N 73 22344

LARS Information Note 030573

Basic Forest Cover Mapping using Digitized Remote Sensor Data and ADP Techniques

by
M. E. Coggeshall
and R. M. Hoffer

The Laboratory for Applications of Remote Sensing

Purdue University, West Lafayette, Indiana

1973

LARS Information Note 030573

Basic Forest Cover Mapping using Digitized Remote Sensor Data and Automatic Data Processing Techniques [1]

M. E. Coggeshall
R. M. Hoffer

May, 1973

Published by the
Laboratory for Applications of Remote Sensing (LARS)
and the
School of Agriculture
Purdue University
West Lafayette, Indiana 47906

[1]This work was supported by the National Aeronautics and Space Administration under Grant No. NGL 15-005-112.

TABLE OF CONTENTS

TABLE OF CONTENTS

(Continued)

LIST OF TABLES

LIST OF TABLES
(Continued)

LIST OF TABLES
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

ABSTRACT

Increasing demands on the forest resource will necessitate increasingly more intensive management in the future. In order to achieve this goal, reliable and timely information over large geographic areas will be required. Remote sensing techniques offer much potential for the procurement of such information.

This research, then, was pointed toward study of that potential. Four objectives were established as follows: 1) to determine the optimum number of the available twelve multispectral scanner (MSS) wavelength bands to use for forest cover mapping with automatic data processing (ADP) techniques; 2) to determine the current capability to map basic forest cover using MSS data and ADP techniques; 3) to determine the relative utility, to forest cover mapping,

of the four spectral regions available in the twelve-channel MSS data (i.e. visible, and near, middle and thermal infrared); and 4) to compare the accuracy of digitized color infrared photography with that of MSS data for forest cover mapping using ADP techniques.

In attaining the first objective, statistics defining the six cover type classes of interest (deciduous forest, coniferous forest, water, forage, corn, and soybeans) were calculated and used by the computer as a basis for the selection of "best" wavelength band combinations ranging in size from one through ten wavelength bands each. With the spectral information contained in each of these combinations, and with all twelve channels, the entire test area was classified into the six defined classes, using the LARSYS programs. Tests of the computer's performance indicated that the use of five wavelength bands would fulfill the dual requirements of adequate accuracy and moderate computer time.

In fulfilling the second objective, the automatically selected "best" combination of five channels (one each from the green and red visible wavelengths, and the near, middle and thermal infrared wavelengths) produced classification accuracies in excess of 90 percent for deciduous and coniferous forest. When these two classes were grouped, the accuracy for combined forest was in excess of 95 percent. The use of all twelve channels caused only a slight increase in overall accuracy.

In satisfying the third objective, the LARSYS feature selection processor was allowed to consider wavelength bands constituting only various subsets of the four spectral regions. On this basis, it selected a number of five-channel combinations. Classifications performed by these various channel combinations indicate that the visible wavelengths are sufficiently accurate for classifying combined forest, but inadequate for differentiating between deciduous and coniferous forest. The infrared channels separated the two forest classes with reasonable accuracy, but allowed confusion between forest and the agricultural classes. The deletion of either the near or the middle infrared individually, did not reduce accuracies, but, when both were deleted, accuracies dropped drastically. The deletion of the thermal infrared had little effect on forest cover mapping but did allow considerable confusion among the agricultural cover types. These results indicate that the thermal infrared is desirable, but not necessary, for basic forest cover mapping, and that accurate classification of deciduous and coniferous forest cover can be achieved with the visible plus either the near or middle infrared spectral regions.

To meet the fourth objective, small-scale color infrared photography, acquired the same day over the test site, was color separated, digitized in three wavelength bands and, automatically classified. In general, the digitized photography was inadequate for automatic forest cover mapping and compared poorly to the MSS data results when similar wavelength bands were used. These results were apparently caused by the narrower dynamic range, poorer spectral resolution, and uneven illumination (due to vignetting and the anti-solar point) of the photographic data.

CHAPTER I

INTRODUCTION

Introductory Statement

Forests have long been recognized as important natural and renewable resources. Thus, when the management of our forests was first begun, it was primarily for the purpose of improving the production of wood and fiber. Later, the importance of the forest to the production of water and the protection and nurturing of wildlife resulted in a general broadening of management objectives. Today, the steady increase in size of our population and the trend toward urbanization has lead to a much greater reliance on the forest resources, as well as an additional and rapidly growing demand for wilderness oriented recreation.

However, despite the fact that the demands on the forest continue to increase, the forest resource base does not. It, in fact, decreases. Urban development and highway construction, for instance, destroy many acres of forest land each year.

The demand for forest recreation, plus an increased awareness of the natural environment, has resulted in the redistribution of some public forest lands to non-commercial management objectives. In addition, environmental organizations have successfully demanded the implementation of management and harvesting practices more compatible with the protection of the environment.

These increasing demands on the forest in general, and commercial forests in particular, are underlining the need for more efficient and intensive management. However, the attainment of this goal is complicated by several factors, the first of which is the fact that our forest lands are not under the control of one unified management agency. Though the U.S. Forest Service controls more timberland than any other single organization, there are other agencies at the federal government level, plus hundreds of state and local agencies, who are also responsible for the management of forest lands. Nor does this exhaust the list of organizations involved since the private sector, especially industry, controls large amounts of often intensively-managed timberland.

This diversity of management groups, with its accompanying multiplicity of management goals, makes a single, closely-coordinated management scheme, difficult to achieve.

A second factor is that, although the forest is admittedly a valuable resource, the per-acre economic return is generally quite marginal. Economics must therefore be considered as a part of any management scheme and the problem of gathering information about a geographically extensive resource (covering roughly a third of the United States) becomes one of acquiring data not only adequate for management purposes, but also at a minimum per-acre expense.

In the past, the periodic national forest surveys, (undertaken at ten-year intervals at an average cost of about six cents per acre) (Glazebrook, 1973), have served as a reasonably satisfactory resource inventory. However, as the demand for goods and services from the forest continues to increase, so does the need for more timely information over vast geographic areas.

One tool which shows promise for the solution of this problem is "remote sensing," defined by Hoffer (1971) as follows:

> "Remote sensing is the discipline involved with the gathering of data about the earth's surface or near-surface environment through the use of a variety of sensor systems that are usually borne by aircraft or spacecraft, and the processing of these data into information useful for the understanding and managing of man's environment."

Remote sensing equipment, mounted in high-flying aircraft or spacecraft, offers the capability to gather large amounts of data over extensive areas in a very short time. The National Aeronautics and Space Administration's Earth Resources Technology Satellite (ERTS), for instance, can obtain data for the entire surface of the earth every eighteen days, producing computer-compatible data tapes and 1:1,000,000 scale, 9-inch x 9-inch frames of imagery, each of which covers 13,243 square miles of terrain (Hoffer, 1971). Such small-scale imagery could serve as the third stage in a multi-stage sampling scheme (Langley et al., 1969, Glazebrook, 1973).

If the past performance of ERTS and other types of remote sensor data-gathering equipment is any indication, it may be assumed that data acquisition is, and will continue to be a less difficult problem than that of reducing the huge amounts of data acquired to useful information (Hoffer, 1972, Hoffer, 1971). This study, therefore, is concerned with several questions pertaining to the extraction, from remotely-sensed data, of information applicable to forest management.

There are two basic methods of deriving such useful information from remotely-sensed imagery. Most familiar and wisely used are the techniques of photo-interpretation, in which a scientist trained in photo-interpretation manually derives information from the imagery, basing his decisions on the image elements of size, shape, tone or color, texture, pattern, association and, of course, experience in both his own particular discipline and as a photo-interpreter (Hoffer et al., 1968, American Society of Photogrammetry, 1968). The second method is based on automatic data processing (ADP) techniques. In this method, a computerized pattern recognition algorithm is "trained" to recognize and categorize various cover types of interest based on spectral (tone) characteristics as recorded by the imaging device. It is the latter data reduction method with which this study is primarily concerned.

Of the variety of sensor systems available, this study is concerned only with the two most commonly used. The oldest, and most highly developed, is the photographic system, with a variety of films and filters available. The second system of interest (primarily because of the more quantitative format and spectral range of the data acquired) is the multispectral scanner (MSS). (A brief description of the University of Michigan's twelve-channel airborne scanner, which was used to acquire the MSS data used in this study, will follow in the Review of Literature). Another type of multispectral scanner, the data from which is currently the focus of a great deal of research and analysis, is aboard the 1972 Earth Resources Technology Satellite (ERTS-1).

Statement of the Problem

The development of ADP techniques, and their application to the inventory of natural resources, have been of increasing interest during the last five to seven years. However, prior to the initiation of this study, little work had been done concerning the potential of these techniques to forest cover mapping. Consequently, answers were needed for several questions in regard to this type of application.

The first question concerns one of the advantages of the scanner over photographic systems, its ability to sense in a large number of discrete wavelength bands or "channels" (the MSS data used in this study, for instance, was acquired in twelve channels). Experience has shown that (for reasons which will be explained in the Review of Literature) it is usually not necessary nor even desirable to use all twelve of these channels to perform a classification task. Therefore, the first question involved in this study could be stated as follows: "What is the optimum number of channels to use in automatically mapping forest cover with MSS data?"

Secondly, since the small amount of work done in the past has often met with limited success, the question arises: "What is the current capability to map forest cover with MSS data and ADP techniques?"

A third question deals with one of the greatest advantages of multispectral scanners over photographic systems--their capability to sense in a much wider range of wavelength bands. The question arising from this is: "Which of the available spectral regions (visible, near infrared, middle infrared, and thermal infrared), are the most valuable for forest cover mapping?"

Finally, the major advantage of scanner data over photographic data involves the quantitative format of the scanner data, (as compared to the more qualitative format of photographic data). However, the capability exists to put photographic imagery into a format compatible with ADP techniques (this digitization process will be briefly described in the Review of Literature). The question to be answered here is: "How does digitized color infrared photography compare with MSS data for forest cover mapping, when using ADP techniques?"

Objectives

1. Determine the optimum number of wavelength bands (or channels) to use in forest cover mapping with multispectral scanner data and automatic data processing techniques.

2. Evaluate the current capability to map forest cover using twelve-channel multispectral scanner data and automatic data processing techniques. This evaluation has two specific sub-objectives:

   a. Evaluate the current capability to automatically differentiate between forest and other cover types.
   b. Evaluate the current capability to automatically differentiate and map deciduous and coniferous forest cover.

3. Determine the relative value of the spectral regions available in the multispectral scanner data (e.g. visible [0.40-0.72 μm], near infrared [0.72-1.4 μm], middle infrared [1.4-4.0 μm], and thermal infrared [4.0-13.5μm]) for basic forest cover mapping.

4. Compare digitized color infrared photography with multispectral scanner data for forest cover mapping, using automatic data processing techniques.

CHAPTER II

REVIEW OF LITERATURE

Introductory Statement

The amount of literature concerning the problems to be dealt with in this study is meager. Although remote sensing devices are adequately described in the literature, these descriptions are necessary only to provide a general understanding of the nature and origin of the data. The automatic analysis of remote sensing data is only in its infancy. Research in this field is currently being conducted at only a few locations, with the Laboratory for Applications of Remote Sensing (LARS) at Purdue University widely recognized as the leader in this type of research. Much of the literature reviewed has LARS as its origin, because this study involved the particular analysis approach developed by LARS and utilized the LARS hardware and software system.

This chapter will begin with a brief discussion of photographic and multispectral scanner systems and the data which they procure, followed by a description of the data analysis sequence.

Remote Sensing Systems

Photographic

There are many types of remote sensing systems available. Photographic systems are the most common and highly developed, however. Their advantages include minimal maintenance, relative ease of operation, a familiar data format, good spatial resolution, relatively low cost for data acquisition, and the potential for three-dimensional (stereoscopic) analysis. The primary disadvantage is the limited spectral range (.4-.9 μm, approximately) of currently available photographic emulsions (Hoffer, 1971).

Cameras are so familiar that a description of their function is unnecessary. A brief description of the photographic data used in this study, however, is in order.

Kodak Aerochrome 2443 infrared film is a false color film similar to ordinary normal color films in that it has three separate emulsion layers each sensitive to a different wavelength band and each forming its own unique dye when processed. Whereas the three emulsion layers of normal color film are sensitive to blue, green, and red light, the emulsion layers of properly filtered color infrared film are sensitive to green, red, and near infrared wavelengths. A yellow filter, which absorbs blue light, is always placed over the lens because all three emulsion layers are sensitive to blue light. When the exposed film is properly processed the green-sensitive layer is developed to a yellow positive image, the red-sensitive layer to a magenta positive image, and the near infrared sensitive layer to a cyan positive image. In the final product, then, an object which reflects only green light would appear blue, an object reflecting only red light would appear green, and an object reflecting only near infrared wavelengths would appear red (Eastman Kodak Company, 1970). In nature, objects reflect varying amounts of all three, so the rendition on the positive photograph will be some combination of all three dye layers.

Color infrared film is particularly applicable to forestry work. While deciduous and coniferous trees appear only slightly different in the visible, generally speaking, the difference between the two is usually much more pronounced in the near infrared. Because of the relatively higher infrared response of the deciduous foliage, healthy deciduous trees photograph magenta or red during the spring and summer while healthy conifers appear bluish purple (note the two triangle-shaped stands of conifers amid the deciduous forest in the northern portion of Seg. 218, Figure 25). Dead or dying deciduous or conifer foliage usually photographs as some shade of green because of the changes in infrared and visible reflectance from the senescing vegetation (American Society of Photogrammetry, 1968).

One of the objectives of this study was to compare results obtained from scanner data with those obtained from photography. This necessitated the quantization of the photography, so that it would be in a format which could be analyzed with a digital computer. The first step in this process involves the photographic separation of the three emulsion layers into positive black & white transparencies. This is accomplished by exposing black & white film to white light projected through the color infrared transparency and each of three filters (No. 49 blue, No. 60 green, and No. 25 red) (Hoffer et al., 1972). The result is three black & white transparencies representing the reflectance characteristics of the scene in the green, red, and near infrared wavelengths, respectively. Figures 21 and 23 give some idea of the appearance of the three separations.

The separations are then individually quantized by obtaining density measurements with a scanning microdensitometer. This instrument uses a light source and an optical system to project a beam through a minute portion of the film. A photoelectric sensor measures the amount of light transmitted through the film creating an electrical signal which is then converted to a digital density measurement and recorded on magnetic tape. The light source is scanned across the film, measuring its density along many small adjacent lines in sequence, thus allowing the accurate transformation of the film density to a digital data format (Hoffer et al., 1972). With the completion of this process, the photography is in a format compatible with a digital computer.

After all three separations have been scanned, the digitized data is spatially registered or overlayed such that any given ground point in the scene coincides in all three channels of data. This is a simple task in the case of multiemulsion photography because there are no spatial distortions or inconsistencies between the three emulsion layers.

Each scan line is numbered consecutively, as is each column of samples along the scan lines, producing a coordinate system by which any point(s) in the data may be accurately designated for further study. Thus, with the three channels stored in coincidence (spatially registered) a given set of coordinates will describe the identical point(s) in each of the three channels (Hoffer et al., 1972)

Multispectral Scanner

Another type of remote sensing instrument is the multispectral scanner (MSS). It has several advantages over photographic systems, including the capability to sense over a much greater spectral range (0.46-11.70 μm for the scanner concerned in this study), and superior spectral resolution (the scanner senses in many narrow wavelength bands as opposed to a few broad bands). In addition, MSS data is acquired in a format compatible with computerized analysis techniques, and it possesses the potential for accurate calibration. However, scanner imagery lacks the potential for stereoscopic analysis and the spatial resolution is generally inferior to photographic films (Hoffer, 1971).

The multispectral scanner has been in existence for some time, but its use could not be considered commonplace until the launch of ERTS in the summer of 1972. Because of the relative newness and sophistication of multispectral scanner systems, a brief description of the operation of the University of Michigan scanner (which collected the data utilized in this study) is necessary so that the reader may appreciate and understand the characteristics of the data used in this study.

As the MSS platform passes over the target, a rotating mirror scans the ground along a swath perpendicular to the flight path of the instrument. The forward motion of the platform causes the mirror to view successive, overlapping strips along the flightline (the degree of overlap of these strips is governed by the configuration of the instrument, and the altitude and ground speed of the platform). The electromagnetic energy reflected and emitted from the target is reflected off the rotating mirror, through a system of optics and into a prism spectrometer which refracts or separates the energy into the various portions of the spectrum.

Fiber optics located at appropriate points intercept the refracted spectral bands and direct the energy to sensitive detecting devices where it is measured in each of twelve channels ranging in wavelength from 0.46 μm in the visible to 11.70 μm in the thermal infrared. The level of response is then fed to a multitrack tape recorder where each of the twelve channels is recorded simultaneously in an analog format on magnetic tape (Smedes et al., 1970). In effect the energy from a specific ground resolution element at a given instant in time is measured and recorded simultaneoulsy in twelve wavelngth bands, thus providing a vector, or "spectral signature" which contains spectral information available about that area on the ground (Hoffer, 1972; Landgrebe and Phillips, 1967). Obviously, there are many other types of multispectral scanner systems which can vary in many ways. The ERTS scanner, for example, has only four wavelength bands, which have a range of 0.5 μm to 1.1 μm wavelength.

The analog data tapes obtained by the University of Michigan scanner system are not compatible with digital computers, so in the analysis sequence developed at LARS, the analog tapes are put through an analog-to-digital processor which reformats the data and rewrites it in digital form on magnetic tape. During this process a number is assigned to each successive scan line of data and a sample designation to each sample point along the scan line. This provides an X, Y coordinate system which allows the accurate designation of any point(s) in the data (Hoffer, 1972). In addition, all channels must be spatially registered or overlayed and stored in coincidence on the data tape. With these operations completed any set of coordinates which the investigator specifies will designate precisely the identical point(s) in all twelve channels of data (Hoffer, 1972). Thus, the investigator is enabled to interface with the data and analyze the spectral characteristics (reflectance and emittance) of a specific ground area using one or more of the twelve available channels.

Automatic Analysis Sequence

Introduction

Since the launch of ERTS, it has become increasingly obvious that the capability exists for collecting enormous quantities of data over large geographic areas in a very short time. Indeed, the problem of data collection seems less difficult than that of reducing the huge amounts of data to useful information (Hoffer, 1971).

Image analysis has traditionally been a manual operation. The photointerpreter plays a very important role in almost all disciplines which deal with the earth's surface. With the rapidly growing capacity for data acquisition and the increasing need for timely information from these data, however, the photointerpreter cannot hope to do the entire job alone.

The human interpreter will never be eliminated. Even with the inevitable advances in computer technology there will always be the need for high-level decisions beyond the capability of machines. However, machines do have the capability to assist the human interpreter by making many lower level decisions very rapidly.

One such automatic data processing technique developed at the Laboratory for Applications of Remote Sensing (LARS) at Purdue University involves the use of digital computers and pattern recognition algorithms in the analysis of aircraft and spacecraft multispectral scanner (MSS) data and digitized photographic imagery (Hoffer, 1972). It should be pointed out immediately, however, that the term "automatic data processing" is somewhat misleading in that there is a definite need for human interaction in all phases of the analysis sequence. Perhaps "computer-aided analysis" would be a more correct term (Hoffer, 1972).

The ADP technique developed at LARS is basically a process of selecting areas in the data where cover type and ground conditions at the time of flight are known, and designating these areas to the computer. After a set of statistical parameters have been determined for these "training samples" a pattern recognition algorithm is "trained" accordingly, and allowed to classify each unknown data point into one of the ground cover classes which it has been trained to recognize (Hoffer, 1971).

Before continuing with a more detailed discussion of the analysis sequence, however, a brief explanation of the term "pattern recognition" is necessary. Automatic pattern recognition involves the use of a machine to recognize patterns exhibited by the amplitude of the spectral response of a subject in a number of wavelength bands or "features." The digitized color infrared photography, then, contains three features and the MSS data contains twelve features.

Pattern recognition consists of two basic operations. The first is that of "training" the machine to recognize the ground cover categories of interest on the basis of their spectral response characteristics. This training procedure is explained below in greater detail. The second step consists of automatically categorizing the unknown data points on the basis of measurements derived from the selected set of features (Cardillo and Landgrebe, 1966). These measurements are the spectral responses of the ground cover types as recorded in the selected set of channels. A further discussion of the classifier programs will also follow.

The software for the actual analysis sequence may be divided into four sections: 1) statistical analysis; 2) channel or "feature" selection; 3) classification or "categorization", and 4) results display (Hoffer, 1972). These four phases are generally accomplished in the order presented, although repetition of one or more is usually necessary.

Statistical Analysis

The first step in the analysis sequence involves the selection of data samples from which the computer may derive the necessary statistical parameters for "training" the classification algorithm. Basically there are two types of categories which the computer may be trained to recognize: 1) economic or informational; and 2) spectral (Hoffer, 1972).

Since the separation of categories, by the classification algorithm, is based on spectral differences, and since categories of informational value may not necessarily be spectrally separable, it follows that for satisfactory results to be produced by these techniques, a category must be both spectrally and informationally separable. This rationale has led to two basic approaches in the selection of training samples (Hoffer, 1972).

The first approach involves the manual selection of training samples on the basis of "ground truth" information. In other words, the categories are defined on the basis of informational separability (Hoffer, 1972) (Figure 1). At this point, however, the investigator does not know if the designated informational categories are spectrally separable.

The researcher has two media by which he may manually select data samples. By requesting a line printer display of the data in one or more channels the researcher obtains an alphanumeric printout in each channel requested. These

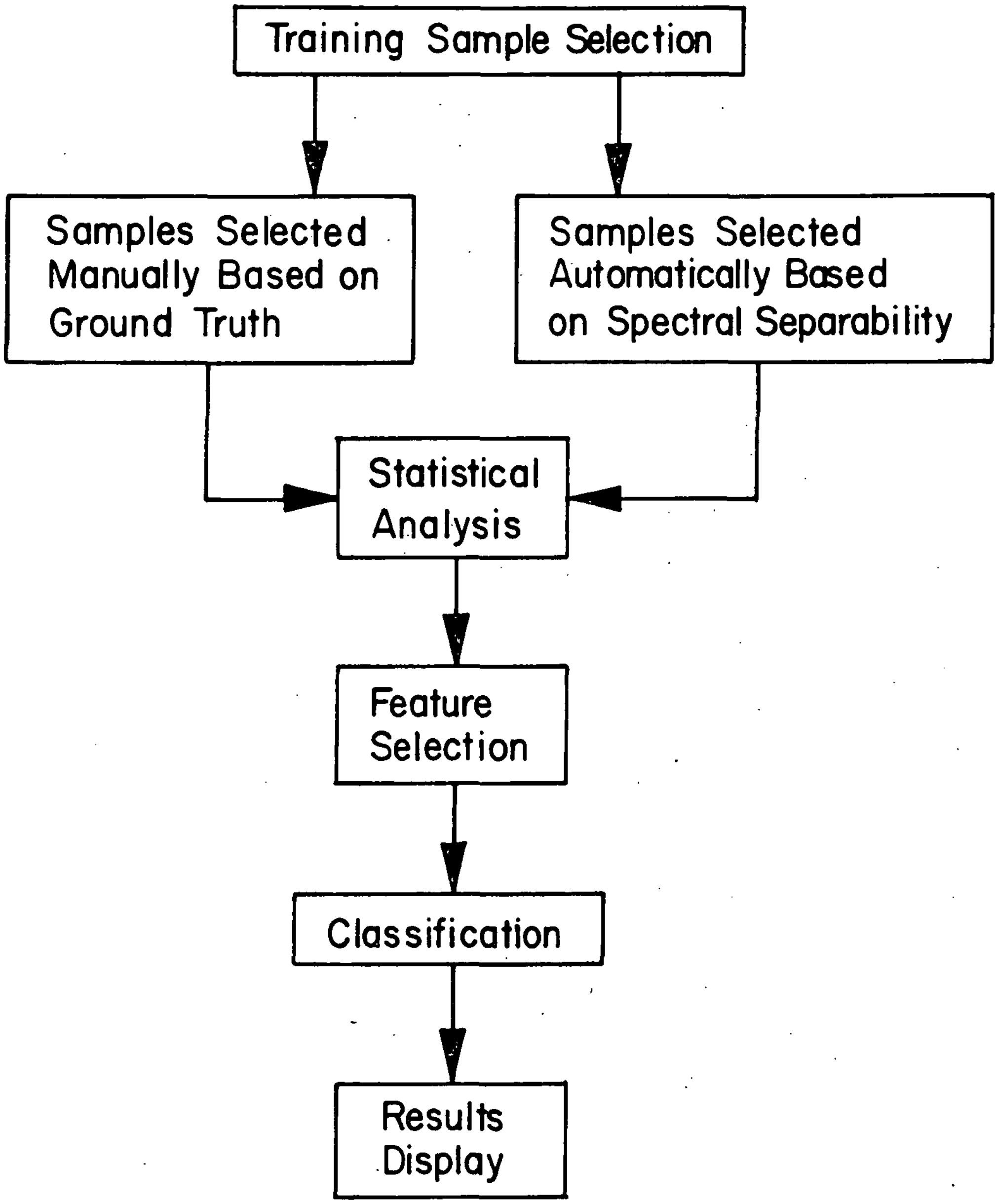


Figure 1. LARS automatic analysis sequence.

displays simulate the analog video display by dividing the continuous gray scale into discrete gray levels with an approximately equal number of points represented by each. An alphanumeric character is assigned to represent each gray level so that the relative visual density of the character corresponds approximately to the relative density of the gray level (i.e. M is assigned to the lowest gray level and a blank to the highest gray level). These characters are then printed out producing a gray level image of the data with numerical line and column designations along the edges. The researcher may then designate rectangular areas in the data by simply specifying line and column coordinates (Smedes et al., 1970; Hoffer, 1972).

Alternatively, the data may be displayed, one channel at a time, through the use of a digital display unit which presents an image in sixteen gray levels on a cathode ray tube (Figures 20, 21, 22, and 23). An attached light pen allows the researcher to outline rectangular data samples directly on the viewing screen with the so designated X, Y coordinates automatically punched on computer cards for later use (Hoffer, 1972).

In the second approach to training sample selection, the categories are defined according to spectral separability. In this approach the investigator designates an area in the data to the computer, and specifies the number of spectrally homogeneous "clusters" into which the data is to be divided. The number of clusters requested is arbitrary, and depends largely on the investigator's knowledge of the spectral characteristics of the data set in question. The computer then assigns the individual data points to the various spectral clusters, and prints out a "spectral cluster map." It then remains for the investigator to determine the identity or informational significance of each spectral class. Usually, the researcher will also request the machine to punch a deck of coordinate cards designating sample areas which represent each of the spectral clusters or classes. These automatically designated areas of homogeneous spectral characteristics may then be used as training samples.

Experience gained at LARS indicates the desirability of using both approaches together in a procedure where the clustering algorithm assists the investigator to spectrally refine manually selected training samples.

After training samples have been selected, whether manually (from line printer displays or the digital display unit), or automatically (by the clustering program), they are submitted to a statistics processor (Figure 1). This program calculates a set of statistical parameters for each class or category represented by training samples. The parameters are based on an assumed Gaussian distribution and include the mean, standard deviation, covariance, and divergence (a statistical measure of the separability of classes) (Smedes et al., 1970). These values constitute a statistical "fingerprint" for each class or category of ground cover, and will be used later as a basis for both feature selection and categorization of unknown data points (Smedes et al., 1970).

The statistics processor may be requested to provide a number of different types of output useful in the analysis sequence. Histograms of individual training fields or of groups of fields which have been designated a class (Figure 2) give the researcher an idea of the distribution of the data points in the various channels (Hoffer, 1972).

Coincident spectral plots (Figures 3 and 4) illustrate the relative amplitude of the spectral responses of the various classes in each of the individual wavelength bands or channels. The mean spectral response, plus or minus one standard deviation, is presented as a line of representative length. The researcher may thus obtain some indication of the statistical quality of the data (high or low variance) (Hoffer, 1972), and of particular importance, an indication of the spectral separability of the ground cover classes in the various wavelength bands. This capability has proven its value in helping researchers to better understand the relative spectral characteristics of the various ground cover types involved.

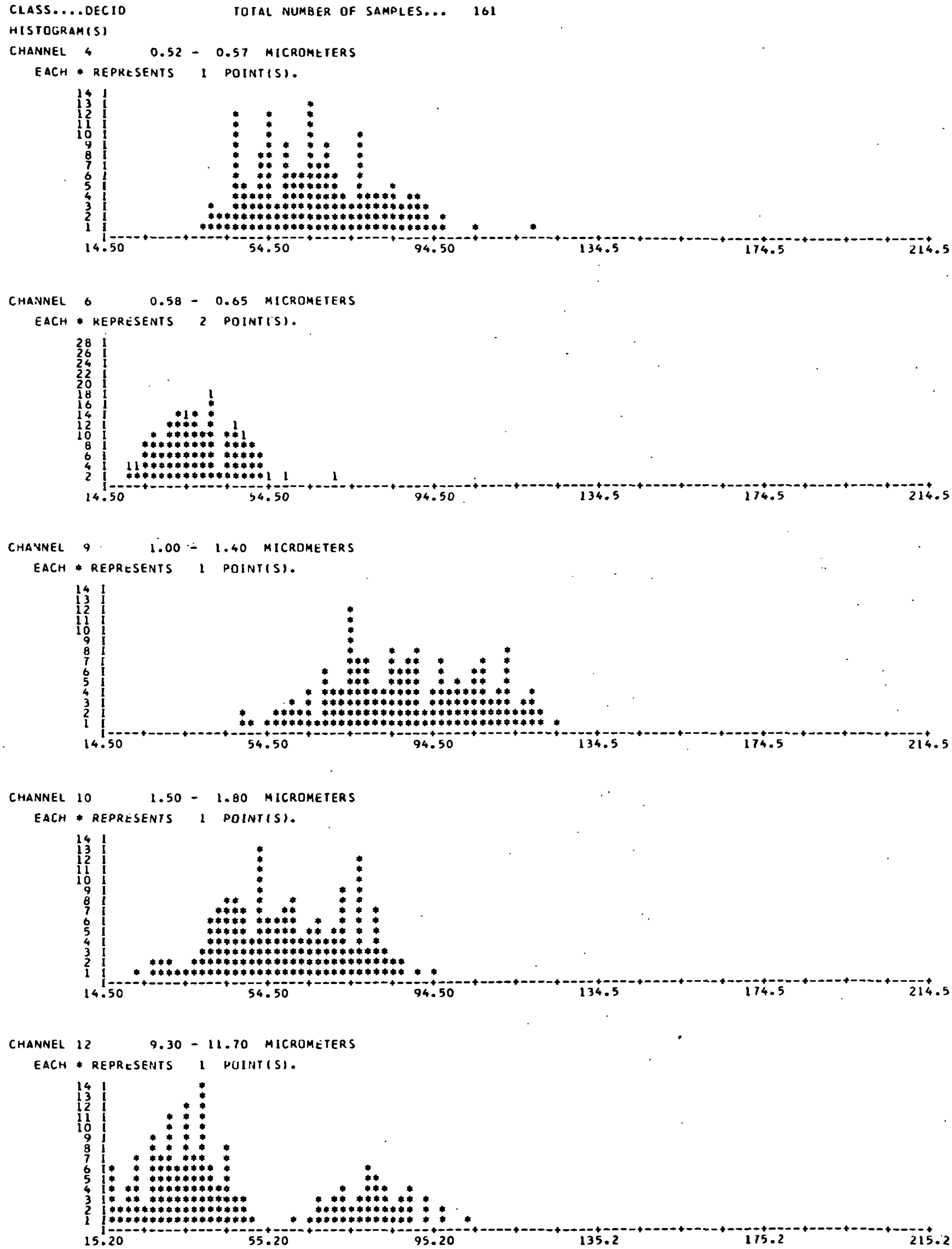


Figure 2. Training class histograms for deciduous forest: channels 4, 6, 9, 10, and 12.

Figure 3

Coincident spectral plot of training field statistics for 12-channel MSS data.

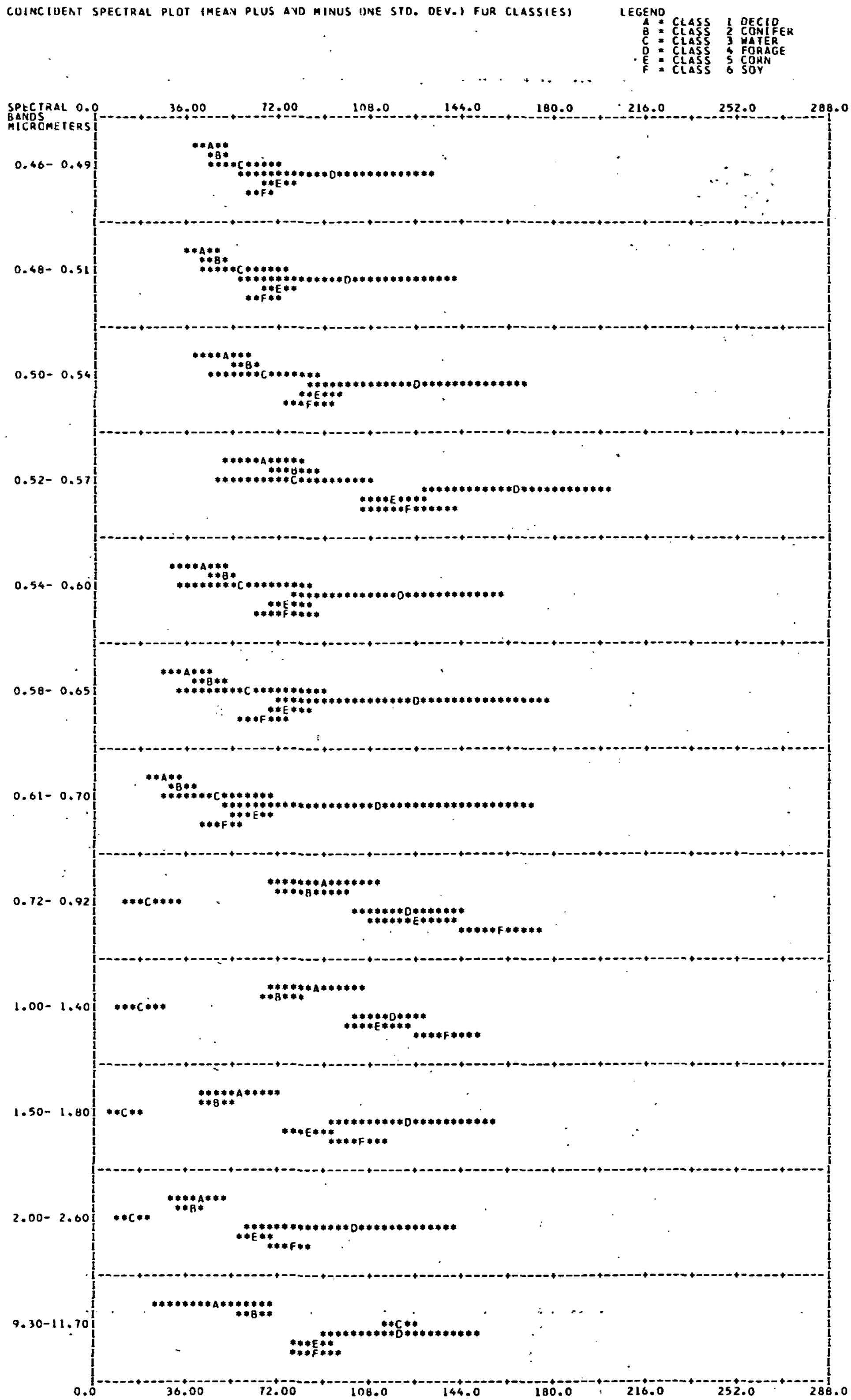

COINCIDENT SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR CLASS(ES)
LEGEND
A = CLASS 1 DECID
B = CLASS 2 CONIFER
C = CLASS 3 WATER
D = CLASS 4 FORAGE
E = CLASS 5 CORN
F = CLASS 6 SOY
SPECTRAL BANDS MICROMETERS
0.0
36.00
72.00
108.0
144.0
180.0
216.0
252.0
288.0
0.46- 0.49
0.48- 0.51
0.50- 0.54
0.52- 0.57
0.54- 0.60
0.58- 0.65
0.61- 0.70
0.72- 0.92
1.00- 1.40
1.50- 1.80
2.00- 2.60
9.30-11.70

Figure 3

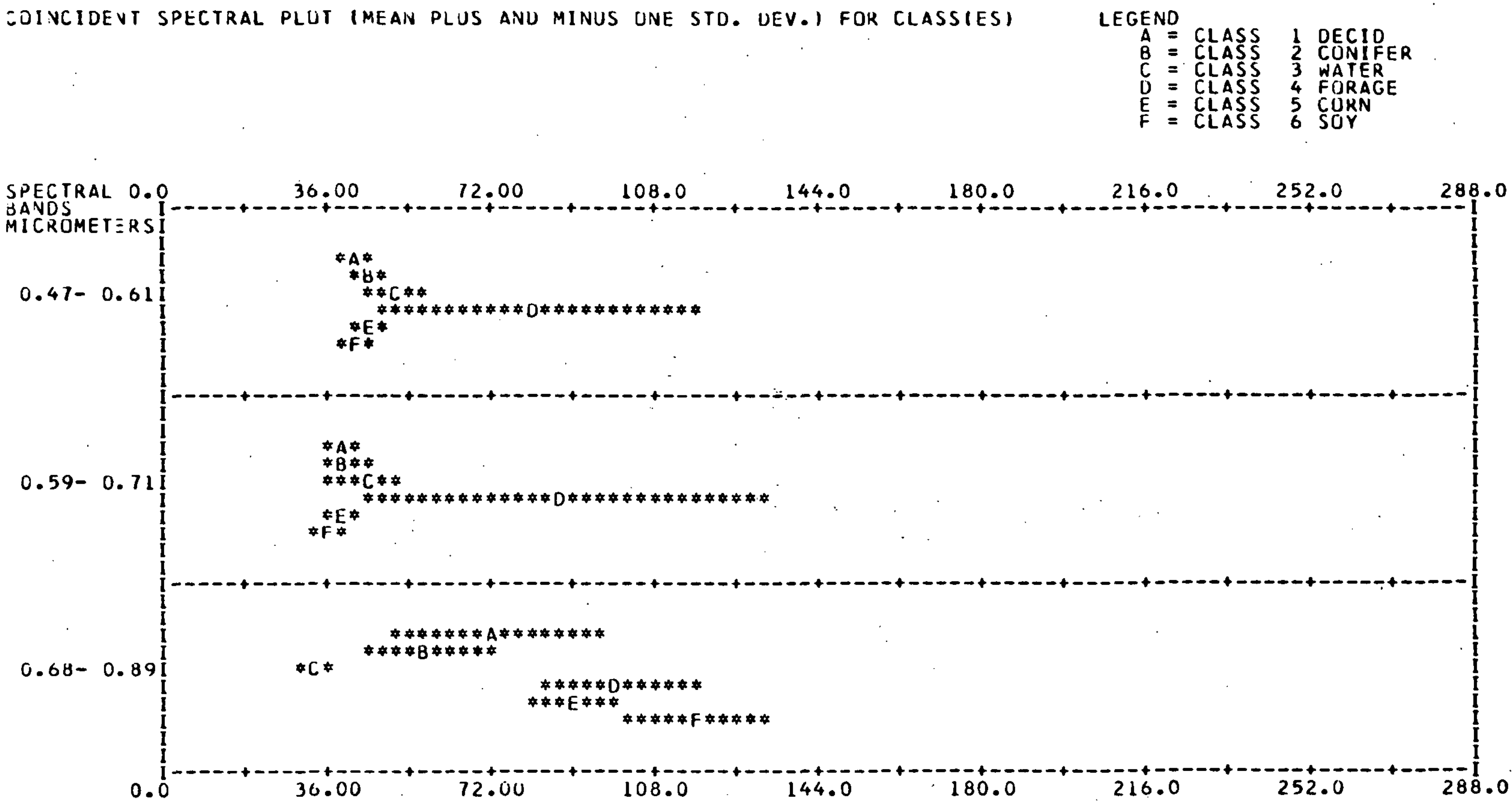


Figure 4. Coincident spectral plot of training field statistics for 3-channel digitized photographic data.

A third form of output is a punched deck containing the statistics mentioned above, which provide a statistical definition of the ground cover classes represented in the training deck (Hoffer, 1972). This statistics deck forms the basis for the following two steps of the analysis sequence.

Feature Selection

The next step in the analysis sequence is that of feature selection (Figure 1). When dealing with digitized color infrared photography there are only three features available, all of which are used, so the feature selection phase may be eliminated. The situation is similar for ERTS MSS imagery which contains only four features. When a larger number of channels are available, however, a feature selection processor becomes desirable.

Experience has shown that the best combination of four or five of the twelve available MSS channels will give classification accuracies only slightly less than the use of all twelve channels, and with a fraction of the computer time (Figure 5). With the cost of computer time at $250 per hour the need for a compromise between analysis cost and quality of results becomes obvious (Smedes et al., 1970).

The problem, then, is that of selecting the best set of channels. With twelve-channel MSS data, for example, the researcher has a choice between 485 possible combinations

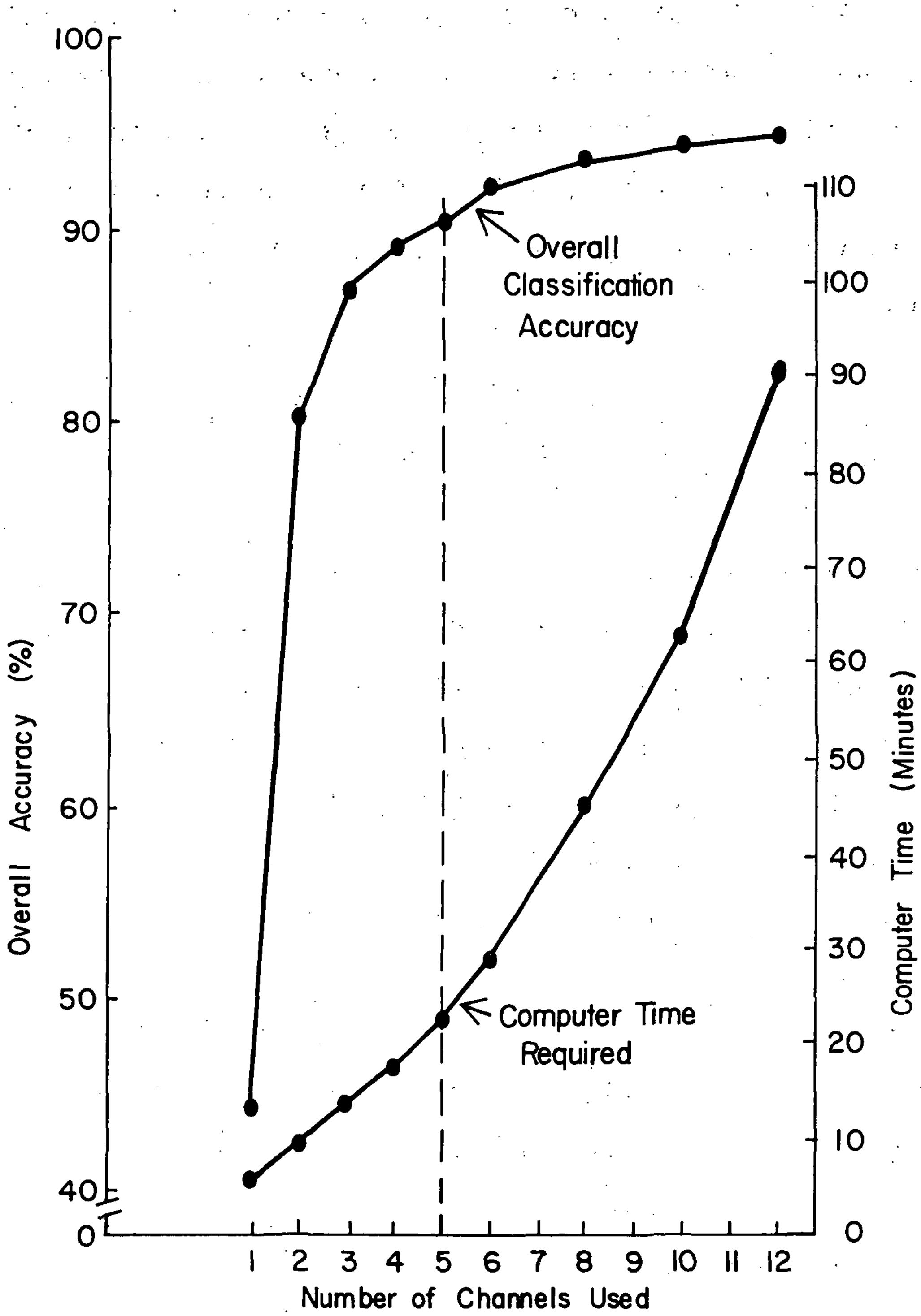


Figure 5. Overall classification accuracy and computer time required over number of channels used.

of four channels. The feature selection processor is designed to give the researcher some idea as to which of these combinations is the best.

Based on the punched output generated by the statistics processor, the feature selection program calculates the separability between all possible pair-wise combinations of cover type classes (as defined by the training deck) for all possible combinations of four channels (or any other number of channels from one to eleven). The processor then ranks the channel combinations.

There are three options, however, by which the researcher may influence the order of ranking. One option provides for the application of differential interclass weighting to one or more combinations of cover type classes. For example, if it was of particular importance to separate "forest" from all other classes, the researcher could simply attach a greater weight or importance to the interclass divergence (statistical measure of distance between classes) of all pair-wise combinations containing the class FOREST. Likewise, if it were of no importance to separate two classes of corn, a weight of zero might be applied such that the processor would disregard the interclass divergence between the two classes. Thus, a channel combination with little or no ability to accurately separate the two would not have its chances of selection reduced as a result.

A second option by which the researcher may influence the ranking of the channel combinations involves a choice between two simple ranking criteria: "average divergence" and "minimum divergence". If average divergence is requested, the processor calculates the average interclass divergence (weighted or unweighted) for all pair-wise combinations of cover type classes. The channel combination offering the highest average interclass divergence is then ranked first.

Minimum divergence, on the other hand, determines the lowest interclass divergence for each and every channel combination. That combination possessing the highest minimum interclass divergence is then ranked first. It is not uncommon for the same channel combination to exhibit both the highest average and the highest minimum divergence.

A third method of influencing channel selection is to simply delete selected channels from consideration by the processor. All three of these options will be discussed further in the chapter on Materials and Procedures.

The whole idea of the feature selection processor, of course, is to assist the researcher in selecting the "best" channel combination. Keep in mind, however, that feature selection is based on statistics derived from samples of the data set to be classified. Since a sample can never be completely representative of the whole, the selected channel combination, though it may be "best" for separating the classes as represented by the training samples, may not necessarily be the "best" for classifying the data as a whole. The highest ranking channel combination according to the feature selection processor, then, is only an approximation.

Classification

The third phase of the analysis sequence involves the classification of the unknown data points (Figure 1). Currently there are two different statistical pattern recognition algorithms in use at LARS for this purpose.

The first and most commonly used is a "perpoint" classifier (classifies data points individually) which requires, as input, the statistics deck, the selected combination of channels, and the coordinates of the area(s) which the researcher wishes the machine to classify. Based on the statistical definitions of the cover classes in each of the selected channels, the machine establishes decision boundaries in N-dimensional space (N = the number of channels used in the classification), then individually assigns the unknown data points to one of the statistically defined classes on a maximum likelihood basis. The results are then recorded on magnetic tape for later display (Hoffer, 1972).

The second is a "perfield" or "per sample" classifier, which, instead of classifying data points individually, classifies entire fields of data points as individual decisions (Anuta et al., 1971). In addition to the statistics deck and the selected channel combination, the researcher is required to submit field coordinates designating samples of known cover type to be classified. The program then classifies each field into one of the cover type classes which it has been trained to recognize, and prints out a table of quantitative results (Table 14 and 15).

The perfield classifier has the advantage of greater speed, hence the consumption of less computer time. In addition, the perfield classifier makes some use of spatial data by considering an entire group or field of data points individually. Thus, if two hypothetical classes possessed similar mean responses, but significantly differing standard deviations in the channels selected for the classification task, the perpoint classifier, by considering data points individually, would likely result in considerable confusion.

The principal disadvantages of the perfield classifier include its inability to establish field boundaries, hence the necessity for the researcher to perform this task in advance. Also, unlike the perpoint classifier, the classification results may not be displayed in a map-like image.

Results Display

With the perpoint classification completed and recorded on magnetic tape, the results may be displayed both quantitatively, in a tabular format, and qualitatively, as a map or image.

The quantitative results display consists of a listing, by class, of all training fields and a tabulation of the number of points in each field classified into each class. This is followed by a summarization of training class performance similar to Tables 5-11.

In order to obtain a more meaningful evaluation of the classification, however, the researcher will have selected "test fields" (samples not used in training, but of known cover type) before the classification was run (to minimize bias). These test fields are then examined by the results display program which determines how well the classifier performed on these areas. The results are then displayed in the same format as decribed above (Smedes et al., 1970) (Tables 5-11 are examples of test class performance tables).

A rejection or "threshold" capability may be used in the display program. By specifying an arbitrary threshold level, the researcher directs the computer to decline final classification of data points which do not look sufficiently like the class to which they have been tentatively assigned. Even though the tentative assignment is to the "most likely" class, these borderline points are placed in a null category prior to the calculation of test results (Smedes et al., 1970). The implications of thresholding will be discussed briefly in the chapter on Materials and Procedures.

Qualitative or map-like displays of classification results may be obtained in one of two forms. First is the alphanumeric line printer display which is very similar to that described earlier in this chapter. The principal difference is that the researcher is required to choose characters to represent the various classes. If desired, such a line printer image may be manually color coded, but this is a time consuming process.

A second and more efficient means of obtaining color coded classification results is by use of the digital display unit, also mentioned earlier. The researcher specifies colors to represent the various classes, and the machine determines the proper gray levels for each of three images which are then displayed one at a time. An attached photographic unit allows the researcher to obtain a multiple exposure, on color film, of the three gray scales, each through a different filter (blue, green, and red). The result is a color composite of the classification results (Figures 26 and 27).

Experience gained at LARS indicates that the initial classification attempt will often fall short of the investigator's objectives. If the unsatisfactory performance is a result of incorrect or inadequate training statistics then the researcher must go through a process of refining his training fields and classes to a point where the test results indicate the true capability to automatically classify the data. By examining output from the various programs, especially the statistics processor and the quantitative results from the display program, the training deck is revised and the sequence repeated. The human element is obviously far from eliminated.

CHAPTER III

MATERIALS AND PROCEDURES

Introductory Statement

The procedures described in this section are adaptations of those in the standard LARS analysis sequence outlined in the Review of Literature. Data input includes multispectral scanner (MSS) imagery, color infrared (CIR) imagery (in both photographic and digital formats), and surface observations. Specific data used are on file in the LARS data library.

Test Site Description

A 1 x 10 mile strip of land in Indiana, designated as Segment 218, was the test site for this research. The site, which has a north-south orientation, is located in Owen County, about 2 1/2 miles west of Spencer, and about 45 miles southwest of Indianapolis. The site is located on the Crawford Upland, a maturely dissected, westward sloping plateau characterized by abundant stream valleys and a well-integrated drainage system. Most of the land area is "in slope," with flat, narrow ridge tops and steep valley walls (Schneider, 1966).

Because of the extensive dissection of the terrain, most of the agricultural land is in pasture and hay. Where the topography allows, however, row crops (corn and soybeans) are present, particularly on the floodplain of the White River (Figure 23).

A dot grid count on 1:120,000 scale color infrared photography reveals about 60 percent of the area to be forested. Most of this forest is composed of natural hardwoods, (primarily tulip poplar, oak, hickory, maple, and ash), though a few small white pine stands are present in the segment. These are presumably plantations on abandoned agricultural lands dating from the Civilian Conservation Corps (CCC) days of the mid 1930's.

Much of the forested area has been grazed by domestic livestock for many years. As a result, many of the forest stands are open and park-like with a low stem density and very incomplete crown closure. The increased illumination of the forest floor allowed by this condition has resulted in an invasion by grass. In short, much of the so-called forested area is, in reality, an intimate mixture of forest and pasture.

Data Utilized

Multispectral Scanner Data

The multispectral scanner data used was collected by the University of Michigan/Willow Run Laboratories with a twelve-channel, single-aperture scanner. The instrument, mounted in a C-47 aircraft, was flown at an altitude of 5,000 feet above terrain and the data utilized was obtained on August 12, 1971 at 1504 Greenwich Mean Time (about 0917 local solar time). This meant that the data had to be sun-angle corrected before it could be used successfully.

The data, was recorded in twelve wavelength bands in an analog format as follows:

Channel	Wavelength Band (μm)	Spectral Region
1	0.46-0.49	visible
2	0.48-0.51	visible
3	0.50-0.54	visible
4	0.52-0.57	visible
5	0.54-0.60	visible
6	0.58-0.65	visible
7	0.61-0.70	visible
8	0.72-0.92	near infrared
9	1.00-1.40	near infrared
10	1.50-1.80	middle infrared
11	2.00-2.60	middle infrared
12	9.30-11.70	thermal infrared

However, analog data is not compatible with a digital computer, so an analog-to-digital processor was necessary in order to convert the data to a format which LARS' IBM 360/67 computer could handle. The digitized channels were next overlaid (registered), and a line and column coordinate system added, to allow the researcher to interface with the data. This data was then designated as Run Number 71052501.

Photographic Data

The photographic data was acquired on Kodak Aerochrome Infrared 2443 film in a 9 1/2 inch format. The aerial photos were acquired by the National Aeronautics and Space Administration using a Wild RC-8 mapping camera equipped with a Wild .510 μm cut-off (minus blue) filter. The camera (with six-inch focal length lens) was mounted in a United States Air Force RB-57F reconnaissance aircraft flown at an altitude of 60,000 feet above terrain. This elicited imagery in a contact scale of 1:120,000. The specific photographic frame used in this research project was exposed on August 12, 1971 at 1526 GMT (about 0939 local solar time), only 22 minutes after the MSS data was acquired (frame number 0076 of NASA Mission 177).

Data in a photographic format is not compatible with a digital computer, so the three emulsion layers had to be photographically separated and individually digitized, as described in the Review of Literature. The digitized data was then designated as "Run Number 71056903". The sensitivities of the photographic emulsion layers provided three channels of data as follows:

Channel	Wavelength Band (μm)	Spectral Region
1	0.47-0.61	visible
2	0.59-0.71	visible
3	0.68-0.89	near infrared

The photography also served as a valuable secondary source of "ground truth", particularly in cases where there were any questions concerning the primary surface observation data.

Surface Observation Data

In May 1971, all farm operators in test Segment 218 were interviewed by agents from local offices of the Agricultural Stabilization and Conservation Service (ASCS). These interviews were performed as part of the "1971 Corn Blight Watch Experiment," which also provided the imagery used in this experiment.

The interviews yielded data on the crop type or land use of each individual field in the entire test segment. This information formed the primary basis for the selection of training and test fields used in this investigation. However, these data had to be used with discretion, and with a knowledge of agricultural practices in the area. For instance, fields observed in May and listed as containing wheat had been harvested before August (the time of aerial data collection). Other fields, described as pasture, or simply as woods, were often grazed woodlots. Other apparent discrepancies were a function of the agricultural practices involved. A field observed as corn might be so weedy as to bear little spectral resemblance to more normal corn fields. It was in such questionable instances that the color infrared photography was used to either verify or correct the surface observation data.

Special Data Analysis Techniques

The basic analysis procedure has already been described in the Review of Literature and diagrammed in Figure 1. Briefly, the first step was to develop a set of fields and classes which could be used to train the computer to spectrally identify the categories of interest. Secondly, in order to obtain a quantitative determination of the accuracy with which the computer performed, it was necessary to select a set of test areas that was both representative and comprehensive. However, before the analysis could begin it was necessary to establish a few rules.

Objective 1 called for a determination of the optimum number of channels to use in mapping forest cover. One would expect the best accuracy to be obtained when using all available channels and, in fact, this usually is the case. However, an increase in the number of channels used in a classification requires a disproportionate increase in computer time (Figure 5), which costs on the order of $250 per hour and brings to bear the obvious action of the law of diminishing returns on classification accuracy. One might conclude that, considering the dual parameters of both accuracy and cost, something less than all twelve channels might be optimum. Indeed, experience has shown that the right combination of four or five channels gives almost the same accuracy as obtained with all channels, and at a far lower cost in terms of computer time.

The optimum channel number study outlined in Objective 1, however, requires the prior development of representative training and test decks to be used as standards throughout. This, in turn, requires a decision as to how many channels should be used during the development of these decks. Therefore, based on past experience and the intuitive feeling developed by the more experienced researchers at LARS, the decision was made to use four channels in the initial development of the training and test decks.

After deciding how many channels to use, it became necessary to decide just how the "best" combination of channels would be selected. As mentioned in the Review of Literature, the separability processor offers the researcher three basic options by which he may influence the computer's selection of the "best" channel combination. The processor may first be requested to select the optimum combination of channels on the basis of either the highest <u>average</u> interclass divergence or highest <u>minimum</u> interclass divergence. Since preliminary studies indicated that deciduous forest and coniferous forest, the two classes of primary concern, would be the most difficult pair of classes to separate, it was decided to select the "best" channel combination on the basis of highest <u>minimum</u> interclass divergence.

Another option in the separability processor allows the researcher to differentially weight one or more pairs of classes. From this, one immediately realizes that within this option, the number of possible ways to influence the selection of the "best" channel combination is limitless. Therefore, in order to keep the analysis following a well-defined procedural path, it was decided to use no differential interclass weighting with the separability processor.

The third option available for influencing channel selection is that of simply deleting one or more channels from consideration by the processor. This option was not used in the development of the standard training and test decks.

Another decision that had to be made was one concerning the use of thresholding in the calculation of classification results. The classifier algorithm is designed to classify each and every point into the class it most nearly resembles, even though the resemblance may be quite remote. Some points, therefore, will be borderline and of doubtful identity. For this reason a thresholding option was incorporated into the display program in which classification performance figures are calculated. The thresholding option simply places borderline points into a separate null or "threshold" class, which would be very useful if it affected only misclassified points; however, it will also threshold weakly (but correctly) classified points. The final result is that classification accuracies cannot be <u>increased</u> by thresholding and, in fact, they are nearly always <u>reduced</u> somewhat. Because of this bias, which may affect different classes in different ways, thresholding was not used in the calculation of any quantitative test results.

With the establishment of rules regarding the number of channels to use initially, the selection of the "best" channel combination, and thresholding, the analysis procedure was followed as outlined in the Review of Literature.

The accuracy of the first classification attempt was quite poor. A careful analysis of the color infrared photo revealed the probable cause to be several questionable designations in the ASCS ground observations.

It was evident, upon careful examination of the photography, that the computer had, in some instances, been trained incorrectly to identify certain cover types, and had then been asked to identify test areas as something which they were not.

The most common discrepancies involved training and test fields designated as either deciduous forest or forage when in fact they were some of both; that is, they were grazed woodlots with very low stand densities in which portions of the fields were pasture (grass) while other areas of the same field consisted of tree foilage. To train the computer to recognize the entire field as either pasture or trees would have certainly been incorrect. Likewise, it would have been unfair to expect the machine to classify such a test area as either one or the other. Such fields, therefore, had to be deleted from consideration as training or test areas.

A similar problem occurred in several fields which were "corn", according to the surface observation data. The farmers concerned had apparently made little or no effort at weed control. Again, it would have been incorrect to train the computer to recognize such a field as corn when its spectral response was due largely to the presence of weeds. Such anomalous fields were therefore deleted.

For the most part, the ASCS ground observation data was adequate for training and test field selection. However, it had been collected three months before the acquisition of the MSS and photographic imagery used in this research project and was intended for use in an agricultural survey. Thus, in addition to some of the observations being out-of-date, the land use definitions utilized were agriculturally oriented and often inadequate for application to forest cover classification. Consequently, apparent discrepancies had to be resolved on the basis of careful interpretation of the color infrared photography. The training and test decks were then appropriately corrected. The analysis procedure was next repeated in its entirety, in order to refine the training deck.

During this procedure, an attempt was made to select test areas in approximately the same proportions as represented by the various cover classes in the segment. While this was not necessary to obtain reliable figures for the classification accuracies of individual classes, it did make possible a more reliable estimate of the classification performance of the segment overall. The training sample selection process was long, subjective and certainly not "automatic" or operational, but it was necessary in order to develop adequate training and test decks to be used as standards in subsequent experiments (Appendix A).

Channel Number Study

As stated previously, during much of the past analysis of MSS data at LARS, four channels have customarily been used for the classification of the data. Though the use of more channels increases accuracy somewhat, it also drastically increases the amount of computer time (and thus the cost). The use of four channels, then, has generally been considered the best trade-off between classification accuracy and computer time. This practice has been based largely on intuition, however, since there have been no formal studies conducted using data acquired by the multispectral scanner in its current configuration.

Therefore, before proceeding with the rest of this research, it was decided to run a simple experiment to see whether or not four channels seemed optimum. The computer was given the statistics derived from the final training deck, and the separability processor was requested to select the best 1, 2, 3, 4, 5, 6, 8 and 10 channels, according to minimum divergence, and without weighting. The flightline was then classified with each of the best n-channel combinations and with all twelve channels. The resulting test class accuracies, along with computer time required, were plotted over number of channels used (Appendix B, Figure 5). Based on these results, the decision was made to use five channels in all subsequent work. The decision was arbitrary, however, in the sense that a detailed cost-benefit study was beyond the scope of this project.

Forest Mapping Capability

To determine the "absolute" capability to map forest cover with MSS data and ADP techniques is impossible. No matter how much time and effort one might devote to refining the training deck, there would always be room for improvement.

However, in order to arrive at an approximation of what might be expected, the results of two classifications were studied. Since it had been previously decided that the use of five channels offered the best trade-off between computer time and accuracy, the results of the classification performed by the best five-channel combination were studied further.

This five-channel classification offered what might be expected in an "operational" situation, assuming of course, that five channels would be used in such a situation. One must fully recognize, of course, that advances in computer technology may make it quite feasible to use all available channels. As a comparison, therefore, the results obtained by the use of all twelve channels were also examined, even though the slight gain in classification accuracy was at the expense of a considerable amount of computer time.

Another consideration is that the second objective of this study requires a determination of the capability to differentiate between general forest cover and other cover types, as well as the capability to distinguish deciduous from coniferous forest. In the classification of the data, deciduous and coniferous forest were treated as separate classes, therefore the results did not give an accurate idea of how well forest cover, in general, could be classified. To remedy this situation, the test class results from deciduous forest and coniferous forest were mathematically combined to form a separate class. In effect, a test point from either of the two forest categories was considered to be correctly classified if it was classified as either deciduous or coniferous forest. Confusion between the two forest categories, then, was not considered in computing the accuracy for the "combined forest" category. As an example consider Table 3 and Figure 8 in which $[(29745 + 1001 + 3 + 85)/(32252 + 88)] \times 100 = 95.4\%$ is the classification accuracy for combined forest. The figures for overall classification accuracy, however, were calculated by the computer with deciduous and coniferous forest considered as separate categories.

Spectral Region Evaluation

For the purposes of this study, the twelve available channels of scanner data may be grouped into four basic regions of the electromagnetic spectrum -- visible, near infrared, middle infrared, and thermal infrared (Figure 6). These spectral regions seem to vary in importance or value as far as the classification of scanner data is concerned. Because of this, it was decided to use the final training and test decks to draw some general conclusions as to the relative values of these spectral regions.

The statistics derived from the training deck were submitted to the separability processor as before, except that all the channels comprising a given spectral region were deleted from consideration in various combinations of one or more spectral regions at a time. The processor, then, was required to select the best combination of five channels from the spectral region or regions which had not been deleted. In one iteration, for instance, all infrared channels were deleted, thus requiring the processor to select from the visible channels only. In another iteration,

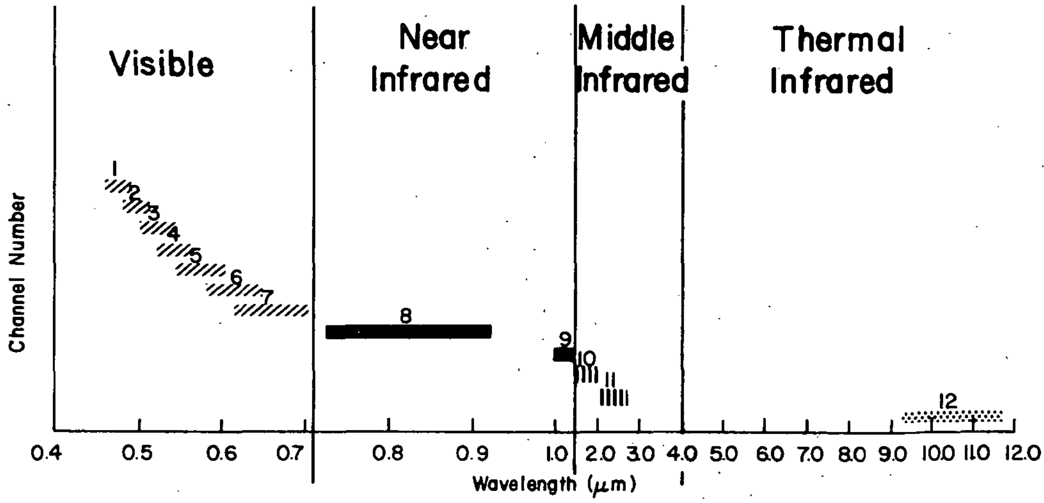


Figure 6. Relationship of MSS data channels to the electromagnetic spectrum.

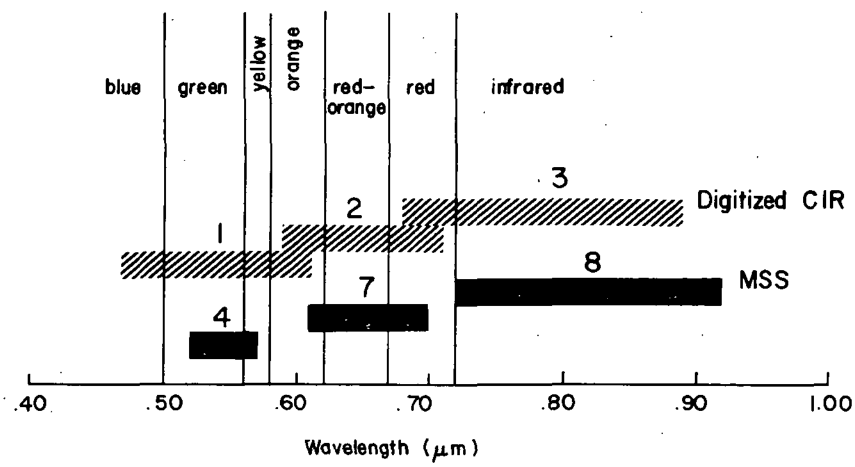


Figure 7. Relationship of the digitized color infrared photographic channels and the most closely corresponding MSS channels.

the thermal channel was deleted from consideration, so that the processor had to select the best combination of five wavelength bands from the eleven reflective wavelength bands remaining; the near infrared was deleted from consideration, etc. For a control, the processor was allowed to consider all twelve channels. As before, the best combination was selected according to minimum divergence and without weighting. The resulting five-channel combinations were then used, one at a time, to classify the entire flightline.

As a check, the same procedure was run on another test site covered by the same MSS instrumentation on the same day. To preserve objectivity, the author had nothing to do with the selection of the training and test fields for this second substudy. The training and test fields selected by the Corn Blight Watch analysts during the summer of 1971 were used. The categories of cover, however, were the same as those in Segment 218 with the only exception being the absence of coniferous forest. Also, as is usually the case, the agricultural categories (forage, corn, and soybeans) had been divided into several subclasses. This breakdown was maintained intact to preserve objectivity. As in Segment 218, only one class of deciduous forest was used.

MSS-Digitized CIR Comparison

Several approaches were tried in order to achieve a comparison between the automatic forest cover mapping capabilities using scanner imagery and digitized color infrared (CIR) photography. The first step, however, was to obtain a line printer display of the digitized photography and carefully determine the coordinates of training and test fields exactly corresponding to those used in the analysis of the scanner imagery. Thus the computer was trained and tested with the same areas on both sets of data. Because of differences in digitization rates between the scanner data and the digitized photography, the numbers of data points were not the same, even though the areas involved were identical. It should also be noted that there were several training and test fields at the southernmost end of the segment which did not appear on the digitized photograph, but which were included in the scanner data analysis. Because the segment was too long to appear in its entirety on any one frame of photography, portions of the two adjacent frames would have had to be digitized in order to include the entire segment, adding significantly to the difficulty of the procedure.

With the transfer of training and test fields completed, the segment was classified, using all three channels of digitized photographic data, and the perpoint classifier as previously described. As a further study a "perfield" classifier was used which, on the basis of the same set of training statistics, classified each test field as an individual decision, into one of the six defined classes.

The results from these two classifications were then compared with similar classifications of the MSS data. Since MSS Channels 4, 7, and 8 correspond approximately to the three available channels of the digitized color infrared photography (Figure 7), classification results using these three MSS channels were utilized for the comparisons.

In the process of evaluating the results from this study, a visual comparison of the two sets of data (MSS and digitized CIR photography) was desired. Gray scale images of the corresponding channels (MSS Channels 4, 7, and 8, and CIR Channels 1, 2, and 3) were photographed from the digital display unit (Figures 20-23). In addition, color infrared reconstitutions of the two sets of data were produced by a process similar to that described in the Review of Literature for the production of color-coded classification results.

Basically, this procedure consists of displaying the three channels in each data set as described in the paragraph above. Instead of obtaining black and white photographs of the individual gray scales, however, a single frame of color film is exposed successively to each of the three appropriately filtered gray scales. For example, in the digitized CIR data, Channel 1 covers the green portion of the spectrum. Since green wavelengths produce a blue rendition on positive color infrared film, the gray scale of Channel 1 is photographed, from the digital display, through a blue filter. Channel 2, which covers the red portion of the spectrum and produces a green rendition on CIR film, is exposed through a green filter. Likewise Channel 3, covering the near infrared wavelengths, is exposed through a red filter. With all three of these filtered gray scales recorded, consecutively, on the same frame of normal color film, a color infrared reconstitution of the data is produced (Figure 25).

Channels 4, 7, and 8 of the MSS data were photographed in the same manner, thereby producing the images in Figure 24. These images of the digitized data provided a means by which the data could be visually compared.

CHAPTER IV

RESULTS AND DISCUSSION

Introductory Statement

Careful interpretation of the color infrared aerial photography allowed corrections and verifications to be made on the ground observation data. The test deck was then corrected accordingly. Next, using the analysis sequence outlined in the Review of Literature, the training deck was refined to the point that it produced acceptably accurate test results. These two decks (listed in Appendix A) were then used as standards throughout the remainder of the study. Table 1 gives a summarization of both decks.

Slightly over one percent of the segment was devoted to training the classifier algorithm, with about half of this training sample area involved in characterizing the spectral response of the widely varied forage category. Test samples involved another 14 percent of the segment and were selected so as to represent the six defined categories in approximately the same proportions as they

Table 1. Summary of training and test classes for analysis of Seg. 218 MSS data.

Cover Type	Training Classes: Number of Points	Training Classes: % of Total Seg.	Training Classes: % of Total Train.	Test Classes: Number of Points	Test Classes: % of Total Seg.	Test Classes: % of Total Test	Test/Train
decid	161	0.05	4.33	32252	9.08	64.77	200.3
conifer	147	0.04	3.95	88	0.02	0.18	0.6
water	321	0.09	8.62	339	0.10	0.68	1.1
forage	1870	0.53	50.24	11760	3.31	23.62	6.3
corn	784	0.22	21.06	2679	0.75	5.38	3.4
soybean	439	0.12	11.79	2676	0.75	5.37	6.1
TOTAL	3722	1.05	100.00	49794	14.02	100.00	

Seg. 218 = 1600 lines x 222 columns = 355,200 points occurred in the segment as a whole. Because of the extremely small amount of coniferous forest present in the segment, only 88 points identified as conifer were available for use as test samples. This was not considered to be a good statistical sample, but the data obviously did not allow a larger selection.

These final decks of training and test samples were used, intact, throughout all phases of this investigation, beginning with the channel number study.

Channel Number Study

It is usually not necessary, nor even desirable, to use a large number of channels in a classification task. Consequently, when there are many channels available, the investigator must have some idea of how many he really needs to use in order to achieve his objectives.

Figure 5 is a comparison between the overall classification results produced by successively larger "best" combinations of channels (Table 2), and the amount of computer time required for the classifications. As can be seen, the accuracy is quite low with only one channel, but as channels are added, it increases rapidly to nearly 90 percent (using three to five channels), and then continues to increase slowly to about 95 percent (when all twelve channels are utilized). The computer time required for the classification is modest with only a few channels, but increases rapidly -- approximately as the square of the number of channels used.

Table 2. Test class performance related to number of channels used.

Number of Channels Used	Classification Accuracy (%) Overall	Combined Forest	Deciduous	Conifer	Water	Forage	Corn	Soybeans
1	44.0	61.3	43.1	84.1	95.9	27.6	80.1	84.2
2	80.5	93.3	87.1	87.5	97.9	55.9	88.1	98.2
3	87.1	94.1	88.8	95.5	98.2	80.6	84.8	95.2
4	89.3	94.9	89.9	96.6	97.6	84.8	94.2	96.2
5	90.8	95.3	92.2	96.6	98.2	85.5	90.7	95.7
6	92.4	97.0	95.0	92.0	98.5	83.8	92.8	97.0
8	93.7	97.5	96.2	96.6	98.5	85.8	93.8	96.3
10	94.7	98.1	97.0	96.6	98.5	87.8	95.6	96.3
12	95.1	98.3	97.2	95.5	98.5	88.6	96.9	96.3

With the cost of computer time at $250 per hour, and the obvious action of the law of diminishing returns on the overall classification accuracy with increased number of channels, it would seem that a combination of far less than twelve channels would be optimum. Without the assistance of a detailed cost-benefit study, it was decided to use the best five-channel combinations of wavelength bands in all subsequent work as the best five-channel combination gave an overall classification accuracy slightly in excess of 90 percent and used only a little more than twenty minutes of computer time.

Forest Mapping Capability

The best five-wavelength band classification results, and the maximum accuracy classification results, (obtained by using all twelve wavelength bands) are illustrated in Figures 8 and 9 and Tables 3 and 4. (A color-coded classification of the northern and southern portions of Segment 218, using the best five-channel combination, is shown later in Figure 26).

The bars labeled "combined forest" in Figures 6 and 7 illustrate results of a mathematical combination of classification results from the deciduous and the coniferous forest categories, and indicate the separability of general forest from other cover types. This combined forest class separates accurately from all other cover types (95.3 percent with the "best" combination of five channels and

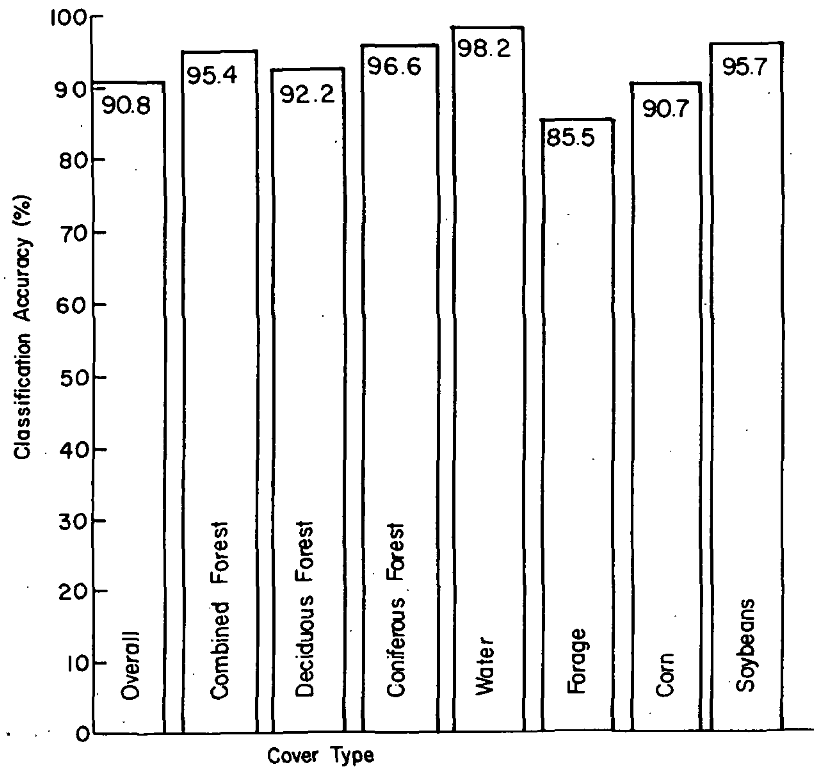


Figure 8. Test class performance of MSS data using best 5-channel combination.

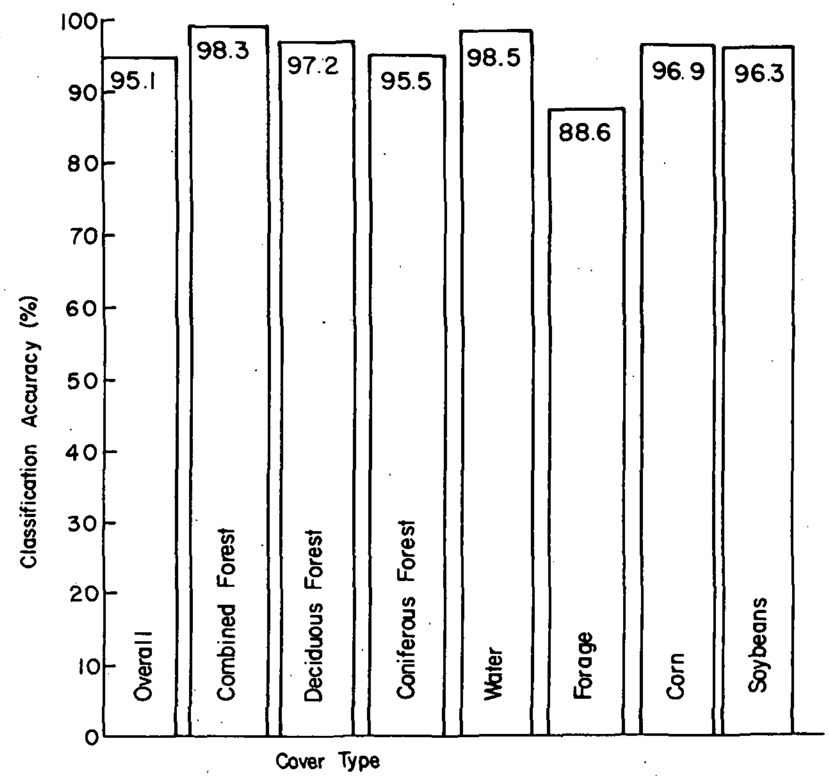


Figure 9. Test class performance of MSS data using all twelve channels.

Table 3. Test class performance using best combination of five channels.

CHANNELS USED

CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND	1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND	9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	92.2	29745	1001	0	378	245	883
2	CONIFER	88	96.6	3	85	0	0	0	0
3	WATER	339	98.2	1	2	333	3	0	0
4	FORAGE	11760	85.5	22	7	2	10052	413	1264
5	CORN	2679	90.7	1	4	0	191	2431	52
6	SOY	2676	95.7	10	0	0	91	15	2560
	TOTAL	49794		29782	1099	335	10715	3104	4759

OVERALL PERFORMANCE(45206/ 49794) = 90.8

AVERAGE PERFORMANCE BY CLASS(558.9/ 6) = 93.2

Table 4. Test class performance using all twelve channels.

CHANNELS USED

CHANNEL 1	SPECTRAL BAND	0.46 TO 0.49 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 2	SPECTRAL BAND	0.48 TO 0.51 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND	0.50 TO 0.54 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 5	SPECTRAL BAND	0.54 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 7	SPECTRAL BAND	0.61 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 8	SPECTRAL BAND	0.72 TO 0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND	1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND	2.00 TO 2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND	9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

				NUMBER OF SAMPLES CLASSIFIED INTO					
	GROUP	NO OF SAMPS	PCT. CORCT	DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	97.2	31339	359	0	263	112	179
2	CONIFER	88	95.5	4	84	0	0	0	0
3	WATER	339	98.5	1	1	334	3	0	0
4	FORAGE	11760	88.6	39	5	1	10420	245	1050
5	CORN	2679	96.9	1	2	0	61	2597	18
6	SOY	2676	96.3	5	1	0	74	18	2578
	TOTAL	49794		31389	452	335	10821	2972	3825

OVERALL PERFORMANCE(47352/ 49794) = 95.1

AVERAGE PERFORMANCE BY CLASS(573.0/ 6) = 95.5

98.3 percent with all twelve channels used), a result showing a potential for using ADP techniques in operational situations.

Table 3 shows that coniferous forest seems to separate quite well from the other cover types considered (about 96 percent), while deciduous forest cover offers a bit more difficulty, as shown by a classification accuracy of 92 percent. Table 3 further indicates that much of the misclassification of deciduous forest is a result of confusion with coniferous forest, as illustrated by the 1001 deciduous test points which were misclassified as coniferous forest.

An examination of Figure 26 illustrates many scattered individual points of conifer in the deciduous forest areas. These misclassified points are apparently areas of shadow in the deciduous forest canopy. These shadow areas are explained by the fact that, like most forest stands, the deciduous forest areas in this segment do not have a crown closure of 100 percent. In fact, crown closure is more on the order of 60 to 70 percent, with far less than that in many of the areas where livestock has been allowed to graze. The resulting small clearings, combined with the extremely rough texture of the uneven-aged forest canopy, create many areas of shadow which, in some cases, were confused with the darker tones of coniferous crowns (note the triangle-shaped conifer stands in the northern portion of Segment 218, Figure 24). This rough texture of the forest canopy resulted in many areas of shadow, but it also caused highly illuminated points on the sunward side of tree crowns. This additional phenomenon seemed to account for many of the data points in deciduous forest areas which were misclassified as agricultural cover types.

It should be noted that the LARS system of determining test area accuracies often results in conservative accuracy percentages. This is because an entire test area must be declared by the researcher to be one cover type or another, rather than a mixture. However, in reality, mixture of cover types are the rule and were often mapped out by the computer as such, but in the tables of test areas, this situation is not apparent. For example, some of the deciduous forest test points "missclassified" as forage were not misclassifications at all. In grazed woodlands where the forest canopy density has decreased and the entire stand has become more open over time, grass has invaded the forest floor. In many cases the classifier, in fact, correctly classified such forage areas under open deciduous stands. Conversely, the system has correctly classified scattered individual tree crowns growing in pasture fields (compare southern portion of Segment 218 in Figure 24 with classification results in Figure 26). Therefore, in some cases, the actual classification accuracy may be even better than the numbers indicate.

The water, forage, corn and soybean classes varied considerably in their classification performance. As is usually the case, water was classified with an extremely high accuracy, due to its low reflectance in the near and middle infrared portions of the spectrum (Figure 3). The row crop categories, corn and soybeans, also were classified with quite high accuracy as a combined class. An examination of Table 3 reveals that what confusion did take place with corn and soybeans was primarily between the two categories rather than with other cover types. Forage, which is a "catch-all" category to a certain extent, since it combines pasture, hay, and stubble, had an extremely wide variance and inevitably classified rather poorly, seldom exceeding 85-88 percent accuracy.

While confusion occurred between many of the categories, it should be emphasized that the confusion between the forest categories and other non-forest categories was minimal, indicating the relatively high spectral separability of forest, in general, from other cover types, using ADP techniques. This result is one of the major, significant findings of this research.

Table 4 lists the results of the classification derived from use of all twelve channels. (These results are also illustrated in Figure 7). The overall classification performance was slightly over 95 percent and, as an individual cover type, only forage did not exceed 95 percent accuracy. While the overall accuracy was increased by about 4 percent over the use of the best five-channel combination, the amount of computer time required to buy this increased accuracy was considerable -- about 90 minutes compared to 20 minutes as indicated in Figure 5. With computer time costing $250 per hour, this is an increase from $83 to $375.

Spectral Region Evaluation

One of the major phases of this research project involved the evaluation of the spectral regions in which the scanner data was obtained, including the visible (0.46-0.72 μm), near infrared (0.72-1.4 μm), middle infrared (1.4-4.0 m) and thermal infrared (4.0-13.5 m). This was the first time that this type of quantitative evaluation of the various spectral regions had been conducted. Tables 5-11 show the test class performances obtained in the various analysis sequences conducted during this phase of the research. From these tables, Figures 10-17 were prepared using the percent correct identification for the test samples of the different cover types. All cases (Tables 5-11) involve only five wavelength bands for the classification. Table 5 is the control in that all twelve wavelength bands were considered by the feature selection processor, with the resulting best five-channel combination used in the classification. In the subsequent analysis

Table 5. Classification results: all channels considered.

SERIAL NUMBER------- 831219706 CLASSIFIED- SEPT 6,1972

CHANNELS USED

CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND	1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND	9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECIDUOU	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOYBEAN

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECIDUOU	CONIFER	WATER	FORAGE	CORN	SOYBEAN
1	DECIDUOU	32252	92.2	29745	1001	0	378	245	883
2	CONIFER	88	96.6	3	85	0	0	0	0
3	WATER	339	98.2	1	2	333	3	0	0
4	FORAGE	11760	85.5	22	7	2	10052	413	1264
5	CORN	2679	90.7	1	4	0	191	2431	52
6	SOYBEAN	2676	95.7	10	0	0	91	15	2560
	TOTAL	49794		29782	1099	335	10715	3104	4759

OVERALL PERFORMANCE(45206/ 49794) = 90.8

AVERAGE PERFORMANCE BY CLASS(558.9/ 6) = 93.2

Table 6. Classification results: only visible channels considered.

SERIAL NUMBER------- 912219701 CLASSIFIED- SEPT 12,1972

CHANNELS USED

CHANNEL 1	SPECTRAL BAND 0.46 TO 0.49 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND 0.50 TO 0.54 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 5	SPECTRAL BAND 0.54 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND 0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

	CLASS		CLASS
1	DECIDUOU	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOYBEAN

TEST CLASS PERFORMANCE

			NUMBER OF SAMPLES CLASSIFIED INTO					
GROUP	NO OF SAMPS	PCT. CORCT	DECIDUOU	CONIFER	WATER	FORAGE	CORN	SOYBEAN
1 DECIDUOU	32252	56.2	18129	11553	1314	403	71	782
2 CONIFER	88	69.3	20	61	6	0	0	1
3 WATER	339	72.9	35	1	247	52	4	0
4 FORAGE	11760	67.3	11	3	252	7916	1959	1619
5 CORN	2679	95.6	0	0	19	17	2560	83
6 SOYBEAN	2676	90.9	18	4	5	61	155	2433
TOTAL	49794		18213	11622	1843	8449	4749	4918

OVERALL PERFORMANCE(31346/ 49794) = 63.0

AVERAGE PERFORMANCE BY CLASS(452.2/ 6) = 75.4

Table 7. Classification results: only infrared channels considered.

SERIAL NUMBER------- 913219703 CLASSIFIED- SEPT 13,1972

CHANNELS USED

CHANNEL 8	SPECTRAL BAND 0.72 TO 0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND 1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND 1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND 2.00 TO 2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND 9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECIDUOU	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOYBEAN

TEST CLASS PERFORMANCE

				NUMBER OF SAMPLES CLASSIFIED INTO					
	GROUP	NO OF SAMPS	PCT. CORCT	DECIDUOU	CONIFER	WATER	FORAGE	CORN	SOYBEAN
1	DECIDUOU	32252	84.9	27386	1491	0	989	2211	175
2	CONIFER	88	89.8	9	79	0	0	0	0
3	WATER	339	98.5	1	1	334	2	1	0
4	FORAGE	11760	78.6	302	1	2	9238	487	1730
5	CORN	2679	78.5	197	0	0	60	2103	319
6	SOYBEAN	2676	75.7	15	0	0	159	476	2026
	TOTAL	49794		27910	1572	336	10448	5278	4250

OVERALL PERFORMANCE(41166/ 49794) = 82.7

AVERAGE PERFORMANCE BY CLASS(506.0/ 6) = 84.3

Table 8. Classification results: visible, middle infrared, thermal infrared channels considered.

SERIAL NUMBER------- 918219704 CLASSIFIED- SEPT 18,1972

CHANNELS USED

CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND	2.00 TO 2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND	9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECIDUOU	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOYBEAN

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECIDUOU	CONIFER	WATER	FORAGE	CORN	SOYBEAN
1	DECIDUOU	32252	93.9	30281	953	0	303	296	419
2	CONIFER	88	95.5	4	84	0	0	0	0
3	WATER	339	97.9	0	2	332	5	0	0
4	FORAGE	11760	83.4	32	0	1	9809	485	1433
5	CORN	2679	94.7	2	2	0	86	2537	52
6	SOYBEAN	2676	97.0	4	0	0	57	18	2597
	TOTAL	49794		30323	1041	333	10260	3336	4501

OVERALL PERFORMANCE(45640/ 49794) = 91.7

AVERAGE PERFORMANCE BY CLASS(562.4/ 6) = 93.7

Table 9. Classification results: visible, near infrared, thermal infrared channels considered.

SERIAL NUMBER------- 918219705   CLASSIFIED-   SEPT 18,1972

CHANNELS USED

CHANNEL 4	SPECTRAL BAND 0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 7	SPECTRAL BAND 0.61 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 8	SPECTRAL BAND 0.72 TO 0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND 1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND 9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECIDUOU	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOYBEAN

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECIDUOU	CONIFER	WATER	FORAGE	CORN	SOYBEAN
1	DECIDUOU	32252	92.5	29836	1201	0	309	302	604
2	CONIFER	88	92.0	7	81	0	0	0	0
3	WATER	339	98.2	0	4	333	2	0	0
4	FORAGE	11302	87.8	59	17	2	9922	357	945
5	CORN	2122	86.8	0	1	0	238	1842	41
6	SOYBEAN	2412	92.8	6	2	0	100	66	2238
	TOTAL	48515		29908	1306	335	10571	2567	3828

OVERALL PERFORMANCE(44252/ 48515) = 91.2

AVERAGE PERFORMANCE BY CLASS(550.2/ 6) = 91.7

Table 10. Classification results: visible and thermal infrared channels considered.

SERIAL NUMBER------- 924219707 CLASSIFIED- SEPT 24,1972

CHANNELS USED

CHANNEL 3	SPECTRAL BAND	0.50 TO 0.54 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 7	SPECTRAL BAND	0.61 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND	9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECIDUOU	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOYBEAN

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	DECIDUOU	CONIFER	WATER	FORAGE	CORN	SOYBEAN
				NUMBER OF SAMPLES CLASSIFIED INTO					
1	DECIDUOU	32252	59.6	19232	11485	17	290	96	1132
2	CONIFER	88	77.3	19	68	0	0	0	1
3	WATER	339	81.1	6	0	275	54	2	2
4	FORAGE	11760	82.1	12	5	214	9656	487	1386
5	CORN	2679	97.9	0	0	0	17	2623	39
6	SOYBEAN	2676	89.8	2	43	0	76	151	2404
	TOTAL	49794		19271	11601	506	10093	3359	4964

OVERALL PERFORMANCE(34258/ 49794) = 68.8

AVERAGE PERFORMANCE BY CLASS(487.9/ 6) = 81.3

Table 11. Classification results: visible and reflective infrared channels considered.

SERIAL NUMBER------- 913219702 CLASSIFIED- SEPT 13,1972

CHANNELS USED

CHANNEL 3	SPECTRAL BAND	0.50 TO	0.54 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO	0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 8	SPECTRAL BAND	0.72 TO	0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO	1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND	2.00 TO	2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

	CLASS		CLASS
1	DECIDUOU	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOYBEAN

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	DECIDUOU	CONIFER	WATER	FORAGE	CORN	SOYBEAN
				NUMBER OF SAMPLES CLASSIFIED INTO					
1	DECIDUOU	32252	93.4	30133	502	1	1026	135	455
2	CONIFER	88	93.2	5	82	0	0	1	0
3	WATER	339	98.5	0	2	334	1	0	2
4	FORAGE	11760	66.6	9	2	2	7828	1920	1999
5	CORN	2679	85.8	0	2	0	205	2299	173
6	SOYBEAN	2676	96.9	10	0	0	58	14	2594
	TOTAL	49794		30157	590	337	9118	4369	5223

OVERALL PERFORMANCE(43270/ 49794) = 86.9

AVERAGE PERFORMANCE BY CLASS(534.5/ 6) = 89.1

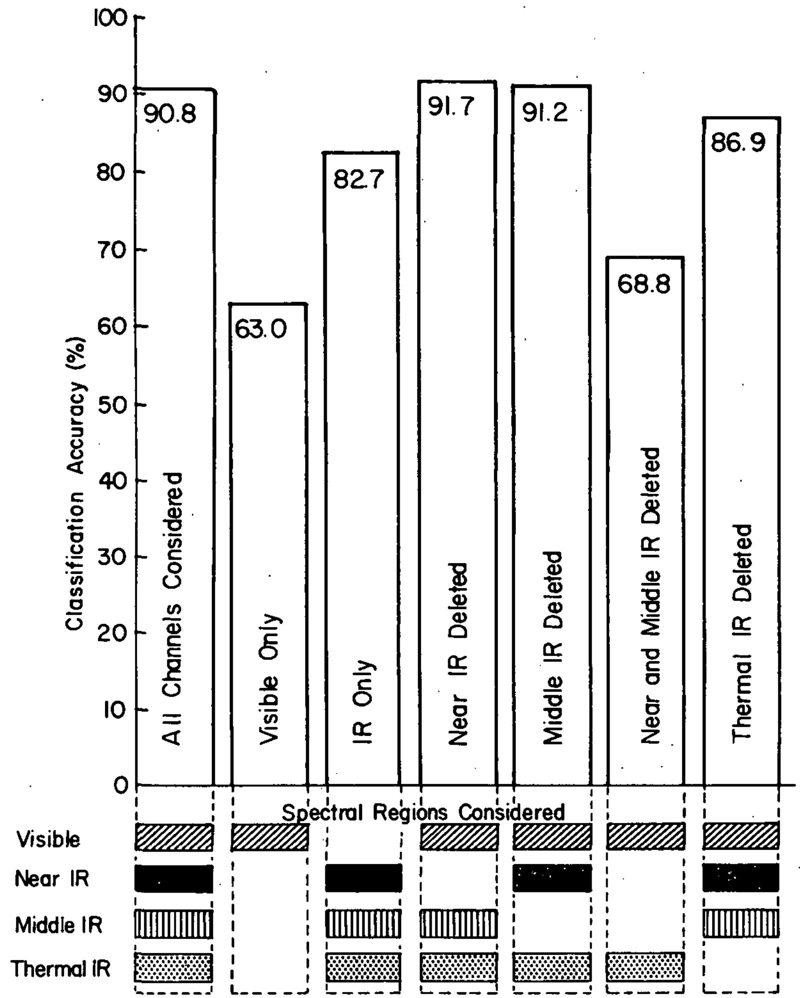


Figure 10. Influence of spectral regions on classification accuracy for overall test classes.

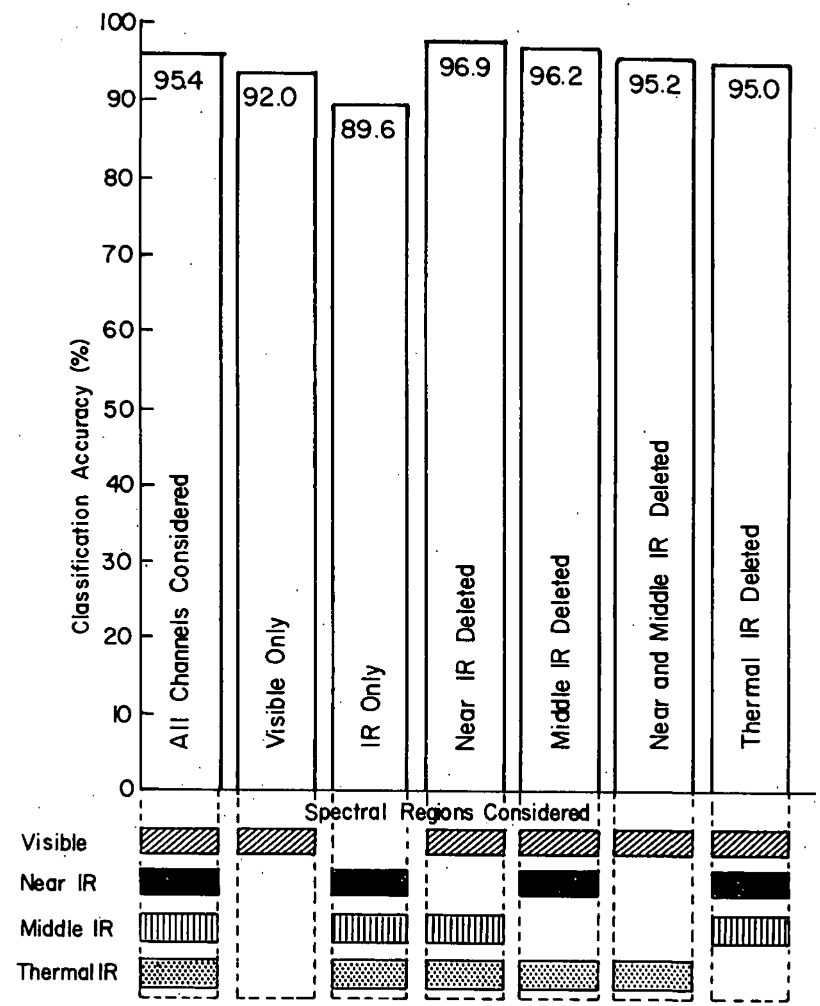


Figure 11. Influence of spectral regions on classification accuracy for combined forest.

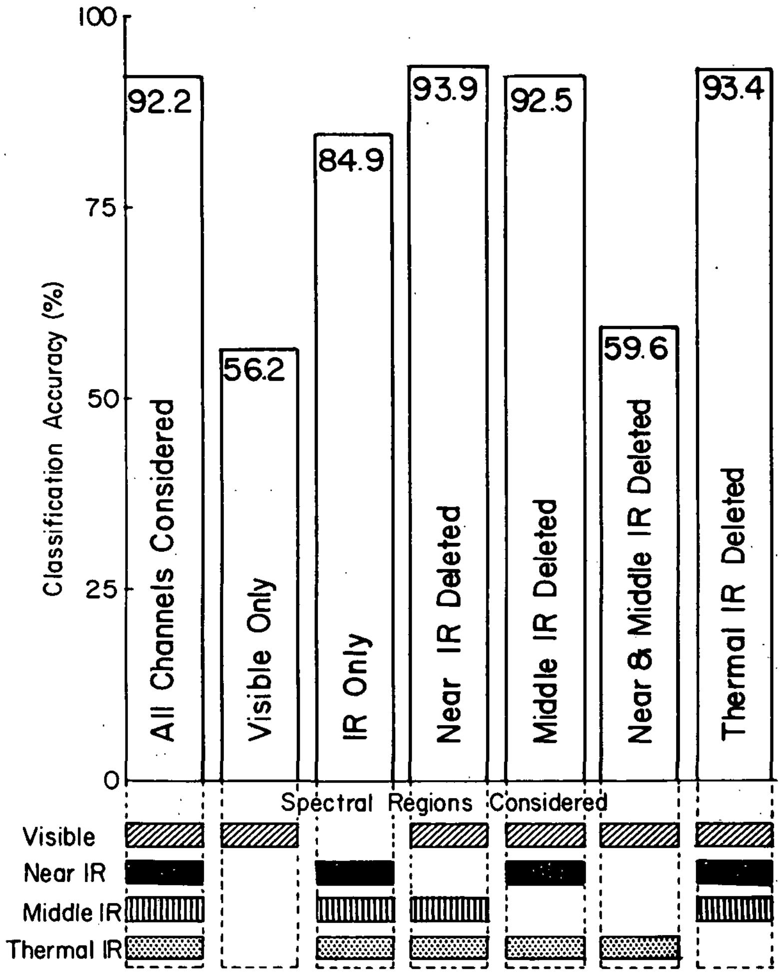


Figure 12. Influence of spectral regions on classification accuracy for deciduous forest.

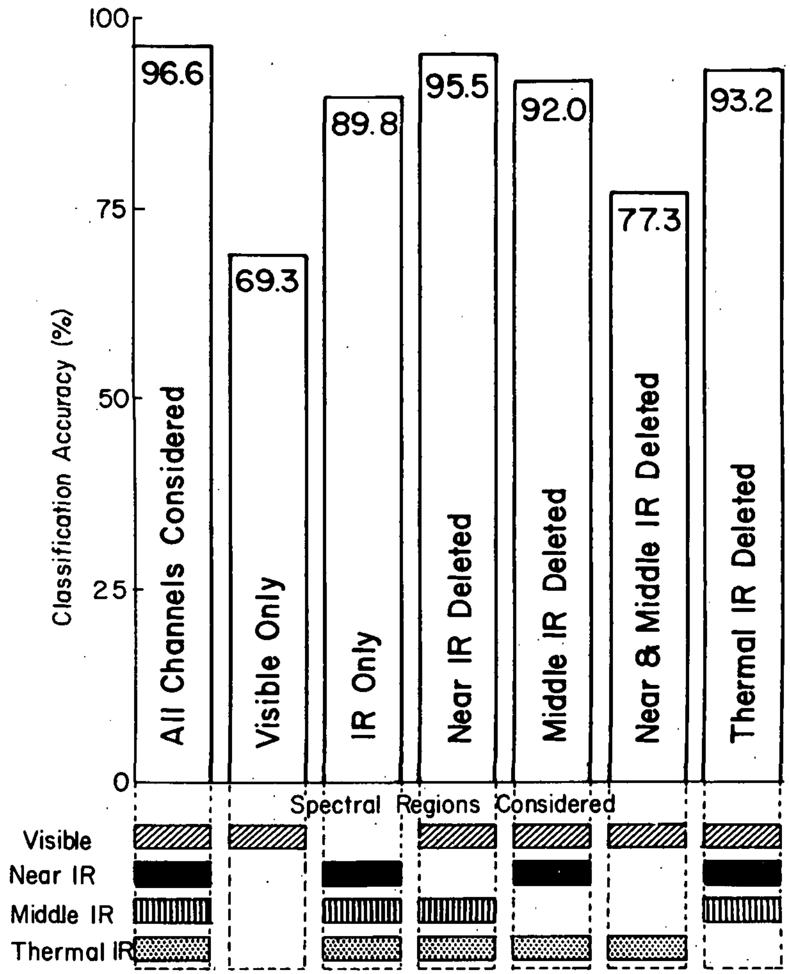


Figure 13. Influence of spectral regions on classification accuracy for coniferous forest.

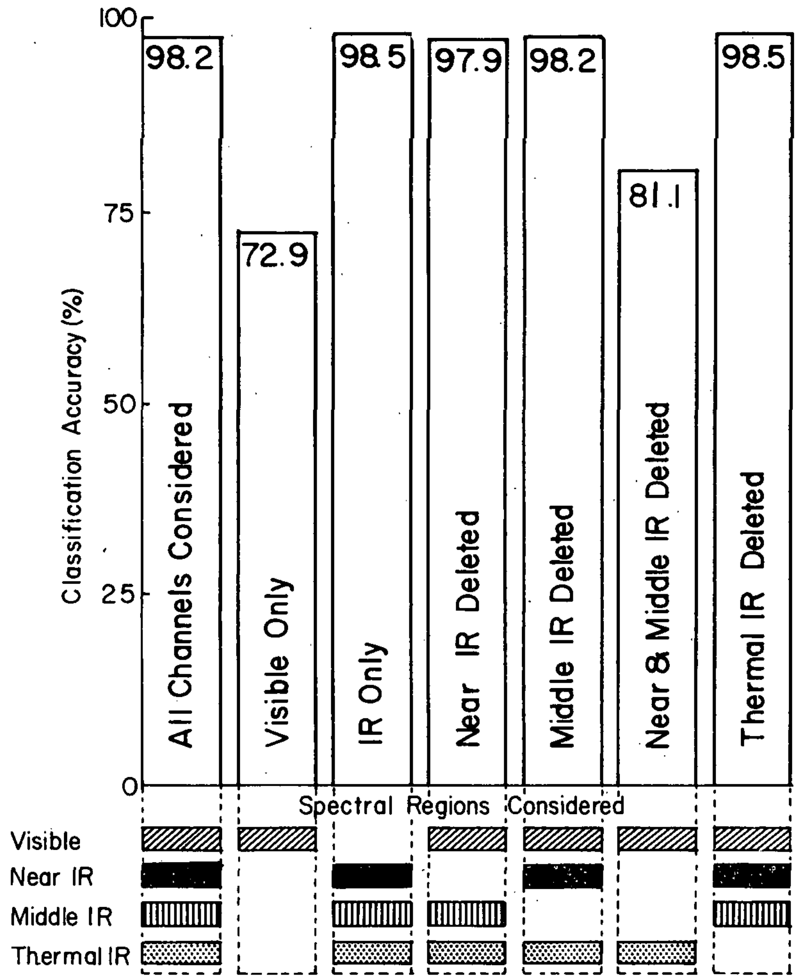


Figure 14. Influence of spectral regions on classification accuracy for water.

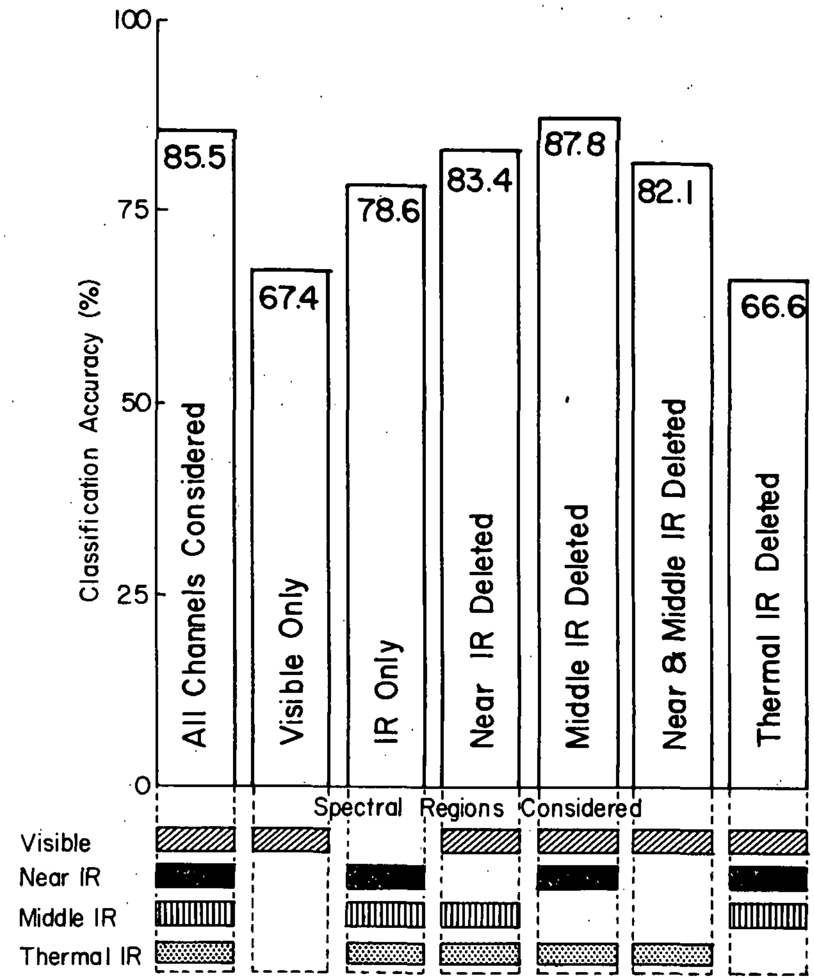


Figure 15. Influence of spectral regions on classification accuracy for forage (pasture, hay, and stubble).

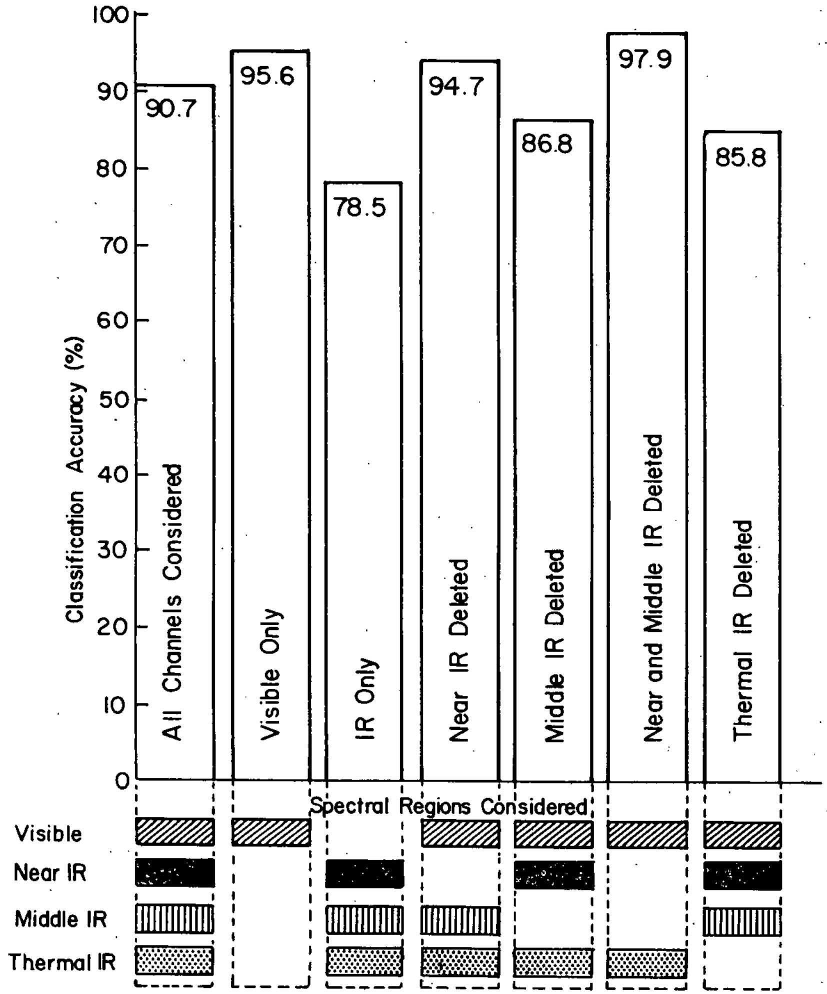


Figure 16. Influence of spectral regions on classification accuracy for corn.

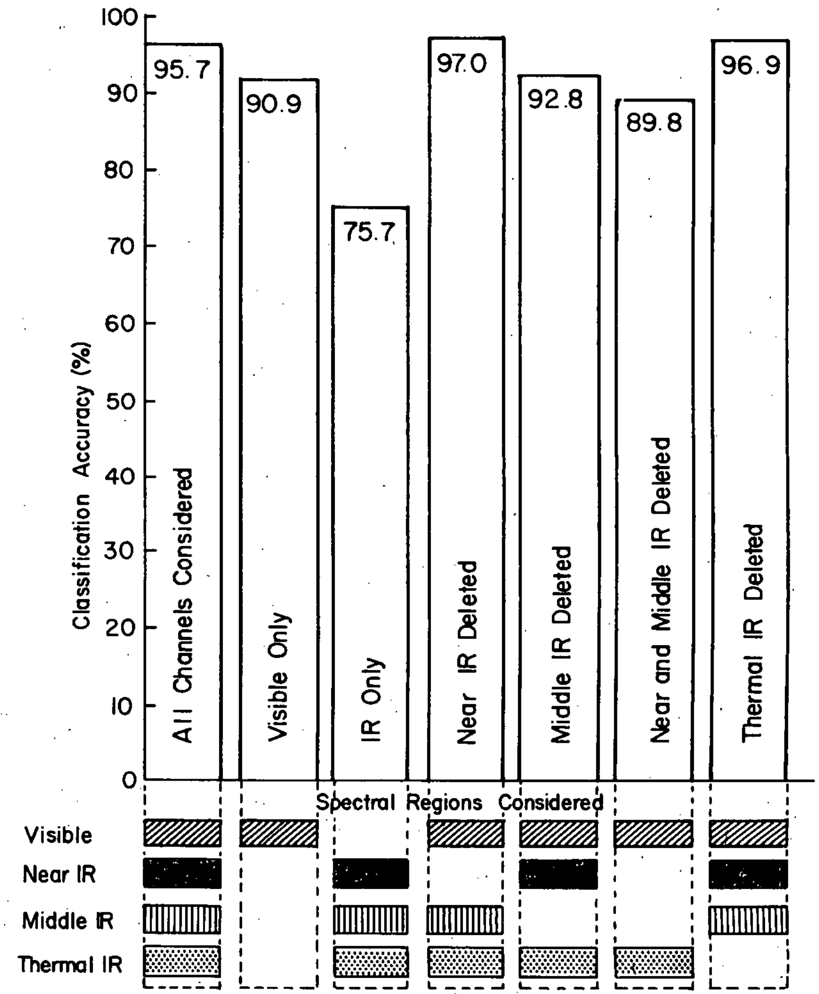


Figure 17. Influence of spectral regions on classification accuracy for soybeans.

sequences, one or more spectral regions were deleted from consideration in the channel selection process, but in each case a total of five wavelength bands was actually used in the classification. It is of particular significance to note that the five wavelength bands actually utilized in the control classification (Table 5) included one in the green portion of the visible, one in the red portion of the visible, and one each in the near infrared, the middle infrared, and the thermal infrared regions.

Figure 10 illustrates the overall test results for the various analysis sequences. The first bar in the figure represents the test results provided by the control combination of channels which was selected upon consideration of all available channels. The remaining bars represent test results obtained from the five-channel combinations selected in the various other channel selection sequences. Because of its predominance in the segment, and hence in the test deck, the deciduous forest class has a greater effect than any other on the overall test results. For this reason, Figure 10 bears a close resemblance to Figure 12.

Figure 11 illustrates the high separability of forest cover (deciduous and coniferous forest combined) from other cover types, when various combinations of spectral regions were considered. In all but two cases the accuracy equaled or exceeded 95 percent. When only visible channels were considered (Table 6) a considerable amount of confusion between forest and water resulted. Figure 3 illustrates that while the mean reflectance of the two forest categories is somewhat lower than that of water in the visible channels, there is still much overlap, which explains the confusion between these categories. Also note from Figure 3 that forest tends to have a significantly lower response than all three of the agricultural classes in the visible channels, so with only the visible channels considered, forest still separates from other cover types with an accuracy in excess of 90 percent.

The five infrared channels alone (visible excluded from consideration) were able to separate forest from other cover types with an accuracy of slightly less than 90 percent (Figure 11). In this case, forest was misclassified as corn and forage (Table 7). This would indicate that forest bears some resemblance to corn and forage in the infrared channels, resulting in confusion when the visible is not included to aid distinction. In all cases, however, there occurred at least some confusion between forest and the agricultural cover types.

A few of these misclassifications were valid. That is, grassy clearings in some of the forested test areas were often classified as forage, which indeed they were. For the most part, however, these misclassifications could probably be attributed to the fact that the highly illuminated sides of tree crowns had spectral responses very similar to those of agricultural cover types.

With combined forest broken down into its two component categories, the classification results were more variable (Figures 12 and 13). A major source of error in all cases was that of deciduous being misclassified as conifer. In several cases, confusion between deciduous and the various agricultural cover types was also significant.

Tables 5-11 and Figure 12 list and illustrate the results for the deciduous forest class. When all channels were considered (Table 5), the largest single source of error was that of deciduous being misclassified as conifer in addition to some confusion with the three agricultual cover types. While the visible channels alone separated combined forest from other cover types with an accuracy of 92 percent (Figure 11), they did a very poor job of differentiating between deciduous and coniferous forest (Table 6, Figure 12). This confusion would be expected by anyone who has ever attempted to differentiate between deciduous and coniferous forest on either panchromatic or normal color photography. In general, conifers have a somewhat lower reflectance than deciduous trees in the visible wavelengths. However, the conifer stands present in Segment 218 were eastern white pine, which has a higher reflectance than most conifers. In fact, the coniferous forest training class actually exhibited a slightly higher mean reflectance than deciduous in the visible channels (Figure 3). These data support the statement that the difference between the deciduous and coniferous forest present in this segment was minimal in the visible portion of the spectrum.

Also, based on the visible wavelengths, a significant number of deciduous forest data points in the test areas were misclassified as water (Table 6). Figure 3 illustrates the spectral similarity between deciduous forest and water, in the visible wavebands, thus explaining the reason for this confusion.

The five infrared channels alone provided much improved separation between deciduous and coniferous forest (Table 7, Figures 12 and 13). Figure 3 illustrates the lower mean reflectance of conifer in the near and middle infrared, particularly in Channels 9 and 10. There was much confusion, however, between deciduous forest and two of the agricultural cover types, corn and forage.

Accuracy did not decrease, when the near infrared was deleted from consideration, (Table 8, Figure 12), nor did it suffer when middle infrared was deleted from consideration (Table 9). However, when both near and middle infrared were deleted so that only the visible and the thermal infrared were considered, recognition accuracies for deciduous forest dropped considerably (Table 10, Figure 12). Combined forest was still classified quite well when both the near and middle infrared were deleted from consideration (Figure 11), but there was considerable confusion between deciduous and coniferous forest, and some confusion between deciduous and soybeans. Apparently the near infrared and the middle infrared regions serve the same function. Thus, while it is not necessary for both regions to be present, one of the two appears necessary for reliable forest cover mapping.

The results of the classification from which the thermal infrared was deleted (Table 11, Figure 12) show good separation between deciduous and conifer, as well as good separation between combined forest (Figure 11) and other cover types. The only problem appears to be some confusion between deciduous and forage (Table 11). This confusion might perhaps be explained by the differences in relative depth of the two canopies; that is, the deciduous forest presents a very deep canopy, perhaps 30-50 feet, while forage has a depth of only a few inches. These differences in relative depth would undoubtedly result in different thermal characteristics for the two cover types. If, in some instances, the only significant differences between two cover types were thermal-related, the presence of the thermal channel would be critical.

The principal source of error in the coniferous forest category (Figure 13) was that of conifers being misclassified as deciduous. The only case where conifer was misclassified to any significant degree as something other than deciduous forest was where only the visible channels were used (Table 6). Here, there was some confusion between coniferous forest and water. The spectral similarities of coniferous forest and water in the visible channels are illustrated by Figure 3. For the most part, however, coniferous forest was highly separable (Figure 13).

In all but two cases, water easily separated from other cover types with a very high degree of accuracy (Figure 14). One exception was the case in which only visible channels were considered (Table 6). Here a considerable number of test points were misclassified as deciduous forest and forage. Researchers at LARS have previously noted and documented the similarities in the visible wavelengths between water, particularly turbid water, and many vegetative cover types (Figure 3). Thus, without the infrared channels present, confusion may be expected to result. The second instance of poor classification for the water category occurred where both the near and the middle infrared were deleted, indicating that, of the three infrared regions, these two are the most important for classifying water. This is borne out by the excellent results obtained when the thermal infrared channel was deleted from consideration (Table 11, Figure 14). This deletion caused no reduction in classification accuracy for water. It is interesting to note that in the channel number study discussed earlier, the best single channel selected was Channel 10, in the middle infrared. This channel alone classified water with an accuracy in excess of 96 percent (Table 2, Appendix B). This is explained by the fact that in this particular wavelength band as in the others constituting the near and middle infrared regions, water has a substantially lower response than most other natural cover types (Figure 3).

Forage was used as a "catch-all" agricultural category, and consisted of pasture, hay, and stubble. As might be expected, it had an extremely wide spectral variance (Figure 3) and for the most part, gave a low classification accuracy relative to the other categories (Figure 15). In all cases the primary source of confusion occurred between forage and row crops. The only exception was when only infrared channels were considered (Table 7). In that case, a few forage test points were misclassified as deciduous forest. For the most part, however, confusion between the forest categories and forage was relatively insignificant. It is of importance to note that forage was the only category whose classification accuracy was substantially reduced by the deletion of the thermal channel (Table 11).

This confusion, allowed by the absence of the thermal infrared, concerned corn and soybeans. The row crop canopy, being deeper and more vigorous, was more influenced by the cooling effects of transpiration than the less vigorous and constantly trampled pasture fields, periodically mowed hay fields, and harvested stubble fields constituting the forage class (Figure 3). The absence of the thermal infrared channel, then, would be expected to result in a certain amount of confusion.

As with forage, there was little confusion between the row crop categories (corn and soybeans) and the forest categories. Misclassification, for the most part, consisted of confusion between the three agricultural cover types, i.e. forage, corn and soybeans (Tables 5-11, Figures 15-17). This confusion did not affect, and in fact, was of little interest to the objectives of this study.

To summarize, it would appear that, for forest cover mapping, the various spectral regions do differ significantly in relative value. The visible channels alone seem to do a good job of separating combined forest from other cover types, but are inadequate as far as differentiating between deciduous and coniferous forest. The infrared channels alone, on the other hand, seem to perform well in differentiating between deciduous and coniferous forest, but are not as satisfactory as the visible for separating forest in general, and deciduous in particular, from other, nonforest, cover types. The logical conclusion, then, would be that both the visible and the infrared channels are necessary for accurate basic forest cover mapping. When either the near or the middle infrared are deleted individually, accuracies remain high, but when both are deleted at the same time, accuracy drops considerably. On the other hand, when the thermal infrared is deleted, the drop in accuracy is slight. This would indicate that of the infrared wavelengths, the reflective infrared (near and middle infrared) is the most important, and that only one of the two reflective infrared wavelength regions is really necessary to obtain good results. This conclusion seems to be supported by the results thus far obtained in the analysis of ERTS multispectral scanner data, which is recorded in two visible and two near infrared channels. The information contained in these four channels seems to be sufficient for accurate basic forest cover mapping (Landgrebe et al. 1972).

This is not to say, however, that the thermal region is unimportant. It is interesting, and of some significance, to note that the separability processor always selected at least one channel from each of the spectral regions which it was allowed to consider. For instance, when it was allowed to consider all twelve channels, i.e. all four spectral regions, it selected two visible, one near infrared, one middle infrared, and the thermal infrared channel. Likewise, in all other cases, it selected at least one channel from each of the available spectral regions. This would indicate that in general, all four regions are important, even though their relative values may vary.

A second set of twelve-channel MSS data, acquired the same day over similar cover types near the Ohio River, was analyzed in the same manner as Segment 218. While the classification accuracies deviated from those described above, the trends were similar,and tended to substantiate the above stated conclusions.

MSS-Digitized CIR Comparison

The results of the comparisons between MSS data and digitized color infrared photography are listed and illustrated in Tables 12-15 and Figures 18, 19 and 27. The three MSS data channels used in this comparison were those which most closely approximated the wavelength bands of the color infrared photos (Figure 7). In general, the digitized photography compared poorly, especially where the perpoint classifications were concerned (Tables 12 and 13 and Figure 18). The greatest discrepancy in classification accuracy between the two sets of data occurred in the forest categories, particularly deciduous forest.

In the MSS data, the primary source of confusion for deciduous forest was with coniferous forest, and vise versa (Table 12). In fact, a mathematical combination of the two forest classes revealed a classification accuracy for combined forest of 93.6 percent with only three channels. The remaining classes, with the exception of forage which was badly confused with row crops, were

Table 12. Perpoint classification results: multispectral scanner data using three channels corresponding to color infrared film bands.

SERIAL NUMBER------- 1215206803 CLASSIFIED- DEC 15,1972

CHANNELS USED

CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 7	SPECTRAL BAND	0.61 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 8	SPECTRAL BAND	0.72 TO 0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	83.9	27061	3133	4	433	161	1460
2	CONIFER	88	89.8	9	79	0	0	0	0
3	WATER	339	96.2	1	9	326	1	2	0
4	FORAGE	11760	64.1	5	10	12	7533	2405	1795
5	CORN	2679	97.5	0	2	0	17	2613	47
6	SOY	2676	92.5	43	0	0	44	114	2475
	TOTAL	49794		27119	3233	342	8028	5295	5777

OVERALL PERFORMANCE(40087/ 49794) = 80.5

AVERAGE PERFORMANCE BY CLASS(523.9/ 6) = 87.3

Table 13. Perpoint classification results: digitized color infrared photography using all three channels.

SERIAL NUMBER------- 1130206803 CLASSIFIED- NOV 30,1972

CHANNELS USED

CHANNEL 1	SPECTRAL BAND	0.47 TO 0.61 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 2	SPECTRAL BAND	0.59 TO 0.71 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND	0.68 TO 0.89 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	34970	36.1	12607	7367	700	951	10389	2956
2	CONIFER	127	63.8	33	81	5	0	7	1
3	WATER	461	97.6	0	7	450	4	0	0
4	FORAGE	11985	68.2	345	601	27	8172	1957	883
5	CORN	2018	75.6	301	133	0	43	1525	16
6	SOY	1758	87.1	83	7	0	31	106	1531
	TOTAL	51319		13369	8196	1182	9201	13984	5387

OVERALL PERFORMANCE(24366/ 51319) = 47.5

AVERAGE PERFORMANCE BY CLASS(428.3/ 6) = 71.4

Table 14. Perfield classification results: multispectral scanner data using three channels corresponding to color infrared film bands.

PERFORMANCE SUMMARY

	CLASS	NO OF FLDS	PCT FLD CORRECT	NO OF SAMS	PCT SAM CORRECT	NUMBER OF FIELDS CLASSIFIED AS DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	46	100.0	32252	100.0	46	0	0	0	0	0
2	CONIFER	4	100.0	88	100.0	0	4	0	0	0	0
3	WATER	15	100.0	339	100.0	0	0	15	0	0	0
4	FORAGE	80	57.5	11760	63.4	0	0	0	46	27	7
5	CORN	10	100.0	2679	100.0	0	0	0	0	10	0
6	SOY	24	95.8	2676	97.9	0	0	0	0	1	23
	TOTALS	179	80.4	49794	91.2	46	4	15	46	38	30

Table 15. Perfield classification results: digitized color infrared photography using all three channels.

PERFORMANCE SUMMARY

	CLASS	NO OF FLDS	PCT FLD CORRECT	NO OF SAMS	PCT SAM CORRECT	NUMBER OF FIELDS CLASSIFIED AS DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	45	84.4	134849	84.4	38	1	0	0	6	0
2	CONIFER	4	75.0	418	82.1	1	3	0	0	0	0
3	WATER	15	100.0	1489	100.0	0	0	15	0	0	0
4	FORAGE	73	78.1	44173	68.1	1	1	0	57	13	1
5	CORN	5	80.0	7741	91.4	1	0	0	0	4	0
6	SOY	16	87.5	6322	94.0	0	0	0	1	1	14
	TOTALS	158	82.9	194992	81.4	41	5	15	58	24	15

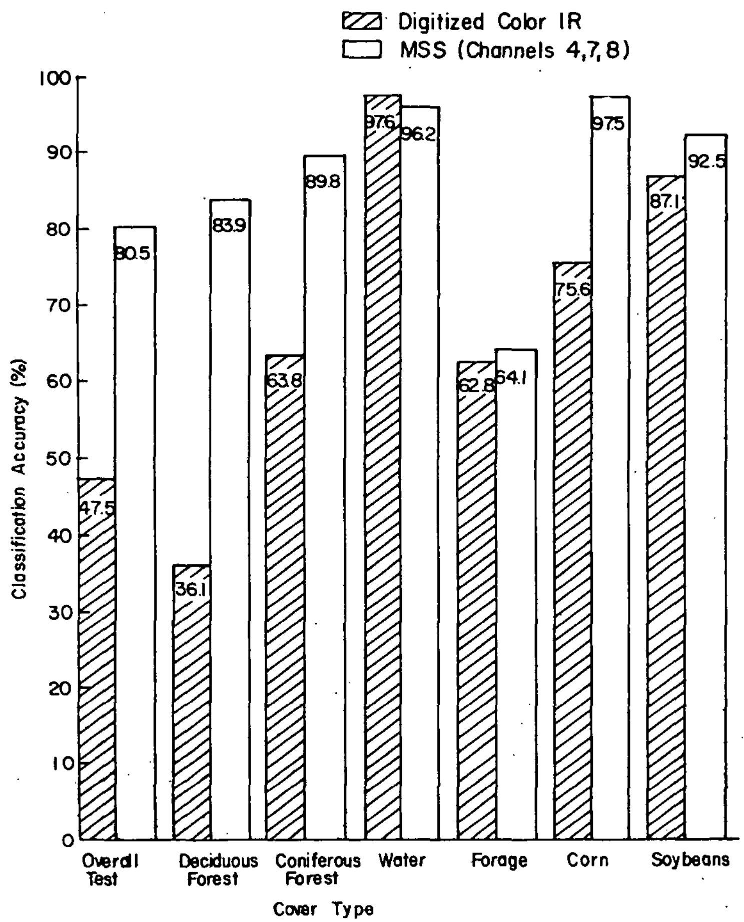


Figure 18. Perpoint classification results: digitized color infrared photography vs. 3-channel MSS data.

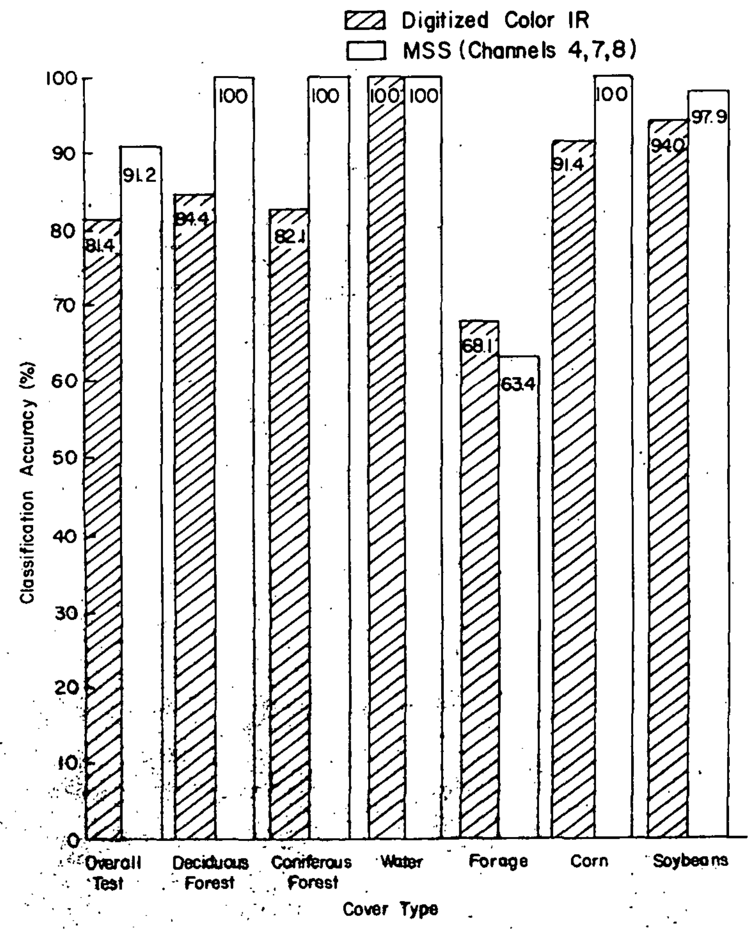


Figure 19. Perfield classification results: digitized color infrared photography vs. 3-channel MSS data.

classified with accuracies approaching those produced by the best combination of five channels (Table 3).

The perpoint classification results produced by the digitized photography, however, were decidedly poorer (Table 13, Figure 18), with the predominant deciduous forest class showing the poorest results of all. Even when the two forest classes were combined, the classification accuracy for general forest was only 57.2 percent.

While confusion between the two forest classes was significant the prime source of confusion was with row crops, especially corn (Table 13). Figure 4 illustrates the similarities between deciduous forest and corn. A comparison of Figures 25 and 27 (northern portion of Segment 218) shows a large forested area almost totally misclassified as corn. An examination of the photography from which the digitized data was obtained revealed uneven illumination across the frame (a combination of vignetting and anti-solar point). Figures 21 and 25 are of a rather limited area, but a close examination shows the western or left side of the northern portion to be somewhat more highly illuminated than the remainder. While the difference is slight, it was apparently enough to cause almost total misclassification of the deciduous forest in that area.

Because the areas used for training were copied from those used with the MSS data, this area of higher illumination was not represented in the training deck, hence, the poor results were probably due, at least in part, to inadequate training for the digitized photographic data. What was sufficient for the MSS data was apparently inadequate for the digitized color infrared photography. Since the plan of analysis did not call for alteration of the training deck for the benefit of the digitized photography, however, the inadequacy of the training deck cannot be substantiated.

An examination of Figure 4, reveals the apparent lack of spectral contrast between the training classes in Channels 1 and 2 of the digitized photography (with the exception of forage). Only in Channel 3 do there appear to be any significant spectral differences, and even there the forest classes show much similarity. The MSS data, on the other hand, (Figure 3) exhibits much more contrast in the three corresponding channels (four:0.52-0.57 μm, seven:0.61-0.70 μm, and eight:0.72-0.92 μm). In all three MSS channels, the two forest classes appear to have a significantly lower response than the three agricultural classes (Figures 3, 20, and 22) with water plainly separable in Channel 8 (Figure 3). In general, then, according to the relative differences shown on the cospectral plots of Figures 3 and 4, the digitized photography has a narrower dynamic range with less contrast between the training classes. The fact that there is greater contrast between general forest and other cover classes in the MSS data than in the digitized photography is evident in Figures 24 and 25.

Another problem may be the limited number of channels available. The spectral region evaluation study, based on various five-channel combinations, concluded that the visible and near-infrared portions of the spectrum should be adequate for accurate forest cover mapping. However, when these two regions were represented by only three channels, (MSS Channels 4, 7, and 8 for purposes of the comparison between the digitized photographic data and the MSS data), the results did not reflect those obtained with the use of five channels. Of further note is the channel number study in which the feature selection processor selected the "best" three-channel combination from the visible, middle infrared, and thermal infrared and still fell short of 90 percent overall classification accuracy (Table 2, Figure 5). Since the number of channels used in a classification determines the number of dimensions, in space, in which decision boundaries are established by the classification algorithm, one might conclude that three dimensions or channels are simply not enough, especially when those channels which are available are limited to the visible and the near infrared portions of the spectrum.

The discrepancies in classification accuracies between the two data sets are less in the perfield classification results (Tables 14 and 15, Figure 19) than in the perpoint results. In addition, for the most part, the perfield classification results are substantially higher, with the exception of forage which actually decreased slightly where the MSS data was concerned. Several classes (including both forest classes) were classified with an accuracy of 100 percent, in the MSS imagery.

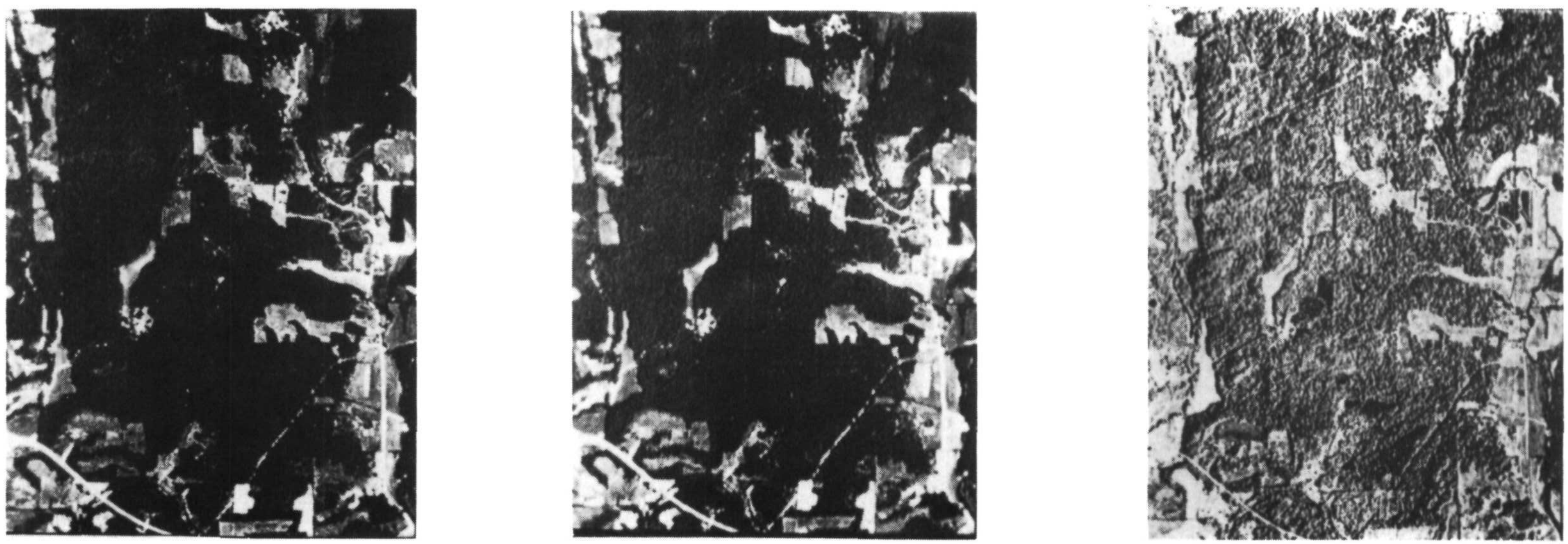
Past work at LARS has indicated that accuracies almost always tend to be higher with the perfield classifier. By looking at the test field as a whole, dissimilar individual data points are averaged in with all the other points in the test field. While they have an influence on both the mean and standard deviation of the test field, such dissimilar points are not classified individually based on their own spectral characteristics, but rather with the remainder of the test field as one decision. In effect, then, the perfield classifier considers spatial as well as spectral information. This is a basic and extremely important aspect of this classifier.

Despite the appearance of tendencies and trends, the validity of comparing these two types of data (digitized photography and MSS) is somewhat questionable. While the two types of data may be processed to the same format, amenable to the same analysis techniques, their acquisition is by entirely different means; the scanner being electronic in nature, while the photographic emulsion is chemical.

Both good and poor results have been reported concerning the automatic analysis of digitized multiemulsion photography. While the results of this study are inconclusive, suffice it to say that automatic analysis of photographic data should be approached with extreme caution. Though photography is cheaper and easier to acquire than scanner data, and is easily interpreted manually, the narrower dynamic range, the illumination problems within this photographic data set, and the fact that the data was limited to only three channels, (and hence only three dimensions in the classifier) seem to pose serious limitations to its analysis by the ADP techniques utilized in this study. The qualitative nature of the photographic emulsion simply does not lend itself to reliable quantitative analysis.

Channel 4 (0.52-0.57μm) Channel 7 (0.61-0.70μm) Channel 8 (0.72-0.92μm)

Figure 20. Digital display images of the northern portion of Seg. 218: MSS Channels 4, 7, and 8.



Channel 1 (0.47-0.61μm) Channel 2 (0.59-0.71μm) Channel 3 (0.68-0.89μm)

Figure 21. Digital display images of the northern portion of Seg. 218: digitized color infrared photo, Channels 1, 2, and 3.

Channel 4 (0.52-0.57μm) Channel 7 (0.61-0.70μm) Channel 8 (0.72-0.92μm)

Figure 22. Digital display images of the southern portion of Seg. 218: MSS Channels 4, 7, and 8.

Channel 1 (0.47–0.61μm) Channel 2 (0.59–0.71μm) Channel 3 (0.68–0.89μm)

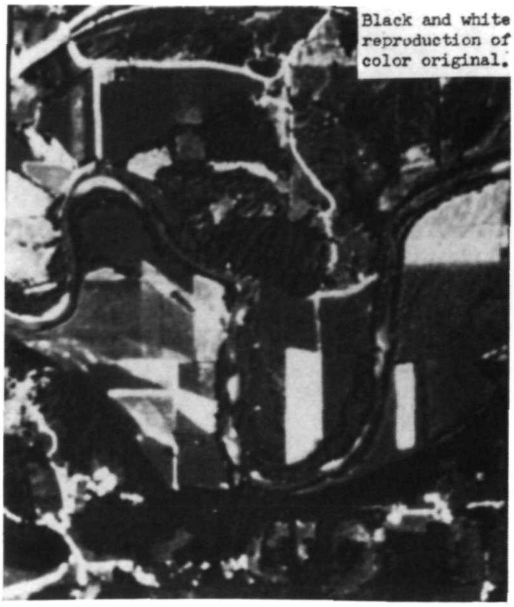
Figure 23. Digital display images of the southern portion of Seg. 218: digitized color infrared photo, Channels 1, 2, and 3.

Northern portion of
Seg. 218

Southern portion of
Seg. 218

Figure 24. Color infrared reconstitution of Seg. 218 using MSS data, Channels 4, 7, and 8.

Northern portion of
Seg. 218



Southern portion of
Seg. 218

Figure 25. Color infrared reconstitution of Seg. 218 using digitized color infrared photographic data, Channels 1, 2, and 3.

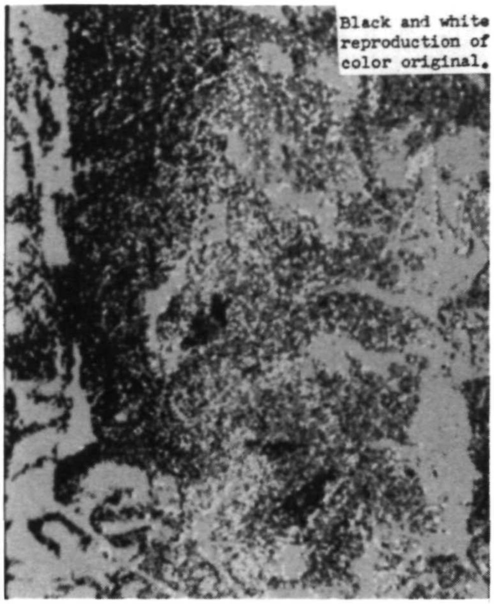
Northern portion of
Seg. 218

Southern portion of
Seg. 218

LEGEND

deciduous forest......green
coniferous forest.....black
water.................blue
forage................yellow
corn..................red
soybeans..............magenta

Figure 26. Classification results for MSS data: best combination of five channels (4, 6, 9, 10, and 12).



Northern portion of
Seg. 218

Southern portion of
Seg. 218

LEGEND

deciduous forest.....green
coniferous forest....black
water................blue
forage...............yellow
corn.................red
soybeans.............magenta

Figure 27. Classification results for digitized color infrared photographic data, using all three channels.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Channel Number Study

For the purposes of this project, the use of five channels seemed to provide the best compromise between classification accuracy and computer time (Figure 5). This conclusion, however, was developed without a cost-benefit analysis. Different circumstances and additional input might well result in a different conclusion.

Forest Mapping Capability

The capability exists to reliably map forest cover using multispectral scanner data and automatic data processing techniques. The use of five of the available twelve scanner channels differentiated forest from other cover types with an accuracy in excess of 95 percent (Table 2, Figure 6). In addition, the classifier algorithm was able to differentiate between deciduous and coniferous forest with accuracies well in excess of 90 percent (Tables 2 and 3, Figure 6). The use of all of the available twelve channels elicited only a slight increase in overall accuracy (Tables 2 and 4, Figure 7).

Spectral Region Evaluation

Results from two sets of data indicate that all four spectral regions (visible, near infrared, middle infrared, and thermal infrared) are valuable in forest cover mapping. Accurate results appear attainable, however, with the visible and either the near or the middle infrared. The visible alone seems to do a good job of separating general forest from other cover classes, but a poor job of differentiating between deciduous and coniferous forest. The near and middle infrared, on the other hand, are quite adequate for separating the two forest classes from each other, but leave some confusion between deciduous forest and other classes of vegetation. Accurate forest cover mapping results appear attainable when the visible is combined with either the near or the middle infrared. This conclusion compares favorably with early results of forest cover mapping using ERTS-1 data. The thermal infrared appears to be desirable, but not necessary for reliable forest cover mapping. As this study, as well as previous investigations have indicated, however, the thermal infrared is very useful in differentiating many non-forest cover types.

MSS-Digitized CIR Comparison

The results obtained in this study indicate the inadequacy of digitized color infrared photography in the area of forest cover mapping with ADP techniques. While the photography was easily interpreted manually, it had several characteristics which severely limited its analysis, in a digital format, by ADP techniques. The narrower dynamic range tended to limit contrast between training classes, and the illumination problems in the original exposure caused considerable confusion. While both the visible and the near infrared portions of the spectrum were present in the digitized photographic data, the fact that these spectral regions were divided into only three rather broad channels (Figure 7), may have been partly responsible for the poor results.

Recommendations

It is recognized that the results obtained in this research cover a somewhat limited set of circumstances. The data was all obtained the same day, over the same geographic area, under similar atmospheric conditions, and without variation in the configuration of the instrumentation used. Given a different set of circumstances and objectives, the conclusions might differ from those obtained in this study. In view of these limitations, the following areas are recommended for expanded study:

1. Determine basic forest cover mapping capability with ERTS data for various geographic areas and seasons.

2. Determine the utility of the various spectral regions for other objectives (agriculture, geology, land use, hydrology, etc.) during the various seasons.

3. Evaluate, in detail, the various wavelength bands within the four spectral regions.

4. Evaluate the effects of the digitization rate of photographic data on its performance for forest cover mapping with automatic data processing techniques.

5. Evaluate temporal changes in the spectral characteristics of forest species from data acquired at various altitudes.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. American Society of Photogrammetry. 1960. Manual of Photographic Interpretation. George Banta, Co., Menasha, Wisconsin. pp. 99-105.

2. American Society of Photogrammetry. 1968. Manual of Color Aerial Photography. George Banta Co., Menasha, Wisconsin. pp. 205-206.

3. Anuta, P.E., S.J. Kristof, D.W. Levandowski, R.B. MacDonald, and T.L. Phillips. 1971. "Crop, Soil, and Geological Mapping from Digitized Multispectral Satellite Photography." Proceedings of the Seventh International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor. pp. 1983-2016.

4. Cardillo, G.P. and D. Landgrebe. 1966. "On Pattern Recognition." LARS Information Note 101866. Laboratory for Applications of Remote Sensing, Purdue University. 18 pp.

5. Eastman Kodak Company. 1970. "Kodak Aerochrome Infrared Film 2443 (Estar Base) and Kodak Aerochrome Infrared Film 3443 (Estar Thin Base)." Eastman Kodak Company. Rochester, N.Y. 5 pp.

6. Glazebrook, T.B. 1973. Personal correspondence with Mr. T.B. Glazebrook, Director of Watershed Management, U.S.D.A., Forest Service, Washington, D.C.

7. Hoffer, R.M., C.J. Johannsen, and M.F. Baumgardner. 1966. "Agricultural Applications of Remote Multispectral Sensing." Proceedings of the Indiana Academy of Science, Vol. 73:386-395.

8. Hoffer, R.M., R.A. Holmes, and J.R. Shay. 1966. "Vegetative, Soil, and Photographic Factors Affecting Tone in Agricultural Remote Multispectral Sensing." Proceedings of the Fourth Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor. pp. 115-134.

9. Hoffer, R.M. 1971. "Remote Sensing -- A Tool for Resource Management." Proceedings of the Third International Symposium of Hydrology Professors. Purdue University, Lafayette, Indiana. (In Press).

10. Hoffer, R.M. 1972. "ADP of Multispectral Scanner Data for Land Use Mapping." Second UNESCO/International Geographical Union Symposium on Geographical Information Systems, Ottawa, Canada, and LARS Information Note 080372. Laboratory for Applications of Remote Sensing, Purdue University. 25 pp.

11. Hoffer, R.M., P.E. Anuta, and T.L. Phillips. 1972. "ADP, Multiband, and Multiemulsion Digitized Photos." Photogrammetric Engineering. 38(10):989-1001.

12. Landgrebe, D.A. and T.L. Phillips. 1967. "A Multi-channel Image Data Handling System for Agricultural Remote Sensing." Proceedings of the Computerized Imaging Techniques Seminar, sponsored by the Society of Photo-optical Instrumentation Engineers, Washington, D.C. 13 pp.

13. Landgrebe, D.A., R.M. Hoffer, F.E. Goodrick, and Staff. 1972. "An Early Analysis of ERTS-1 Data." LARS Information Note 092972. Laboratory for Applications of Remote Sensing, Purdue University. 21 pp.

14. Langley, P.G., R.C. Aldrich, and R.C. Heller. 1969. "Multi-Stage Sampling of Forest Resources by Using Space Photography . . . An Apollo 9 Case Study." Proceedings of the Second Annual Earth Resources Aircraft Program Status Review, NASA Manned Spacecraft Center, Houston, Texas. Vol. II, Sec. 19:1-21.

15. Schneider, A.F. 1966. "Physiography." From Natural Features of Indiana. Indiana Academy of Science. pp. 40-56.

16. Smedes, H.W., K.L. Pierce, M.C. Tanguay, and R.M. Hoffer. 1970. "Digital Computer Terrain Mapping from Multispectral Data." Journal of Spacecraft and Rockets. Vol. 7:1025-1031.

APPENDICES

APPENDIX A

Table 1A

Training and test fields used for analysis of multispectral scanner data: Run 71052501.

Table 1A

SAVED TRAINING FIELDS

	RUN NUMBER	FIELD DESIG.	FIRST LINE	LAST LINE	LINE INT.	FIRST COLUMN	LAST COLUMN	COLUMN INT.	FIELD TYPE	OTHER INFORMATION	CLASSIFY CLASS
1	71052501	TRN519	519	525	1	26	32	1	DECID	FOREST	DECID
2	71052501	TRN173	173	188	1	186	192	1	DECID	FOREST	DECID
3	71052501	TRN46	46	49	1	67	70	1	CONIFER	FOREST	CONIFER
4	71052501	TRN48	48	48	1	76	78	1	CONIFER	FOREST	CONIFER
5	71052501	TRN52	52	53	1	66	67	1	CONIFER	FOREST	CONIFER
6	71052501	TRN55	55	55	1	73	77	1	CONIFER	FOREST	CONIFER
7	71052501	TRN68	68	72	1	52	52	1	CONIFER	FOREST	CONIFER
8	71052501	TRN333	333	339	1	83	88	1	CONIFER	FOREST	CONIFER
9	71052501	TRN396	396	399	1	109	126	1	CONIFER	FOREST	CONIFER
10	71052501	TRN1217	1217	1219	1	75	80	1	RIVER	WATER	WATER
11	71052501	TRN1174	1174	1174	1	197	202	1	RIVER	WATER	WATER
12	71052501	TRN1216	1216	1217	1	68	73	1	RIVER	WATER	WATER
13	71052501	TRN1239	1239	1245	1	77	80	1	RIVER	WATER	WATER
14	71052501	TRN1273	1273	1282	1	74	76	1	RIVER	WATER	WATER
15	71052501	TRN1290	1290	1294	1	82	85	1	RIVER	WATER	WATER
16	71052501	TRN1291	1291	1293	1	140	143	1	RIVER	WATER	WATER
17	71052501	TRN877	877	879	1	41	45	1	POND	WATER	WATER
18	71052501	TRN1175	1175	1175	1	11	20	1	RIVER	WATER	WATER
19	71052501	TRN1184	1184	1185	1	30	32	1	RIVER	WATER	WATER
20	71052501	TRN146	146	148	1	108	112	1	POND	WATER	WATER
21	71052501	TRN151	151	155	1	113	119	1	POND	WATER	WATER
22	71052501	TRN155	155	159	1	120	129	1	POND	WATER	WATER
23	71052501	TRN155	155	156	1	23	24	1	POND	WATER	WATER
24	71052501	TRN227	227	228	1	52	53	1	POND	WATER	WATER
25	71052501	TRN337	337	338	1	108	111	1	POND	WATER	WATER
26	71052501	TRN831	831	834	1	11	14	1	POND	WATER	WATER
27	71052501	TRN843	843	846	1	4	8	1	POND	WATER	WATER
28	71052501	TRN847	847	849	1	2	5	1	POND	WATER	WATER
29	71052501	TRN506	506	510	1	73	86	1	PASTURE	FORAGE	FORAGE
30	71052501	TRN650	650	654	1	48	56	1	PASTURE	FORAGE	FORAGE
31	71052501	TRN335	335	339	1	197	204	1	PASTURE	FORAGE	FORAGE
32	71052501	TRN564	564	574	1	205	217	1	PASTURE	FORAGE	FORAGE
33	71052501	TRN405	405	419	1	211	215	1	PASTURE	FORAGE	FORAGE
34	71052501	TRN32	32	35	1	50	57	1	PASTURE	FORAGE	FORAGE
35	71052501	TRN56	56	67	1	188	195	1	PASTURE	FORAGE	FORAGE
36	71052501	TRN196	196	204	1	180	192	1	PASTURE	FORAGE	FORAGE
37	71052501	TRN1143	1143	1152	1	47	58	1	HAY	FORAGE	FORAGE
38	71052501	TRN1449	1449	1452	1	127	142	1	HAY	FORAGE	FORAGE
39	71052501	TRN853	853	859	1	144	171	1	HAY	FORAGE	FORAGE
40	71052501	TRN817	817	825	1	100	118	1	HAY	FORAGE	FORAGE
41	71052501	TRN1275	1275	1284	1	109	125	1	STUBBLE	FORAGE	FORAGE
42	71052501	TRN105	105	111	1	189	197	1	STUBBLE	FORAGE	FORAGE
43	71052501	TRN115	115	127	1	187	193	1	STUBBLE	FORAGE	FORAGE
44	71052501	TRN1202	1202	1209	1	184	208	1	STUBBLE	FORAGE	FORAGE
45	71052501	TRN1189	1189	1193	1	184	208	1	STUBBLE	FORAGE	FORAGE
46	71052501	TRN678	678	681	1	173	185	1	STUBBLE	FORAGE	FORAGE
47	71052501	TRN1250	1250	1257	1	93	100	1	CORN	ROW	CORN
48	71052501	TRN1275	1275	1282	1	93	100	1	CORN	ROW	CORN
49	71052501	TRN1403	1403	1412	1	194	213	1	CORN	ROW	CORN
50	71052501	TRN1492	1492	1506	1	33	42	1	CORN	ROW	CORN
51	71052501	TRN1481	1481	1485	1	33	42	1	CORN	ROW	CORN
52	71052501	TRN1487	1487	1512	1	49	51	1	CORN	ROW	CORN
53	71052501	TRN661	661	670	1	174	181	1	CORN	ROW	CORN
54	71052501	TRN681	681	685	1	137	143	1	CORN	ROW	CORN
55	71052501	TRN683	683	685	1	153	167	1	CORN	ROW	CORN
56	71052501	TRN698	698	703	1	141	143	1	CORN	ROW	CORN

Table 1A, cont.

57	71052501	TRN1253	1253	1274	1	129	135	1	SOY	ROW	SOY
58	71052501	TRN1191	1191	1193	1	43	46	1	SOY	ROW	SOY
59	71052501	TRN1473	1473	1479	1	78	90	1	SOY	ROW	SOY
60	71052501	TRN1027	1027	1031	1	5	25	1	SOY	ROW	SOY
61	71052501	TRN1045	1045	1048	1	124	128	1	SOY	ROW	SOY
62	71052501	TRN498	498	500	1	99	117	1	SOY	ROW	SOY

SAVED TEST FIELDS

	RUN NUMBER	FIELD DESIG.	FIRST LINE	LAST LINE	LINE INT.	FIRST COLUMN	LAST COLUMN	COLUMN INT.	FIELD TYPE	OTHER INFORMATION	DISPLAY CLASS
1	71052501	TEST1	1	25	1	61	157	1	DECID	FOREST	DECID
2	71052501	TEST43	43	51	1	122	156	1	DECID	FOREST	DECID
3	71052501	TEST48	48	88	1	161	179	1	DECID	FOREST	DECID
4	71052501	TEST72	72	83	1	113	137	1	DECID	FOREST	DECID
5	71052501	TEST77	77	107	1	1	22	1	DECID	FOREST	DECID
6	71052501	TEST88	88	110	1	107	138	1	DECID	FOREST	DECID
7	71052501	TEST91	91	122	1	160	178	1	DECID	FOREST	DECID
8	71052501	TEST98	98	134	1	73	93	1	DECID	FOREST	DECID
9	71052501	TEST123	123	144	1	115	128	1	DECID	FOREST	DECID
10	71052501	TEST149	149	158	1	59	103	1	DECID	FOREST	DECID
11	71052501	TEST116	116	161	1	6	19	1	DECID	FOREST	DECID
12	71052501	TEST150	150	190	1	212	222	1	DECID	FOREST	DECID
13	71052501	TEST191	191	209	1	123	160	1	DECID	FOREST	DECID
14	71052501	TEST220	220	261	1	200	222	1	DECID	FOREST	DECID
15	71052501	TEST245	245	286	1	140	155	1	DECID	FOREST	DECID
16	71052501	TEST246	246	262	1	177	200	1	DECID	FOREST	DECID
17	71052501	TEST256	256	295	1	43	54	1	DECID	FOREST	DECID
18	71052501	TEST297	297	316	1	25	64	1	DECID	FOREST	DECID
19	71052501	TEST312	312	325	1	120	184	1	DECID	FOREST	DECID
20	71052501	TEST317	317	361	1	19	40	1	DECID	FOREST	DECID
21	71052501	TEST342	342	366	1	93	133	1	DECID	FOREST	DECID
22	71052501	TEST339	339	352	1	166	192	1	DECID	FOREST	DECID
23	71052501	TEST386	386	403	1	42	58	1	DECID	FOREST	DECID
24	71052501	TEST386	386	404	1	60	68	1	DECID	FOREST	DECID
25	71052501	TEST371	371	390	1	115	188	1	DECID	FOREST	DECID
26	71052501	TEST390	390	402	1	145	172	1	DECID	FOREST	DECID
27	71052501	TEST408	408	429	1	160	183	1	DECID	FOREST	DECID
28	71052501	TEST437	437	446	1	149	153	1	DECID	FOREST	DECID
29	71052501	TEST431	431	455	1	141	148	1	DECID	FOREST	DECID
30	71052501	TEST464	464	491	1	199	210	1	DECID	FOREST	DECID
31	71052501	TEST508	508	526	1	99	126	1	DECID	FOREST	DECID
32	71052501	TEST466	466	475	1	1	27	1	DECID	FOREST	DECID
33	71052501	TEST519	519	540	1	33	40	1	DECID	FOREST	DECID
34	71052501	TEST575	575	578	1	177	181	1	DECID	FOREST	DECID
35	71052501	TEST575	575	602	1	161	176	1	DECID	FOREST	DECID
36	71052501	TEST631	631	647	1	190	222	1	DECID	FOREST	DECID
37	71052501	TEST635	635	649	1	58	73	1	DECID	FOREST	DECID
38	71052501	TEST657	657	677	1	107	126	1	DECID	FOREST	DECID
39	71052501	TEST785	785	826	1	136	203	1	DECID	FOREST	DECID
40	71052501	TEST814	814	854	1	31	51	1	DECID	FOREST	DECID
41	71052501	TEST858	858	870	1	180	222	1	DECID	FOREST	DECID
42	71052501	TEST935	935	974	1	46	111	1	DECID	FOREST	DECID
43	71052501	TEST1007	1007	1066	1	183	211	1	DECID	FOREST	DECID
44	71052501	TEST1079	1079	1098	1	99	130	1	DECID	FOREST	DECID
45	71052501	TEST1197	1197	1218	1	94	115	1	DECID	FOREST	DECID
46	71052501	TEST1354	1354	1369	1	189	222	1	DECID	FOREST	DECID
47	71052501	TEST344	344	348	1	74	77	1	CONIFER	FOREST	CONIFER
48	71052501	TEST409	409	411	1	145	150	1	CONIFER	FOREST	CONIFER
49	71052501	TEST413	413	420	1	141	144	1	CONIFER	FOREST	CONIFER
50	71052501	TEST512	512	514	1	144	149	1	CONIFER	FOREST	CONIFER

Table 1A, cont.

51	71052501	TEST294	294	295	1	158	159	1	POND	WATER	WATER
52	71052501	TEST834	834	837	1	4	10	1	POND	WATER	WATER
53	71052501	TEST1214	1214	1227	1	7	7	1	RIVER	WATER	WATER
54	71052501	TEST1219	1219	1230	1	83	86	1	RIVER	WATER	WATER
55	71052501	TEST1191	1191	1192	1	164	167	1	RIVER	WATER	WATER
56	71052501	TEST1195	1195	1200	1	161	162	1	RIVER	WATER	WATER
57	71052501	TEST1224	1224	1238	1	161	164	1	RIVER	WATER	WATER
58	71052501	TEST1213	1213	1214	1	58	63	1	RIVER	WATER	WATER
59	71052501	TEST1252	1252	1259	1	80	82	1	RIVER	WATER	WATER
60	71052501	TEST1261	1261	1267	1	157	159	1	RIVER	WATER	WATER
61	71052501	TEST1279	1279	1282	1	153	155	1	RIVER	WATER	WATER
62	71052501	TEST1285	1285	1287	1	149	150	1	RIVER	WATER	WATER
63	71052501	TEST1297	1297	1299	1	121	126	1	RIVER	WATER	WATER
64	71052501	TEST1206	1206	1215	1	163	166	1	RIVER	WATER	WATER
65	71052501	TEST1216	1216	1223	1	162	165	1	RIVER	WATER	WATER
66	71052501	TEST10	10	15	1	23	30	1	PASTURE	FORAGE	FORAGE
67	71052501	TEST135	135	140	1	163	174	1	PASTURE	FORAGE	FORAGE
68	71052501	TEST141	141	144	1	153	164	1	PASTURE	FORAGE	FORAGE
69	71052501	TEST121	121	142	1	215	222	1	PASTURE	FORAGE	FORAGE
70	71052501	TEST164	164	169	1	179	184	1	PASTURE	FORAGE	FORAGE
71	71052501	TEST182	182	187	1	115	135	1	PASTURE	FORAGE	FORAGE
72	71052501	TEST205	205	211	1	2	7	1	PASTURE	FORAGE	FORAGE
73	71052501	TEST216	216	219	1	128	134	1	PASTURE	FORAGE	FORAGE
74	71052501	TEST235	235	241	1	157	164	1	PASTURE	FORAGE	FORAGE
75	71052501	TEST230	230	237	1	122	133	1	PASTURE	FORAGE	FORAGE
76	71052501	TEST291	291	296	1	140	149	1	PASTURE	FORAGE	FORAGE
77	71052501	TEST288	288	297	1	124	132	1	PASTURE	FORAGE	FORAGE
78	71052501	TEST300	300	308	1	153	157	1	PASTURE	FORAGE	FORAGE
79	71052501	TEST272	272	280	1	211	222	1	PASTURE	FORAGE	FORAGE
80	71052501	TEST350	350	357	1	145	160	1	PASTURE	FORAGE	FORAGE
81	71052501	TEST330	330	337	1	47	51	1	PASTURE	FORAGE	FORAGE
82	71052501	TEST382	382	399	1	197	208	1	PASTURE	FORAGE	FORAGE
83	71052501	TEST420	420	431	1	208	215	1	PASTURE	FORAGE	FORAGE
84	71052501	TEST408	408	417	1	51	58	1	PASTURE	FORAGE	FORAGE
85	71052501	TEST426	426	429	1	27	35	1	PASTURE	FORAGE	FORAGE
86	71052501	TEST458	458	467	1	113	119	1	PASTURE	FORAGE	FORAGE
87	71052501	TEST463	463	469	1	175	182	1	PASTURE	FORAGE	FORAGE
88	71052501	TEST471	471	483	1	173	184	1	PASTURE	FORAGE	FORAGE
89	71052501	TEST486	486	496	1	151	159	1	PASTURE	FORAGE	FORAGE
90	71052501	TEST475	475	495	1	56	67	1	PASTURE	FORAGE	FORAGE
91	71052501	TEST499	499	508	1	23	28	1	PASTURE	FORAGE	FORAGE
92	71052501	TEST499	499	509	1	42	52	1	PASTURE	FORAGE	FORAGE
93	71052501	TEST491	491	501	1	76	94	1	PASTURE	FORAGE	FORAGE
94	71052501	TEST532	532	550	1	88	102	1	PASTURE	FORAGE	FORAGE
95	71052501	TEST543	543	551	1	127	140	1	PASTURE	FORAGE	FORAGE
96	71052501	TEST564	564	570	1	127	165	1	PASTURE	FORAGE	FORAGE
97	71052501	TEST582	582	591	1	206	222	1	PASTURE	FORAGE	FORAGE
98	71052501	TEST572	572	580	1	48	55	1	PASTURE	FORAGE	FORAGE
99	71052501	TEST559	559	565	1	24	35	1	PASTURE	FORAGE	FORAGE
100	71052501	TEST619	619	628	1	84	99	1	PASTURE	FORAGE	FORAGE
101	71052501	TEST634	634	647	1	137	147	1	PASTURE	FORAGE	FORAGE
102	71052501	TEST649	649	663	1	133	169	1	PASTURE	FORAGE	FORAGE
103	71052501	TEST649	649	655	1	195	210	1	PASTURE	FORAGE	FORAGE
104	71052501	TEST693	693	704	1	115	125	1	PASTURE	FORAGE	FORAGE
105	71052501	TEST700	700	703	1	178	203	1	PASTURE	FORAGE	FORAGE
106	71052501	TEST881	881	888	1	106	132	1	PASTURE	FORAGE	FORAGE
107	71052501	TEST908	908	916	1	29	39	1	PASTURE	FORAGE	FORAGE
108	71052501	TEST969	969	976	1	153	172	1	PASTURE	FORAGE	FORAGE
109	71052501	TEST954	954	968	1	169	181	1	PASTURE	FORAGE	FORAGE
110	71052501	TEST985	985	990	1	106	130	1	PASTURE	FORAGE	FORAGE
111	71052501	TEST1021	1021	1039	1	32	41	1	PASTURE	FORAGE	FORAGE
112	71052501	TEST1089	1089	1098	1	59	83	1	PASTURE	FORAGE	FORAGE

Table 1A, cont.

113	71052501	TEST1075	1075	1084	1	146	163	1	PASTURE	FORAGE	FORAGE
114	71052501	TEST1123	1123	1129	1	117	133	1	PASTURE	FORAGE	FORAGE
115	71052501	TEST1131	1131	1140	1	123	147	1	PASTURE	FORAGE	FORAGE
116	71052501	TEST1162	1162	1175	1	166	181	1	PASTURE	FORAGE	FORAGE
117	71052501	TEST1196	1196	1206	1	134	146	1	PASTURE	FORAGE	FORAGE
118	71052501	TEST1179	1179	1186	1	85	102	1	PASTURE	FORAGE	FORAGE
119	71052501	TEST1343	1343	1356	1	50	59	1	PASTURE	FORAGE	FORAGE
120	71052501	TEST1313	1313	1317	1	164	180	1	PASTURE	FORAGE	FORAGE
121	71052501	TEST1360	1360	1384	1	166	180	1	PASTURE	FORAGE	FORAGE
122	71052501	TEST1390	1390	1400	1	184	222	1	PASTURE	FORAGE	FORAGE
123	71052501	TEST1482	1482	1489	1	149	210	1	PASTURE	FORAGE	FORAGE
124	71052501	TEST1131	1131	1142	1	47	58	1	HAY	FORAGE	FORAGE
125	71052501	TEST1403	1403	1416	1	130	150	1	HAY	FORAGE	FORAGE
126	71052501	TEST1499	1499	1517	1	161	174	1	HAY	FORAGE	FORAGE
127	71052501	TEST1510	1510	1516	1	133	148	1	HAY	FORAGE	FORAGE
128	71052501	TEST1496	1496	1501	1	107	126	1	HAY	FORAGE	FORAGE
129	71052501	TEST1474	1474	1483	1	1	10	1	HAY	FORAGE	FORAGE
130	71052501	TEST94	94	99	1	185	192	1	STUBBLE	FORAGE	FORAGE
131	71052501	TEST164	164	173	1	170	176	1	STUBBLE	FORAGE	FORAGE
132	71052501	TEST293	293	302	1	213	215	1	STUBBLE	FORAGE	FORAGE
133	71052501	TEST440	440	451	1	122	131	1	STUBBLE	FORAGE	FORAGE
134	71052501	TEST447	447	462	1	167	172	1	STUBBLE	FORAGE	FORAGE
135	71052501	TEST529	529	532	1	108	120	1	STUBBLE	FORAGE	FORAGE
136	71052501	TEST689	689	704	1	110	113	1	STUBBLE	FORAGE	FORAGE
137	71052501	TEST696	696	703	1	88	93	1	STUBBLE	FORAGE	FORAGE
138	71052501	TEST725	725	733	1	22	32	1	STUBBLE	FORAGE	FORAGE
139	71052501	TEST1016	1016	1021	1	60	79	1	STUBBLE	FORAGE	FORAGE
140	71052501	TEST1221	1221	1252	1	61	69	1	STUBBLE	FORAGE	FORAGE
141	71052501	TEST1402	1402	1415	1	176	189	1	STUBBLE	FORAGE	FORAGE
142	71052501	TEST1455	1455	1464	1	118	131	1	STUBBLE	FORAGE	FORAGE
143	71052501	TEST1062	1062	1068	1	156	172	1	STUBBLE	FORAGE	FORAGE
144	71052501	TEST1252	1252	1274	1	109	125	1	STUBBLE	FORAGE	FORAGE
145	71052501	TEST1199	1199	1209	1	173	183	1	STUBBLE	FORAGE	FORAGE
146	71052501	TEST650	650	660	1	174	181	1	CORN	ROW	CORN
147	71052501	TEST698	698	700	1	154	169	1	CORN	ROW	CORN
148	71052501	TEST707	707	714	1	134	146	1	CORN	ROW	CORN
149	71052501	TEST924	924	934	1	159	169	1	CORN	ROW	CORN
150	71052501	TEST1212	1212	1248	1	172	193	1	CORN	ROW	CORN
151	71052501	TEST1417	1417	1438	1	157	167	1	CORN	ROW	CORN
152	71052501	TEST1482	1482	1512	1	52	82	1	CORN	ROW	CORN
153	71052501	TEST1482	1482	1492	1	85	103	1	CORN	ROW	CORN
154	71052501	TEST1503	1503	1512	1	152	157	1	CORN	ROW	CORN
155	71052501	TEST1510	1510	1513	1	196	203	1	CORN	ROW	CORN
156	71052501	TEST294	294	318	1	218	222	1	SOY	ROW	SOY
157	71052501	TEST706	706	711	1	190	194	1	SOY	ROW	SOY
158	71052501	TEST921	921	926	1	109	124	1	SOY	ROW	SOY
159	71052501	TEST1057	1057	1059	1	139	157	1	SOY	ROW	SOY
160	71052501	TEST1101	1101	1112	1	158	171	1	SOY	ROW	SOY
161	71052501	TEST1144	1144	1161	1	1	3	1	SOY	ROW	SOY
162	71052501	TEST1175	1175	1179	1	30	33	1	SOY	ROW	SOY
163	71052501	TEST1186	1186	1189	1	39	42	1	SOY	ROW	SOY
164	71052501	TEST1220	1220	1222	1	11	30	1	SOY	ROW	SOY
165	71052501	TEST1215	1215	1218	1	46	51	1	SOY	ROW	SOY
166	71052501	TEST1192	1192	1196	1	13	26	1	SOY	ROW	SOY
167	71052501	TEST1258	1258	1264	1	17	29	1	SOY	ROW	SOY
168	71052501	TEST1420	1420	1442	1	129	140	1	SOY	ROW	SOY
169	71052501	TEST1420	1420	1429	1	143	152	1	SOY	ROW	SOY
170	71052501	TEST1431	1431	1443	1	143	150	1	SOY	ROW	SOY
171	71052501	TEST1466	1466	1478	1	33	45	1	SOY	ROW	SOY
172	71052501	TEST1477	1477	1479	1	49	76	1	SOY	ROW	SOY
173	71052501	TEST1508	1508	1514	1	107	122	1	SOY	ROW	SOY
174	71052501	TEST1537	1537	1544	1	162	180	1	SOY	ROW	SOY

Table 1A, cont.

175	71052501	TEST1137	1137	1155	1	17	42	1	SOY	ROW	SOY
176	71052501	TEST1131	1131	1136	1	32	43	1	SOY	ROW	SOY
177	71052501	TEST1156	1156	1165	1	17	23	1	SOY	ROW	SOY
178	71052501	TEST1140	1140	1165	1	10	12	1	SOY	ROW	SOY
179	71052501	TEST1198	1198	1208	1	15	28	1	SOY	ROW	SOY

Table 2A

Training and test fields used for analysis of digitized color infrared photography: Run 71056903.

Table 2A

SAVED TRAINING FIELDS

	RUN NUMBER	FIELD DESIG.	FIRST LINE	LAST LINE	LINE INT.	FIRST COLUMN	LAST COLUMN	COLUMN INT.	FIELD TYPE	OTHER INFORMATION	CLASSIFY CLASS
1	71056903	TRN 1712	1712	1744	1	337	349	1	DECID	FOREST	DECID
2	71056903	TRN 2506	2506	2520	1	91	105	1	DECID	FOREST	DECID
3	71056903	TRN 1428	1428	1434	1	135	141	1	CONIFER	FOREST	CONIFER
4	71056903	TRN 1430	1430	1430	1	153	151	1	CONIFER	FOREST	CONIFER
5	71056903	TRN 1442	1442	1446	1	135	137	1	CONIFER	FOREST	CONIFER
6	71056903	TRN 1450	1450	1450	1	147	157	1	CONIFER	FOREST	CONIFER
7	71056903	TRN 1480	1480	1490	1	119	121	1	CONIFER	FOREST	CONIFER
8	71056903	TRN 2076	2076	2086	1	183	197	1	CONIFER	FOREST	CONIFER
9	71056903	TRN 2208	2208	2212	1	229	251	1	CONIFER	FOREST	CONIFER
10	71056903	TRN 1676	1676	1678	1	63	69	1	POND	WATER	WATER
11	71056903	TRN 1660	1660	1664	1	205	217	1	POND	WATER	WATER
12	71056903	TRN 1666	1666	1674	1	211	221	1	POND	WATER	WATER
13	71056903	TRN 1674	1674	1684	1	223	237	1	POND	WATER	WATER
14	71056903	TRN 2080	2080	2082	1	225	231	1	POND	WATER	WATER
15	71056903	TRN 1840	1840	1842	1	121	123	1	POND	WATER	WATER
16	71056903	TRN 3172	3172	3178	1	69	77	1	POND	WATER	WATER
17	71056903	TRN 3196	3196	3202	1	51	59	1	POND	WATER	WATER
18	71056903	TRN 3206	3206	3214	1	45	51	1	POND	WATER	WATER
19	71056903	TRN 3276	3276	3276	1	127	135	1	POND	WATER	WATER
20	71056903	TRN 3942	3942	3942	1	77	89	1	RIVER	WATER	WATER
21	71056903	TRN 3964	3964	3968	1	117	123	1	RIVER	WATER	WATER
22	71056903	TRN 4028	4028	4030	1	173	183	1	RIVER	WATER	WATER
23	71056903	TRN 4035	4036	4038	1	197	209	1	RIVER	WATER	WATER
24	71056903	TRN 4074	4074	4092	1	197	203	1	RIVER	WATER	WATER
25	71056903	TRN 4160	4160	4178	1	195	197	1	RIVER	WATER	WATER
26	71056903	TRN 4202	4202	4208	1	207	215	1	RIVER	WATER	WATER
27	71056903	TRN 4194	4194	4200	1	305	313	1	RIVER	WATER	WATER
28	71056903	TRN 3940	3940	3940	1	409	425	1	RIVER	WATER	WATER
29	71056903	TRN 1404	1404	1410	1	111	121	1	PASTURE	FORAGE	FORAGE
30	71056903	TRN 1462	1462	1478	1	331	347	1	PASTURE	FORAGE	FORAGE
31	71056903	TRN 1765	1766	1782	1	327	349	1	PASTURE	FORAGE	FORAGE
32	71056903	TRN 1792	1792	1810	1	1	25	1	PASTURE	FORAGE	FORAGE
33	71056903	TRN 2064	2064	2076	1	371	391	1	PASTURE	FORAGE	FORAGE
34	71056903	TRN 2228	2228	2258	1	417	425	1	PASTURE	FORAGE	FORAGE
35	71056903	TRN 2578	2578	2604	1	413	443	1	PASTURE	FORAGE	FORAGE
36	71056903	TRN 2774	2774	2788	1	147	161	1	PASTURE	FORAGE	FORAGE
37	71056903	TRN 2460	2460	2468	1	187	209	1	PASTURE	FORAGE	FORAGE
38	71056903	TRN 3150	3150	3164	1	223	259	1	HAY	FORAGE	FORAGE
39	71056903	TRN 3222	3222	3234	1	297	343	1	HAY	FORAGE	FORAGE
40	71056903	TRN 3888	3888	3906	1	115	137	1	HAY	FORAGE	FORAGE
41	71056903	TRN 1564	1564	1578	1	333	347	1	STUBBLE	FORAGE	FORAGE
42	71056903	TRN 1584	1584	1604	1	329	345	1	STUBBLE	FORAGE	FORAGE
43	71056903	TRN 2840	2840	2846	1	347	371	1	STUBBLE	FORAGE	FORAGE
44	71056903	TRN 3966	3966	3974	1	385	439	1	STUBBLE	FORAGE	FORAGE
45	71056903	TRN 4002	4002	4014	1	385	435	1	STUBBLE	FORAGE	FORAGE
46	71056903	TRN 4162	4162	4180	1	251	275	1	STUBBLE	FORAGE	FORAGE
47	71056903	TRN 2800	2800	2822	1	349	361	1	CORN	ROW	CORN
48	71056903	TRN 2844	2844	2858	1	285	301	1	CORN	ROW	CORN
49	71056903	TRN 2852	2852	2858	1	313	339	1	CORN	ROW	CORN
50	71056903	TRN 2886	2886	2900	1	293	299	1	CORN	ROW	CORN
51	71056903	TRN 4102	4102	4122	1	219	237	1	CORN	ROW	CORN
52	71056903	TRN 4172	4172	4188	1	221	239	1	CORN	ROW	CORN
53	71056903	TRN 4446	4446	4468	1	401	443	1	CORN	ROW	CORN
54	71056903	TRN 2438	2438	2444	1	225	259	1	SOY	ROW	SOY
55	71056903	TRN 3624	3624	3632	1	59	107	1	SOY	ROW	SOY
56	71056903	TRN 3660	3660	3668	1	273	285	1	SOY	ROW	SOY
57	71056903	TRN 3978	3978	3982	1	141	149	1	SOY	ROW	SOY
58	71056903	TRN 4106	4106	4160	1	281	293	1	SOY	ROW	SOY

Table 2A, cont.

SAVED TEST FIELDS

	RUN NUMBER	FIELD DESIG.	FIRST LINE	LAST LINE	LINE INT.	FIRST COLUMN	LAST COLUMN	COLUMN INT.	FIELD TYPE	OTHER INFORMATION	DISPLAY CLASS
1	71056903	TEST1334	1334	1386	1	125	273	1	DECID	FOREST	DECID
2	71056903	TEST1422	1422	1440	1	213	269	1	DECID	FOREST	DECID
3	71056903	TEST1434	1434	1528	1	277	307	1	DECID	FOREST	DECID
4	71056903	TEST1502	1502	1570	1	1	57	1	DECID	FOREST	DECID
5	71056903	TEST1586	1586	1696	1	17	51	1	DECID	FOREST	DECID
6	71056903	TEST1484	1484	1526	1	199	245	1	DECID	FOREST	DECID
7	71056903	TEST1542	1542	1620	1	145	179	1	DECID	FOREST	DECID
8	71056903	TEST1532	1532	1576	1	197	249	1	DECID	FOREST	DECID
9	71056903	TEST1532	1532	1596	1	261	309	1	DECID	FOREST	DECID
10	71056903	TEST1594	1594	1646	1	221	241	1	DECID	FOREST	DECID
11	71056903	TEST1668	1668	1688	1	115	197	1	DECID	FOREST	DECID
12	71056903	TEST1658	1658	1754	1	385	425	1	DECID	FOREST	DECID
13	71056903	TEST1750	1750	1796	1	215	297	1	DECID	FOREST	DECID
14	71056903	TEST1886	1886	1986	1	95	123	1	DECID	FOREST	DECID
15	71056903	TEST1988	1988	2036	1	81	157	1	DECID	FOREST	DECID
16	71056903	TEST2038	2038	2134	1	71	119	1	DECID	FOREST	DECID
17	71056903	TEST1872	1872	1958	1	269	291	1	DECID	FOREST	DECID
18	71056903	TEST1862	1862	1902	1	325	379	1	DECID	FOREST	DECID
19	71056903	TEST1876	1876	1902	1	381	419	1	DECID	FOREST	DECID
20	71056903	TEST2016	2016	2050	1	241	345	1	DECID	FOREST	DECID
21	71056903	TEST2090	2090	2144	1	201	267	1	DECID	FOREST	DECID
22	71056903	TEST2076	2076	2108	1	313	353	1	DECID	FOREST	DECID
23	71056903	TEST2148	2148	2192	1	235	361	1	DECID	FOREST	DECID
24	71056903	TEST2178	2178	2226	1	111	169	1	DECID	FOREST	DECID
25	71056903	TEST2194	2194	2214	1	275	327	1	DECID	FOREST	DECID
26	71056903	TEST2222	2222	2276	1	321	361	1	DECID	FOREST	DECID
27	71056903	TEST2274	2274	2338	1	283	303	1	DECID	FOREST	DECID
28	71056903	TEST2290	2290	2312	1	305	307	1	DECID	FOREST	DECID
29	71056903	TEST2372	2372	2394	1	17	95	1	DECID	FOREST	DECID
30	71056903	TEST2348	2348	2418	1	393	419	1	DECID	FOREST	DECID
31	71056903	TEST2464	2464	2500	1	225	271	1	DECID	FOREST	DECID
32	71056903	TEST2506	2506	2560	1	107	123	1	DECID	FOREST	DECID
33	71056903	TEST2604	2604	2686	1	335	365	1	DECID	FOREST	DECID
34	71056903	TEST2732	2732	2772	1	165	193	1	DECID	FOREST	DECID
35	71056903	TEST2730	2730	2770	1	379	443	1	DECID	FOREST	DECID
36	71056903	TEST2790	2790	2836	1	239	271	1	DECID	FOREST	DECID
37	71056903	TEST3086	3086	3168	1	283	405	1	DECID	FOREST	DECID
38	71056903	TEST3128	3128	3230	1	107	147	1	DECID	FOREST	DECID
39	71056903	TEST3228	3228	3262	1	361	443	1	DECID	FOREST	DECID
40	71056903	TEST3408	3408	3502	1	139	249	1	DECID	FOREST	DECID
41	71056903	TEST3578	3578	3708	1	369	425	1	DECID	FOREST	DECID
42	71056903	TEST3734	3734	3774	1	233	287	1	DECID	FOREST	DECID
43	71056903	TEST3988	3988	4034	1	219	267	1	DECID	FOREST	DECID
44	71056903	TEST4344	4344	4378	1	387	443	1	DECID	FOREST	DECID
45	71056903	TEST2604	2604	2616	1	367	377	1	DECID	FOREST	DECID
46	71056903	TEST2096	2096	2106	1	173	181	1	CONIFER	FOREST	CONIFER
47	71056903	TEST2232	2232	2236	1	291	301	1	CONIFER	FOREST	CONIFER
48	71056903	TEST2238	2238	2258	1	277	285	1	CONIFER	FOREST	CONIFER
49	71056903	TEST2468	2468	2472	1	297	311	1	CONIFER	FOREST	CONIFER
50	71056903	TEST1978	1978	1980	1	291	295	1	POND	WATER	WATER
51	71056903	TEST3180	3180	3190	1	59	69	1	POND	WATER	WATER
52	71056903	TEST4026	4026	4066	1	59	61	1	RIVER	WATER	WATER
53	71056903	TEST4020	4020	4022	1	159	169	1	RIVER	WATER	WATER
54	71056903	TEST4038	4038	4056	1	209	217	1	RIVER	WATER	WATER
55	71056903	TEST4104	4104	4122	1	203	207	1	RIVER	WATER	WATER
56	71056903	TEST4216	4216	4222	1	263	273	1	RIVER	WATER	WATER
57	71056903	TEST4170	4170	4178	1	319	325	1	RIVER	WATER	WATER
58	71056903	TEST4158	4158	4168	1	325	329	1	RIVER	WATER	WATER
59	71056903	TEST4120	4120	4142	1	329	335	1	RIVER	WATER	WATER
60	71056903	TEST4064	4064	4080	1	331	339	1	RIVER	WATER	WATER
61	71056903	TEST4036	4036	4062	1	337	341	1	RIVER	WATER	WATER
62	71056903	TEST4008	4008	4026	1	339	345	1	RIVER	WATER	WATER
63	71056903	TEST3986	3986	3998	1	335	341	1	RIVER	WATER	WATER
64	71056903	TEST3976	3976	3982	1	341	349	1	RIVER	WATER	WATER

Table 2A, cont.

65	71056903	TEST1348	1348	1362	1	59	75	1	PASTURE	FORAGE	FORAGE
66	71056903	TEST1584	1584	1636	1	391	405	1	PASTURE	FORAGE	FORAGE
67	71056903	TEST1626	1626	1638	1	291	315	1	PASTURE	FORAGE	FORAGE
68	71056903	TEST1642	1642	1650	1	279	297	1	PASTURE	FORAGE	FORAGE
69	71056903	TEST1736	1736	1744	1	209	251	1	PASTURE	FORAGE	FORAGE
70	71056903	TEST1810	1810	1816	1	235	249	1	PASTURE	FORAGE	FORAGE
71	71056903	TEST1842	1842	1858	1	231	253	1	PASTURE	FORAGE	FORAGE
72	71056903	TEST1850	1850	1864	1	283	303	1	PASTURE	FORAGE	FORAGE
73	71056903	TEST1922	1922	1940	1	395	429	1	PASTURE	FORAGE	FORAGE
74	71056903	TEST1960	1960	1986	1	241	253	1	PASTURE	FORAGE	FORAGE
75	71056903	TEST1972	1972	1982	1	267	283	1	PASTURE	FORAGE	FORAGE
76	71056903	TEST1992	1992	2006	1	267	235	1	PASTURE	FORAGE	FORAGE
77	71056903	TEST2064	2064	2082	1	125	137	1	PASTURE	FORAGE	FORAGE
78	71056903	TEST2106	2106	2118	1	279	309	1	PASTURE	FORAGE	FORAGE
79	71056903	TEST2238	2238	2256	1	137	151	1	PASTURE	FORAGE	FORAGE
80	71056903	TEST2172	2172	2216	1	375	413	1	PASTURE	FORAGE	FORAGE
81	71056903	TEST2262	2262	2290	1	405	419	1	PASTURE	FORAGE	FORAGE
82	71056903	TEST2280	2280	2288	1	89	103	1	PASTURE	FORAGE	FORAGE
83	71056903	TEST2344	2344	2364	1	241	255	1	PASTURE	FORAGE	FORAGE
84	71056903	TEST2346	2346	2364	1	343	363	1	PASTURE	FORAGE	FORAGE
85	71056903	TEST2368	2368	2404	1	335	359	1	PASTURE	FORAGE	FORAGE
86	71056903	TEST2386	2386	2432	1	157	175	1	PASTURE	FORAGE	FORAGE
87	71056903	TEST2444	2444	2466	1	95	113	1	PASTURE	FORAGE	FORAGE
88	71056903	TEST2444	2444	2466	1	137	153	1	PASTURE	FORAGE	FORAGE
89	71056903	TEST2422	2422	2448	1	181	217	1	PASTURE	FORAGE	FORAGE
90	71056903	TEST2405	2406	2430	1	305	323	1	PASTURE	FORAGE	FORAGE
91	71056903	TEST2506	2506	2554	1	223	239	1	PASTURE	FORAGE	FORAGE
92	71056903	TEST2538	2538	2554	1	273	293	1	PASTURE	FORAGE	FORAGE
93	71056903	TEST2575	2576	2590	1	103	129	1	PASTURE	FORAGE	FORAGE
94	71056903	TEST2602	2602	2620	1	147	161	1	PASTURE	FORAGE	FORAGE
95	71056903	TEST2584	2584	2596	1	275	341	1	PASTURE	FORAGE	FORAGE
96	71056903	TEST2626	2626	2642	1	409	443	1	PASTURE	FORAGE	FORAGE
97	71056903	TEST2706	2706	2730	1	207	231	1	PASTURE	FORAGE	FORAGE
98	71056903	TEST2740	2740	2768	1	283	305	1	PASTURE	FORAGE	FORAGE
99	71056903	TEST2770	2770	2806	1	279	341	1	PASTURE	FORAGE	FORAGE
100	71056903	TEST2772	2772	2780	1	385	425	1	PASTURE	FORAGE	FORAGE
101	71056903	TEST2874	2874	2904	1	253	269	1	PASTURE	FORAGE	FORAGE
102	71056903	TEST2890	2890	2900	1	355	409	1	PASTURE	FORAGE	FORAGE
103	71056903	TEST3290	3290	3304	1	237	281	1	PASTURE	FORAGE	FORAGE
104	71056903	TEST3350	3350	3366	1	109	133	1	PASTURE	FORAGE	FORAGE
105	71056903	TEST3448	3448	3484	1	339	367	1	PASTURE	FORAGE	FORAGE
106	71056903	TEST3486	3486	3498	1	315	353	1	PASTURE	FORAGE	FORAGE
107	71056903	TEST3530	3530	3544	1	233	275	1	PASTURE	FORAGE	FORAGE
108	71056903	TEST3608	3608	3648	1	119	135	1	PASTURE	FORAGE	FORAGE
109	71056903	TEST3728	3728	3748	1	307	349	1	PASTURE	FORAGE	FORAGE
110	71056903	TEST3754	3754	3774	1	167	207	1	PASTURE	FORAGE	FORAGE
111	71056903	TEST3832	3832	3846	1	249	289	1	PASTURE	FORAGE	FORAGE
112	71056903	TEST3848	3848	3868	1	251	309	1	PASTURE	FORAGE	FORAGE
113	71056903	TEST3950	3950	3966	1	205	241	1	PASTURE	FORAGE	FORAGE
114	71056903	TEST3914	3914	3942	1	351	373	1	PASTURE	FORAGE	FORAGE
115	71056903	TEST3990	3990	4008	1	291	317	1	PASTURE	FORAGE	FORAGE
116	71056903	TEST4250	4250	4262	1	341	373	1	PASTURE	FORAGE	FORAGE
117	71056903	TEST4322	4322	4364	1	159	181	1	PASTURE	FORAGE	FORAGE
118	71056903	TEST4362	4362	4398	1	345	371	1	PASTURE	FORAGE	FORAGE
119	71056903	TEST4424	4424	4442	1	367	443	1	PASTURE	FORAGE	FORAGE
120	71056903	TEST1692	1692	1702	1	321	333	1	PASTURE	FORAGE	FORAGE
121	71056903	TEST3854	3854	3886	1	113	143	1	HAY	FORAGE	FORAGE
122	71056903	TEST4452	4452	4486	1	281	329	1	HAY	FORAGE	FORAGE
123	71056903	TEST1536	1536	1546	1	323	339	1	STUBBLE	FORAGE	FORAGE
124	71056903	TEST1690	1690	1714	1	305	317	1	STUBBLE	FORAGE	FORAGE
125	71056903	TEST1970	1970	1996	1	399	407	1	STUBBLE	FORAGE	FORAGE
126	71056903	TEST2302	2302	2328	1	253	263	1	STUBBLE	FORAGE	FORAGE
127	71056903	TEST2314	2314	2350	1	323	333	1	STUBBLE	FORAGE	FORAGE
128	71056903	TEST2506	2506	2514	1	245	251	1	STUBBLE	FORAGE	FORAGE
129	71056903	TEST2880	2880	2900	1	211	271	1	STUBBLE	FORAGE	FORAGE
130	71056903	TEST2860	2860	2904	1	245	251	1	STUBBLE	FORAGE	FORAGE

Table 2A, cont.

131	71056903	TEST2950	2950	2968	1	99	121	1	STUBBLE	FORAGE	FORAGE
132	71056903	TEST3596	3596	3606	1	167	207	1	STUBBLE	FORAGE	FORAGE
133	71056903	TEST3698	3698	3708	1	313	351	1	STUBBLE	FORAGE	FORAGE
134	71056903	TEST3990	3990	4016	1	355	383	1	STUBBLE	FORAGE	FORAGE
135	71056903	TEST4040	4040	4104	1	171	185	1	STUBBLE	FORAGE	FORAGE
136	71056903	TEST4104	4104	4160	1	251	275	1	STUBBLE	FORAGE	FORAGE
137	71056903	TEST4448	4448	4474	1	371	393	1	STUBBLE	FORAGE	FORAGE
138	71056903	TEST2772	2772	2798	1	349	361	1	CORN	ROW	CORN
139	71056903	TEST2886	2886	2890	1	313	339	1	CORN	ROW	CORN
140	71056903	TEST2906	2906	2928	1	283	305	1	CORN	ROW	CORN
141	71056903	TEST3386	3386	3414	1	319	341	1	CORN	ROW	CORN
142	71056903	TEST4022	4022	4104	1	355	427	1	CORN	ROW	CORN
143	71056903	TEST1970	1970	2022	1	413	423	1	SOY	ROW	SOY
144	71056903	TEST2904	2904	2920	1	375	389	1	SOY	ROW	SOY
145	71056903	TEST3380	3380	3396	1	233	261	1	SOY	ROW	SOY
146	71056903	TEST3690	3690	3694	1	283	329	1	SOY	ROW	SOY
147	71056903	TEST3784	3784	3808	1	327	349	1	SOY	ROW	SOY
148	71056903	TEST3880	3880	3912	1	45	55	1	SOY	ROW	SOY
149	71056903	TEST3874	3874	3912	1	67	73	1	SOY	ROW	SOY
150	71056903	TEST3868	3868	3916	1	83	111	1	SOY	ROW	SOY
151	71056903	TEST3918	3918	3926	1	85	101	1	SOY	ROW	SOY
152	71056903	TEST3940	3940	3952	1	113	123	1	SOY	ROW	SOY
153	71056903	TEST3970	3970	3976	1	137	143	1	SOY	ROW	SOY
154	71056903	TEST3978	3978	3988	1	75	113	1	SOY	ROW	SOY
155	71056903	TEST3992	3992	4006	1	75	121	1	SOY	ROW	SOY
156	71056903	TEST4038	4038	4042	1	71	111	1	SOY	ROW	SOY
157	71056903	TEST4024	4024	4034	1	143	155	1	SOY	ROW	SOY
158	71056903	TEST4124	4124	4134	1	87	113	1	SOY	ROW	SOY

APPENDIX B

Table 1B. Test class performance using best one channel.

CHANNELS USED

CHANNEL 10 SPECTRAL BAND 1.50 TO 1.80 MICROMETERS CALIBRATION CODE = 1 CO = 0.0

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	43.1	13890	5842	45	1	11777	697
2	CONIFER	88	84.1	12	74	1	0	1	0
3	WATER	339	95.9	8	6	325	0	0	0
4	FORAGE	11760	27.6	32	17	0	3241	1629	6841
5	CORN	2679	80.1	215	0	0	0	2147	317
6	SOY	2676	84.2	4	0	0	13	405	2254
	TOTAL	49794		14161	5939	371	3255	15959	10109

OVERALL PERFORMANCE(21931/ 49794) = 44.0

AVERAGE PERFORMANCE BY CLASS(415.0/ 6) = 69.2

Table 2B. Test class performance using best combination of two channels.

CHANNELS USED

CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	DECID	NUMBER OF SAMPLES CLASSIFIED INTO CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	87.1	28094	2005	10	271	386	1486
2	CONIFER	88	87.5	8	77	2	0	1	0
3	WATER	339	97.9	4	2	332	0	1	0
4	FORAGE	11760	55.9	16	9	9	6574	2402	2750
5	CORN	2679	88.1	2	2	0	0	2361	314
6	SOY	2676	98.2	8	0	0	13	27	2628
	TOTAL	49794		28132	2095	353	6858	5178	7178

OVERALL PERFORMANCE(40066/ 49794) = 80.5

AVERAGE PERFORMANCE BY CLASS(514.8/ 6) = 85.8

Table 3B. Test class performance using best combination of three channels.

CHANNELS USED

CHANNEL 6	SPECTRAL BAND 0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND 1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND 9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	88.8	28640	1700	0	573	292	1047
2	CONIFER	88	95.5	3	84	0	1	0	0
3	WATER	339	98.2	0	2	333	2	2	0
4	FORAGE	11760	80.6	17	6	5	9483	750	1499
5	CORN	2679	84.8	2	1	0	7	2272	397
6	SOY	2676	95.2	4	0	0	105	20	2547
	TOTAL	49794		28666	1793	338	10171	3336	5490

OVERALL PERFORMANCE(43359/ 49794) = 87.1

AVERAGE PERFORMANCE BY CLASS(543.1/ 6) = 90.5

Table 4B. Test class performance using best combination of four channels.

CHANNELS USED

CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND	9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	DECID	CONIFER	WATER	FORAGE	CORN	SOY
				NUMBER OF SAMPLES CLASSIFIED INTO					
1	DECID	32252	89.9	28987	1615	0	405	288	957
2	CONIFER	88	96.6	3	85	0	0	0	0
3	WATER	339	97.6	1	2	331	4	1	0
4	FORAGE	11760	84.8	20	3	2	9977	480	1278
5	CORN	2679	94.2	1	2	0	104	2524	48
6	SOY	2676	96.2	6	0	0	70	25	2575
	TOTAL	49794		29018	1707	333	10560	3318	4858

OVERALL PERFORMANCE(44479/ 49794) = 89.3

AVERAGE PERFORMANCE BY CLASS(559.4/ 6) = 93.2

Table 5B. Test class performance using best combination of five channels.

CHANNELS USED

CHANNEL 4	SPECTRAL BAND 0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND 0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND 1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND 1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND 9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	92.2	29745	1001	0	378	245	883
2	CONIFER	88	96.6	3	85	0	0	0	0
3	WATER	339	98.2	1	2	333	3	0	0
4	FORAGE	11760	85.5	22	7	2	10052	413	1264
5	CORN	2679	90.7	1	4	0	191	2431	52
6	SOY	2676	95.7	10	0	0	91	15	2560
	TOTAL	49794		29782	1099	335	10715	3104	4759

OVERALL PERFORMANCE(45206/ 49794) = 90.8

AVERAGE PERFORMANCE BY CLASS(558.9/ 6) = 93.2

Table 6B. Test class performance using best combination of six channels.

CHANNELS USED

CHANNEL 4	SPECTRAL BAND 0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND 0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND 1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND 1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND 2.00 TO 2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND 9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	95.0	30648	631	0	311	263	399
2	CONIFER	88	92.0	7	81	0	0	0	0
3	WATER	339	98.5	1	1	334	3	0	0
4	FORAGE	11760	83.8	29	3	2	9858	423	1445
5	CORN	2679	92.8	1	3	0	127	2487	61
6	SOY	2676	97.0	5	0	0	60	14	2597
	TOTAL	49794		30691	719	336	10359	3187	4502

OVERALL PERFORMANCE(46005/ 49794) = 92.4

AVERAGE PERFORMANCE BY CLASS(559.3/ 6) = 93.2

Table 7B. Test class performance using best combination of eight channels.

CHANNELS USED

CHANNEL 4	SPECTRAL BAND	0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND	0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 7	SPECTRAL BAND	0.61 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 8	SPECTRAL BAND	0.72 TO 0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND	1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND	1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND	2.00 TO 2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND	9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	96.2	31036	402	0	290	169	355
2	CONIFER	88	96.6	3	85	0	0	0	0
3	WATER	339	98.5	1	1	334	3	0	0
4	FORAGE	11760	85.8	53	6	2	10090	342	1267
5	CORN	2679	93.8	0	1	0	152	2512	14
6	SOY	2676	96.3	5	1	0	75	17	2578
	TOTAL	49794		31098	496	336	10610	3040	4214

OVERALL PERFORMANCE(46635/ 49794) = 93.7

AVERAGE PERFORMANCE BY CLASS(567.2/ 6) = 94.5

Table 8B. Test class performance using best combination of ten channels.

CHANNELS USED

CHANNEL 2	SPECTRAL BAND 0.48 TO 0.51 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND 0.50 TO 0.54 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND 0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 7	SPECTRAL BAND 0.61 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 8	SPECTRAL BAND 0.72 TO 0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND 1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND 1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND 2.00 TO 2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND 9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

				NUMBER OF SAMPLES CLASSIFIED INTO					
GROUP	NO OF SAMPS	PCT. CORCT	DECID	CONIFER	WATER	FORAGE	CORN	SOY
1 DECID	32252	97.0	31271	376	0	268	97	240
2 CONIFER	88	96.6	3	85	0	0	0	0
3 WATER	339	98.5	1	1	334	3	0	0
4 FORAGE	11760	87.8	45	6	2	10325	284	1098
5 CORN	2679	95.6	1	2	0	100	2561	15
6 SOY	2676	96.3	4	1	0	76	17	2578
TOTAL	49794		31325	471	336	10772	2959	3931

OVERALL PERFORMANCE(47154/ 49794) = 94.7

AVERAGE PERFORMANCE BY CLASS(571.8/ 6) = 95.3

Table 9B. Test class performance using all twelve channels.

CHANNELS USED

CHANNEL 1	SPECTRAL BAND 0.46 TO 0.49 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 2	SPECTRAL BAND 0.48 TO 0.51 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 3	SPECTRAL BAND 0.50 TO 0.54 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 4	SPECTRAL BAND 0.52 TO 0.57 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 5	SPECTRAL BAND 0.54 TO 0.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 6	SPECTRAL BAND 0.58 TO 0.65 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 7	SPECTRAL BAND 0.61 TO 0.70 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 8	SPECTRAL BAND 0.72 TO 0.92 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 9	SPECTRAL BAND 1.00 TO 1.40 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 10	SPECTRAL BAND 1.50 TO 1.80 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 11	SPECTRAL BAND 2.00 TO 2.60 MICROMETERS	CALIBRATION CODE = 1	CO = 0.0
CHANNEL 12	SPECTRAL BAND 9.30 TO 11.70 MICROMETERS	CALIBRATION CODE = 1	CO = 32.70

CLASSES

	CLASS		CLASS
1	DECID	4	FORAGE
2	CONIFER	5	CORN
3	WATER	6	SOY

TEST CLASS PERFORMANCE

	GROUP	NO OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO DECID	CONIFER	WATER	FORAGE	CORN	SOY
1	DECID	32252	97.2	31339	359	0	263	112	179
2	CONIFER	88	95.5	4	84	0	0	0	0
3	WATER	339	98.5	1	1	334	3	0	0
4	FORAGE	11760	88.6	39	5	1	10420	245	1050
5	CORN	2679	96.9	1	2	0	61	2597	18
6	SOY	2676	96.3	5	1	0	74	18	2578
	TOTAL	49794		31389	452	335	10821	2972	3825

OVERALL PERFORMANCE(47352/ 49794) = 95.1

AVERAGE PERFORMANCE BY CLASS(573.0/ 6) = 95.5

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

School of Agriculture
Purdue University

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

Basic Forest Cover Mapping using Digitized Remote Sensor Data and Automatic Data Processing Techniques

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

scientific report

5. AUTHOR(S) *(First name, middle initial, last name)*

Michael E. Coggeshall
Roger M. Hoffer

6. REPORT DATE

May 1973

7a. TOTAL NO. OF PAGES

131

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.

NASA Grant NGL 15-005-112

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

LARS Information Note 030573

10. DISTRIBUTION STATEMENT

unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

NASA

13. ABSTRACT

Remote sensing equipment and automatic data processing techniques offer much potential for the procurement of information necessary to meet the demand for more intensive management of our forest resources.

On the basis of automatically calculated statistics derived from manually-selected training samples, the feature selection processor of LARSYS was directed to select, upon consideration of various groups of the four available spectral regions, a series of "best" channel combinations whose automatic classification performances (for six cover types, including both deciduous and coniferous forest) were tested, analyzed and further compared with automatic classification results obtained from digitized color infrared photography.

Results indicated: 1) that the use of five, of the available 12, channels offers an acceptable compromise between classification accuracy and computer time; 2) that five channels (one each from the visible green and red, and the near, middle and thermal infrared) can classify basic forest cover with accuracies well in excess of 90 percent; 3) that a combination of the visible region plus either the near or middle infrared will provide sufficient spectral information for accurate basic forest cover mapping; and 4) that the qualitative nature of photographic data does not lend itself to reliable quantitative analysis.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

030573 Basic Forest Cover Mapping Using Digitized Remote Sensing Data and Automatic Data Processing Techniques. Michael E. Coggeshall and R. M. Hoffer. Remote sensing equipment and automatic data processing techniques offer much potential for the procurement of information necessary to meet the demand for more intensive management of our forest resources.

On the basis of automatically calculated statistics derived from manually selected "training" samples, the feature selection processor of LARSYS was directed to select, upon consideration of various groups of the four available spectral regions, a series of "best" channel combinations whose automatic classification performances (for six cover types, including both deciduous and coniferous forest) were tested, analyzed and further compared with automatic classification results obtained from digitized color infrared photography.

Results indicate: 1) that the use of five, of the available 12, channels offers an acceptable compromise between classification accuracy and computer time; 2) that five channels (one each from the visible green and red, and the near, middle and thermal infrared) can classify basic forest cover with accuracies well in excess of 90 percent; 3) that a combination of the visible region plus either the near or middle infrared will provide sufficient spectral information for accurate basic forest cover mapping; and 4) that the qualitative nature of photographic data does not lend itself to reliable quantitative analysis.