to be correlated with the probability of that pixel being good habitat. The maps produced might therefore be better described as "probability" maps than "suitability" maps, as they are refered to for convenience in this paper. The results obtained support the belief that, when their limitations are not underestimated, these and similar models can be very useful tools in decision making for wildlife management.

5. ACKNOWLEDGEMENTS

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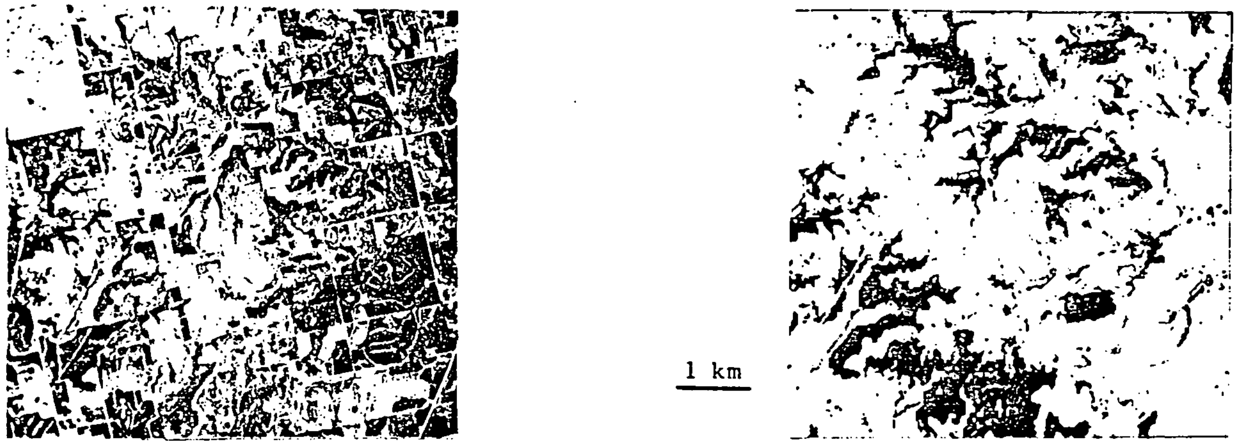

Fig. 1. (Left) IR aerial photo (NHAP) and (right) classified forest cover of study area. (On classified image gray is forest appearing younger, mostly on south-facing slopes; other forest is black.)

Fig. 2. Usable woodlots.
(SW corner of study area. Single forest cells and small isolated woodlots were eliminated.)

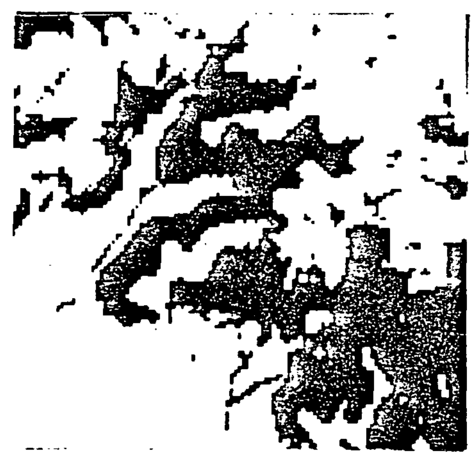

Fig. 3. Forest minus small clearings.
(SW corner of study area.)

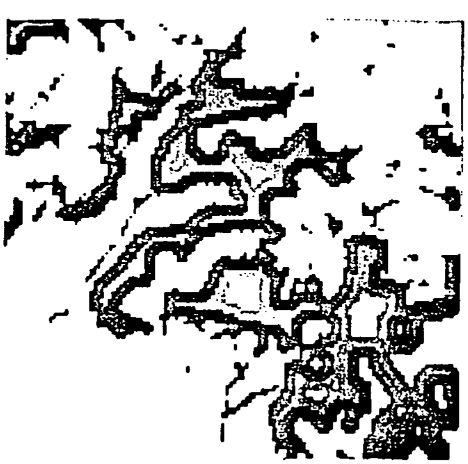

Fig. 4. Distance from edge.
(SW corner of study area. Darker areas have a higher probability of being good habitat.)

Fig. 5. Distance from edge and forest type.
(SW corner of study area. Darker areas have a higher probability of being good habitat.)

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Fig. 6. Habitat suitability map.
(Darker areas have higher probability of being good habitat. Black are roads.)

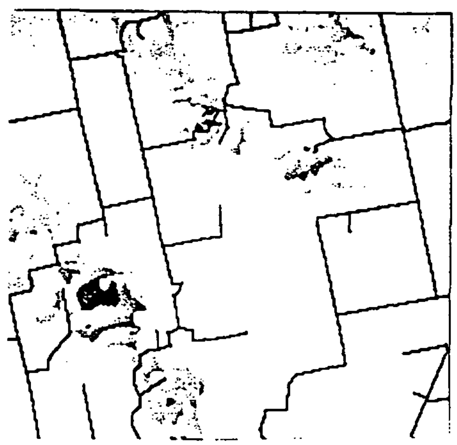

Fig. 7. Suggested release sites.
(Darker areas are more likely to be good release sites. Black are roads.)

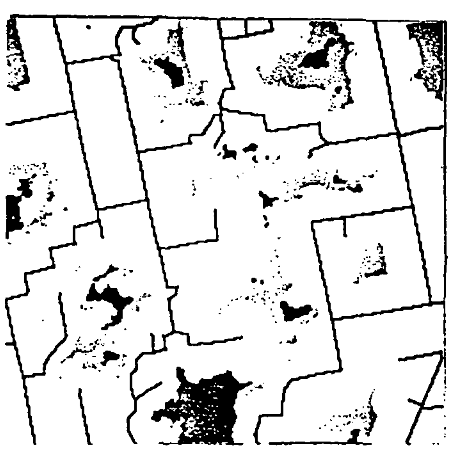

Fig. 8. Difficulty of access.
(Darker areas are harder to reach from roads. Roads are in black.)

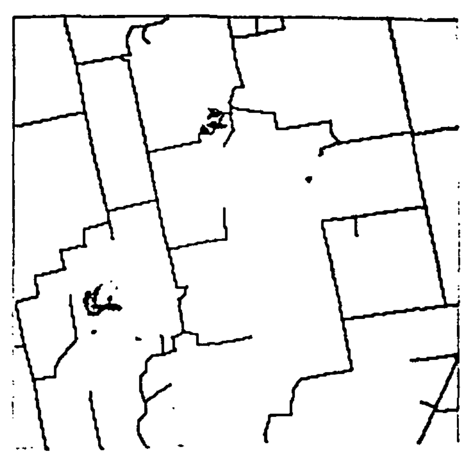

Fig. 9. Good and accessible potential release sites.

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KANSAS APPLIED REMOTE SENSING PROGRAM

The University of Kansas
Space Technology Center
Lawrence, Kansas 66045

Land use/land cover map of Lawrence, Kansas and vicinity prepared by computer processing of Landsat 4 Thematic Mapper digital data.

MAJOR KARS PROGRAM RESEARCH AND APPLICATION AREAS

Geographic information system design, construction and application

Integrated natural resources inventories

Land use/land cover inventory, change detection and mapping

Irrigated lands inventories

Wildlife habitat evaluation

Strip mined lands assessment

Crop and rangeland evaluation

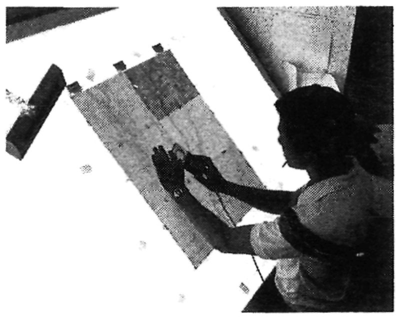
Thematic mapping

Technology transfer/remote sensing education

FACILITIES

KARS Program offices and laboratories are located in the University of Kansas Space Technology Center. The Program has complete facilities for processing and interpreting remote sensing data in both image and digital formats, state-of-the-art cartographic production, statistical analysis and geographic data processing. Graphic arts, photographic and other support services are provided within the Space Technology Center.

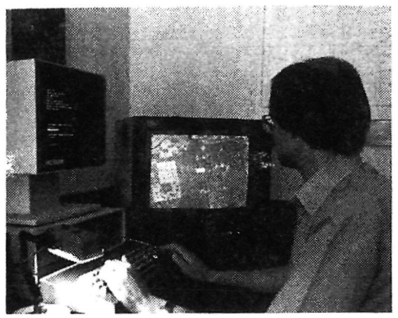
The KARS Program's Image Interpretation Laboratory is furnished with a complete range of equipment for viewing and analyzing imagery, and for transferring image data to base maps of various scales. Included are a Bausch and Lomb Zoom Transfer Scope, an Itek Color Additive Viewer,



a Variscan Rear Projection Viewer, five Richards Light Tables with Bausch and Lomb Zoom 240 stereoscopes, a Saltzman Reducing/Enlarging Projector, a MacBeth Color Spot Densitometer and a complete assemblage of other visual image interpretation aids.

Analysis of digital remote sensing data, digitizing and other computer-assisted data processing operations are supported by facilities of the KARS Digital Data Analysis Laboratory. KARS' digital data analysis system is based upon a DEC PDP 11/23 computer. Support equipment includes an 80-megabyte Control Data Corporation disc drive, a Kennedy 9100 tape drive, a Sky Computers SKYMNK array processor, and a Versatec 8222-F 22-inch electrostatic printer/plotter. Color video display functions are provided by a Terak 8510/a-8600HDX microcomputer having a 19-inch RGB monitor capable of 640 x 480-pixel resolution. Digitizing is accomplished with an Altek AC90SM microprocessor-controlled digitizer having a 42 x 60-inch backlighted digitizing tablet.

KARS' computer system supports a comprehensive array of software for interactive digital image processing and classification, geographic information system operations, statistical analysis and computer mapping. Remote terminals also enable KARS staff to draw upon the substantial



facilities of the University of Kansas Honeywell Level 66 Computer System.

Aerial photography in support of KARS projects is acquired from a Cessna 180 Skywagon accessible to KARS staff. Both a multispectral cluster of four Hasselblad 500EL 70mm-format cameras and a Fairchild nine-inch format cartographic camera are available for photographic missions.

Custom designed cartographic and graphic products are prepared by KARS staff using negative scribing and photo-mechanical techniques. Production of color graphics and color separations are standard procedures. Printing services are available. KARS staff also have access to Tektronix computer graphics systems, computer mapping software, and both flatbed and drum plotters.

THE UNIVERSITY OF KANSAS APPLIED REMOTE SENSING (KARS) PROGRAM

The University of Kansas Applied Remote Sensing (KARS) Program was established by the National Aeronautics and Space Administration (NASA) in 1972 to conduct applied research on techniques which will enable public agencies and private firms to better utilize available satellite and airborne remote sensing systems. The KARS Program is an applied research program of the University of Kansas Space Technology Center. The Space Technology Center was established in 1972 by NASA and the State of Kansas to enhance research and education in space-related science and technology through multi-disciplinary research efforts. The KARS staff is comprised of specialists having backgrounds in ecology, geography, forestry, wildlife biology, engineering, cartography, computer science, environmental studies and natural resources management.

Projects undertaken by the KARS Program with local, regional, state and federal agencies and private industry are designed to identify and enhance the manner in which remote sensing technology can aid in decision-making, policy formulation, planning and in meeting other needs and responsibilities. The KARS Program and Kansas agencies have established the Kansas Interagency Task Force on Applied Remote Sensing to foster the utilization of remote sensing and related spatial data analysis techniques by Kansas state government. All KARS services are provided at large to public agencies and private firms, both within and outside of Kansas, on a contractual basis.

The KARS Program has provided assistance and services to more than forty agencies in Kansas, Missouri and other states in the Great Plains/Rocky Mountain region. Contractual applied remote sensing projects have been carried out for the NASA Earth Resources Laboratory, NASA Ames Research Center, U.S. Fish and Wildlife Service, U.S. Office of Surface Mining, USDA/Soil Conservation Service, U.S. Environmental Protection Agency, U.S. National Park Service, Kansas Fish and Game Commission, Missouri River Basin Commission, Mid-America Regional Council, and Farmland Industries, Inc. Projects have involved land use/land cover inventory, monitoring land use change, wildlife habitat evaluation, mapping of irrigated lands, surface mined lands inventory, recreational area planning, soil conservation needs assessment, aquatic vegetation mapping, rangeland condition evaluation, urban area analysis and education and training. In addition, KARS staff have provided remote sensing consulting services in India, Mexico and several states.

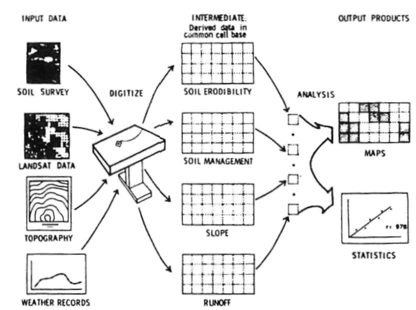
For additional information contact:

Kansas Applied Remote Sensing (KARS) Program
University of Kansas
Space Technology Center
2291 Irving Hill Drive
Lawrence, Kansas 66045-2969

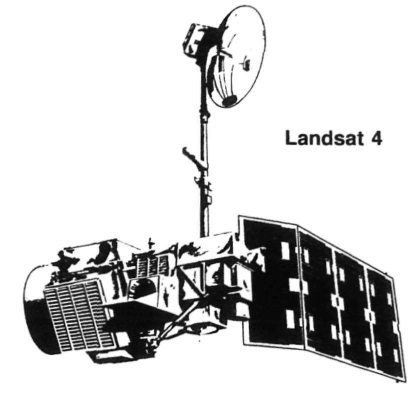
Telephone: 913/864-4775
KANS-A-N 564-4775

KARS NEWSLETTER

The KARS Program publishes the quarterly *KARS NEWSLETTER* which is designed to foster the application of remote sensing data and to provide a forum for communication on remote sensing-related matters. Current circulation is approximately 2,000. Readers include employees of local, state, regional and federal agencies, research centers, colleges and universities, and private firms. Most readers reside in the Midwest and Western U.S., but Newsletters are mailed throughout the United States and to several other nations. Subscriptions are available upon request.



Computer-based *Geographic Information Systems* aid in decision-making by facilitating the analysis of data acquired from many different sources.



REMOTE SENSING

Remote Sensing is the science of acquiring information about an object or area in the absence of physical contact with the entity of interest. Remote sensing systems, such as cameras, scanners and radars, mounted aboard aircraft and spacecraft are increasingly being used to inventory, evaluate and monitor the extent and condition of phenomena such as land use, water resources, crop and rangeland, conservation practices and urbanization. The Kansas Applied Remote Sensing (KARS) Program was established to assist public agencies and private firms concerned with natural resources management, agriculture, regional planning and related issues in employing remote sensing technology. Data acquired by remote sensing, especially when used in concert with information obtained in traditional ways, can often enable such agencies and firms to make better, more rapid, and/or more cost effective decisions regarding problems with which they must deal.

KARS

SERVICES OF THE KARS PROGRAM

The KARS Program provides the following services:

Interpretation of remote sensing data in support of land use/land cover, environmental, planning, agricultural and natural resources inventories and analyses;

Research in the analysis of remote sensing data and in applications of remote sensing/geographic information systems technologies;

Geocoding, geographic information system design and production; statistical analysis, design of sampling surveys, areal statistical data summaries;

Analysis of trends, projections, spatial modeling, monitoring of change on a seasonal (e.g., range burning, harvesting) or annual basis (e.g., land use, wildlife habitat);

Map production using state-of-the-art cartographic techniques including negative scribing, color separation and computer graphics;

Field investigation either in support of remote sensing data collection or independently designed to meet specific agency or client requirements;

Aerial photography in support of KARS research and applications projects;

Location and acquisition of remote sensing data; flight mission design;

Instruction in remote sensing techniques, interpretation and applications; short courses, workshops, seminars; technology transfer.