REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA
A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REMOTE SENSING APPLICATIONS IN FORESTRY

ANALYSIS OF REMOTE SENSING DATA FOR
EVALUATING FOREST AND RANGE RESOURCES

by

Robert N. Colwell, et al

School of Forestry and Conservation
University of California

Annual Progress Report   30 September, 1969

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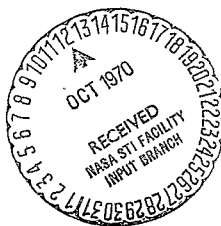
ABSTRACT

In the introductory chapter of this annual report, the rationale is given for a systematic forestry remote sensing research program of the type in which our Laboratory is engaged. The unit organization of our Laboratory that has been developed in order to conduct a comprehensive program also is described and a statement is given of the types of programs that are investigated by the Laboratory's five major units, viz., (1) Operational Feasibility, (2) Spectral Characteristics, (3) Image Enhancement and Inter-pretation, (4) Automatic Image Classification and Data Processing, and (5) Training.

Chapters 2, 3, 4, 5 and 6 deal, respectively, with the activities and accomplishments of these five units during the past year. Most of these activities have been oriented toward a single objective: developing a capability for extracting useful, timely earth resources information from data of the type that soon will be provided by ERTS-A and supporting data-collection vehicles.

In all of these studies a maximum effort has been made to relate remote sensing capabilities to user requirements, based on the presumption that the primary user will be the actual manager of earth resources. Chapter 2 of this report gives a great deal of practical and philosophical consideration to this aspect of the problem. When this rigorous criterion is applied it serves to reinforce our earlier conclusion that the obtaining of useful earth resource information by means of remote sensing from air-craft and spacecraft is, at best, a difficult task. When an attempt is made to extract such information from only one photograph, the results can be quite discouraging. However, our results show that the amount of useful information derivable by means of remote sensing is greatly increased when

we employ multiband, and/or multidate photography, and when we employ multi-enhancement techniques through the use of various optical and electronic image combiners. Furthermore, our studies on automatic data processing techniques demonstrate that the extraction of useful earth resource information is facilitated when the human exercises the opportunity that can be his to interact with the machine at each of several stages in the information-extraction process.

ACKNOWLEDGMENTS

iii

TABLE OF CONTENTS

INTRODUCTION

Robert N. Colwell
Gene A. Thorley

The tremendous worldwide scientific interest in Earth Resources
Technology Satellites and the imminent possibility of using ERTS data for
surveying earth resources has led to an accelerated program at our Forestry
Remote Sensing Laboratory and elsewhere for maximizing the usefulness of
such data. A systematic program of the type in which our Laboratory is
engaged is one which (1) carefully defines user requirements for earth
resource data, including a determination of accuracy standards and timing
of the informational needs, (2) provides an assessment as to which needs
show significant promise of being met by the use of remote sensing, (3)
attempts to demonstrate the technical feasibility of meeting those needs
through remote sensing, (4) develops a means of properly calibrating
remote sensing data acquired, and (5) determines the extent to which the
proposed system and procedures would be more efficient in meeting the
user requirements than are the various systems and procedures currently
being employed. Appropriately, our remote sensing research efforts are being
conducted, not only with these considerations in mind, but also on specific
earth resource problems which, when solved, will have the greatest economic
impact.

It is probable that the major economic benefits derivable from the
Earth Resources Survey Program will be those which permit more intelligent
management of renewable earth resources. Normally the supply and quality
of renewable resources will vary from year to year and from season to
season because the associated environmental factors vary. Managers of

these renewable resources can profit greatly if they are provided periodic-
ally with detailed, accurate and timely information regarding the state
or condition of such resources and of various environmental factors (tem-
perature, precipitation, insects, pathogens, etc.) with which they are
known to interact. In fact, most of the activities engaged in by fores-
ters, range managers and water resource managers merely consist of their
responses to the periodic changes in these environmental factors, however
inadequate the information about such factors may be. It follows that
such resource managers could better perform their tasks if periodically
they were given better information regarding both the resources and the
associated environmental factors. Judging from work which recently has
been done by our group and by other NASA-financed investigators under the
Earth Resources Survey Program, by far the best way to maintain the
necessary surveillance of renewable earth resources and many of the
associated environmental factors is by means of photography and related
imagery obtained from aircraft and/or spacecraft. Beyond this generaliza-
tion, however, little has been agreed upon up to the present time. There
is great need for developing techniques which will be regarded as optimum
for maintaining surveillance of the earth's renewable resources by means
of aerial and space photography.

During the period covered by this report, the program of our Forestry
Remote Sensing Laboratory has attempted to take maximum advantage of the
S065 space photography and existing high flight coverage to determine the
applicability of ERTS type data to solve the wildland resource manager's
data acquisition and analysis problems. Our experience to date has con-
vinced us of the necessity to use a systems concept and team approach in
solving problems of interest to the wildland resource manager. With a

2

view to using a systems approach of the type previously described, our
Forestry Remote Sensing Laboratory has been organized to include five func-
tional units (see Figure 1.1). These units address themselves to the most
important problems which must be solved if a remote sensing system is to
be employed successfully for earth resources inventory purposes. The five
problem areas investigated under this team concept are as follows:

(1) determination of the feasibility of providing the resource mana-
ger with operationally useful information through the use of remote sen-
sing techniques;

(2) definition of the spectral characteristics of wildland resources
and the optimum procedures for calibrating the tone and color character-
istics of multispectral imagery of those resources;

(3) determination of the extent to which humans can extract useful
earth resource information through a study of remote sensing imagery in
either original form or when enhanced by various means;

(4) determination of the extent to which automatic data handling
and processing equipment can extract useful earth resources information
from remote sensing data and

(5) effective dissemination of remote sensing results through the
offering of various kinds of training programs in which the interaction
between users and scientists can be emphasized.

The five units of our Forestry Remote Sensing Laboratory which are
engaged in these five problem areas are respectively, (1) the Operational
Feasibility Unit, (2) the Spectral Characteristics Unit, (3) the Image
Enhancement and Interpretation Unit, (4) The Automatic Image Classifica-
tion and Data Processing Unit and (5) the Training Unit.

Consistent with the organization that has just been described, and

3

FORESTRY REMOTE
SENSING LABORATORY

| OPERATIONAL FEASIBILITY | SPECTRAL CHARACTERISTICS | IMAGE ENHANCEMENT AND INTERPRETATION | AUTOMATIC IMAGE CLASSIFICATION AND DATA PROCESSING | TRAINING |
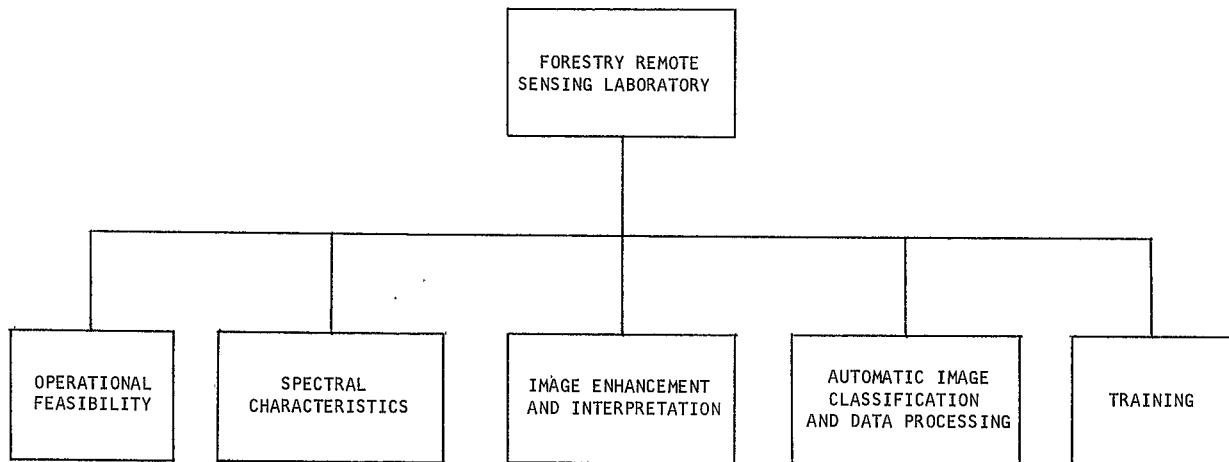
Figure 1.1 Organizational diagram of the Forestry Remote Sensing Laboratory, School of Forestry and Conservation, University of California, Berkeley, California.

mindful of the problems which each of the five units of our Forestry

Remote Sensing Laboratory seeks to solve, the next five chapters of this

report are devoted, respectively, to the activities of these five units.

OPERATIONAL FEASIBILITY

William C. Draeger

Introduction

Responsibilities of the unit consist primarily of the development of operationally feasible means of using remote sensing capabilities to satisfy information requirements of users concerned with earth resource management. In fulfilling this responsibility, the unit provides the link between basic technical studies conducted by other units of the Forestry Remote Sensing Laboratory and elsewhere, and the applications of these techniques to actual earth resource management problems.

The functions of the unit are performed by various sections, some of which are concerned with studies conducted wholly by the unit, while others involve direct services to, and interactions with, other units of the Forestry Remote Sensing Laboratory.

A. Studies Conducted Within the Unit

1. Investigation of user requirements

a) Interviews and research are conducted to ascertain the types of information required or desired by land managers which could potentially be supplied, at least in part, by means of remote sensing.

b) Determinations are made of the form of data, and methods of data distribution which would provide maximum utility to the user.

2. Determination of technical feasibility

a) The unit makes analyses of basic research conducted within the field of remote sensing to ascertain the technical feasibility of performing needed operations.

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                    │   OPERATIONAL        │
                    │   FEASIBILITY        │
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│ REQUIREMENTS │ │ FEASIBILITY  │ │ STUDIES  │ │  ACTIVITIES  │
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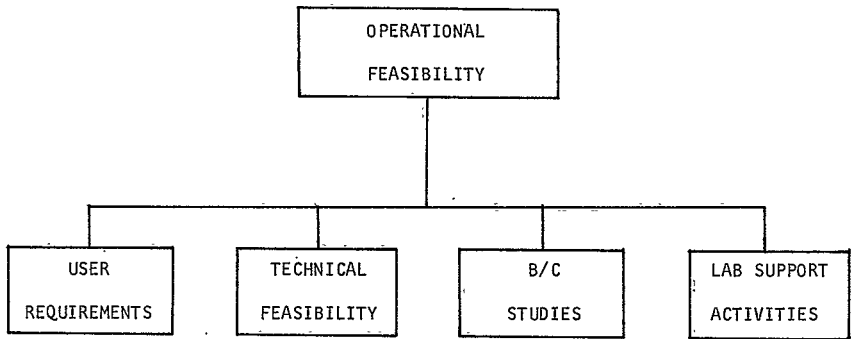
Figure 2.1   FUNCTIONAL DIAGRAM, SHOWING SECTIONS OF THE

OPERATIONAL FEASIBILITY UNIT

b) Within-unit studies of operational techniques of remote
sensing

3. Integration of needs and techniques

Use is made of the findings of 1 and 2 above to provide quantita-
tive economic criteria for decisions regarding the deployment of
operational remote sensing systems, based on a determination of
the costs to be incurred and the benefits to be derived from
such undertakings.

B. Studies Involving Interactions With Other Units

1. Studies designed to provide coherence and direction to certain
aspects of the Lab program

The determination made by personnel of this unit of specific
problems and needs within the field of earth resource management
should provide a basis., in part, for the organization of the research
efforts of the Lab as a whole. As a result of such determinations,
the various units, rather than operating as wholly autonomous bodies,
are able collectively to contribute to the solution of specific
application-oriented problems.

2. Studies designed to make Lab findings applicable to operational
problems

The Operational Feasibility Unit provides one means whereby the
results of the research performed by various units of the Lab can
be channeled to their ultimate end use, i.e. application to earth
resource management problems.

<u>Current Research Activities</u>

A. <u>Annual Progress Report for the study entitled "Applications</u>
<u>of Remote Sensing in Multiple Use Wildland Management"</u> .

I. <u>Introduction and Justification</u>

To date the bulk of remote sensing research in forestry has
dealt with the capability of various sensors or interpretation systems
to perform rather isolated tasks related to forest land management, often
on what is essentially a qualitative level. In addition, limited
attempts have been made to quantify findings as to resolution require-
ments and filmfilter sensitivity requirements for performance of specific
tasks at given levels of accuracy.

However, the field of remote sensing in general, and that branch
concerned with natural resource inventory and management in particular,
are rapidly approaching a more demanding stage of development--one in
which investigators will be expected to recommend an integrated remote
sensing system for performing <u>several</u> <u>interrelated</u> tasks. Parallel with
the development of such an integrated system, there should be the develop-
ment of fully operational procedures which will meet current needs of
persons engaged in earth resource management. Certainly these tasks
have been performed to a certain extent in terms of medium-to large-
scale black-and-white aerial photography, which has been used by various
disciplines for decades. The same cannot be said, however, for the
many relatively sophisticated sensor-vehicle systems which have been
developed or perfected during the past few years.

A number of projects are currently underway which seek to develop
operational high-altitude or orbital sensing systems, all of which
entail large expenditures, both in the procurement of data, and in

development of facilities to handle and process these data. This necessitates a thorough analysis of the potential economic benefits to be derived from such undertakings before they can be justified, for certainly justification cannot rely solely on the basis of technical feasibility.

Thus any pertinent discussion of the usefulness of such systems must focus on the informational needs of land managers which might best be satisfied by means of remote sensing. Such information would serve several purposes.

A. It would form a basis (at least in part) for determination of the net benefits and costs of various systems. (It should be mentioned that benefits as mentioned here might include so called intangibles, and that costs might include significant "opportunity costs".)

B. It could provide considerable insight into the heretofore little discussed problem of how data gathered by means of remote sensing systems might most efficiently be "filtered down" to the ultimate user in the most usable form.

C. It would facilitate the legitimate "selling" of remote sensing to the practicing wildland manager. Many applications of remote sensing are presently available on an operational basis, and many more are sure to be developed, but often they are not used. Skepticism on the part of potential users has arisen for a variety of reasons, including their ignorance of remote sensing capabilities, a lack of economic justification for the use of such techniques, the lack of qualified interpreters, etc. This situation might be alleviated if the potential were described to the user in relevant terms.

This study attempts to investigate what would seem to be one

10

of the more promising uses for remote sensing data obtained from high-
altitude aircraft or satellites--namely the use of such data in making
"integrated interpretations" of operational management units, in their
entirity. Such interpretations are made with the realization that a
multiplicity of potential uses exist for a management unit, and the,
objective is to facilitate the formulation of complex management,
policy, and development decisions regarding the allocation of lands to
various uses.

The argument for using small scale imagery in such a study basi-
cally stems from two factors: 1) the inherent characteristics of such
data which cannot be provided through other methods, and 2) the pressing
needs of earth resource managers for timely, accurate information often
best obtained from such imagery; This is true not only in presently
underdeveloped countries, but also in those areas, now managed to some
degree, where population and technology trends are creating require-
ments for information not currently available.

Among the unique advantages of small scale imagery obtained from
aircraft or space vehicles are several of interest to the manager of
wildland resources:

1. The synoptic view. Probably the most obvious characteristic
of small scale imagery is the large area covered by each image, thus
enabeling any particular feature to be viewed in relation to its sur-
roundings. Often a natural feature which is not readily identified
when viewed alone can be identified if it can be related to the sur-
rounding topography. In addition, the synoptic view often enables the
interpreter to more fully judge the significance of the various features
of interest. Finally, many natural features are of such a large size

that they can only be viewed in their entirety from relatively high altitudes.

2. Opportunity for sequential coverage. Often annual, seasonal, or even daily variation in the appearance of a terrain or vegetation type is an aid to its identification, and therefore suggests the desireability of image coverage being obtained at periodic intervals. Theoretically, a satellite in sun-synchronous orbit will pass over any given point of the earth's surface at the same time of day. Thus, with suitable planning and control, any point on the earth's surface can be imaged sequentially as desired, with uniform lighting conditions, weather permitting. Furthermore, this capability affords a chance to obtain imagery of widely spaced points within very short intervals, which is often impossible with conventional aircraft given the usual time, distance, and cost restrictions.

3. Uniformity of the image. In the past, the only available method of examining large areas of land on aerial imagery was by means of a photomosaic--a patchwork of perhaps hundreds of individual photos. Often photos comprising such a mosaic had been obtained at different times of day, at different exposures, or with varying camera orientations, As a result, colors or tones, shadows, weather and ground conditions, and spatial geometry were not constant throughout the mosaic. By means of high-altitude reconnaissance it is possible to cover vast areas of land with one image, thus providing uniform conditions.

Even though small scale imagery might lend itself to the extraction of data pertinent to an integrated interpretation of managerial units, the question must be considered as to whether such data are, in fact, needed by the earth resource manager. The nature of current

problems in wildland policy and management would suggest that such needs do exist and that, to a surprising extent, these needs are not being met by present techniques.

Certainly the data needs of those entrusted with the care of wildland resources varies with the type of land involved: i.e. its geographic location, the degree of intensity to which the land is presently being managed, its resource endowment, and the social and economic environment of the region or nation within which the land occurs. It seems obvious, however, that a need for integrated, broad scale inventories exists in both under-developed regions, and intensively managed areas, but for somewhat different reasons.

In presently undeveloped wildlands, the most pressing requirement is for a knowledge as to what resources or potentials for resource developments are present. Vast areas of such unmapped resources exist, primarily in South America, Africa, Australia, and the extreme northern latitudes. Naturally, meaningful policy decisions pertaining to potential economic development, priorities of resource use, and areas to be managed are impossible without adequate resource inventories.

A much more pertinent problem in relatively highly developed countries such as the United States is that of somehow managing limited areas possessing numerous resources, all of which are in high demand. The opinion has been frequently expressed that small scale imagery is of little use to wildland managers in the United States, because we essentially know what wildland resources are present, where they are located, and in what amounts. Such opinions overlook both the potential of remote sensing, and numerous management problems not yet satisfactorily solved in this country.

13

Economic benefits can accrue from remote sensing applications
in two basic ways. One is by providing the same kinds of data which
are now collected by more conventional means, but at a lower cost or
in a more useful form or accuracy. As an example, such operations as
timber type mapping, mapping of ownership boundaries, and detection of
insect and disease outbreaks are all things which can be and have been
done on the ground, but which can usually be performed much more
efficiently using aerial photography. The second way in which benefits
can be realized is through the accomplishment of tasks which are simply
infeasible using conventional techniques. For example, only by means
of aerial photography could a vegetation map of a vast, inaccessible
area such as the Amazon Basin be obtained. It would, for all practical
purposes, be impossible to conduct such a survey on the ground.

Thus small scale imagery cannot be eliminated from consideration
for use in this country simply because we allegedly already possess
adequate inventories of our wildland resources. These inventories need
to be updated periodically, and future inventories could be obtained
quicker, cheaper, and with a greater degree of accuracy using small
scale imagery. But more importantly, only a lack of foresight or imagi-
nation would prevent one from concluding that there may well be some
kinds of resource information which are presently badly needed but un-
available and which might be provided by means of small scale remote
sensing imagery.

For example, it has recently been suggested that in order to
provide for adequate land use planning for the state of Alaska, a
state-wide survey of potential land use would be essential. Furthermore,
to many experts it appears that the only practical way to compile such

14

data for the more than 500,000 square miles comprising the state is by
means of an aerial photographic survey. Such a survey would not, of
course, be highly detailed, but rather could only be concerned with
fairly gross features. It would seem that such an undertaking, which
is currently under serious consideration by government officials, might
face many of the problems which are considered in the following investi-
gation.

II. Description of Research Performed

A. General

This study concentrates on the applicability of remote sensing
techniques to the multiple use management of wildland areas. The
research consisted first of an attempt to define the multiple use con-
cept as practiced by the U. S. Forest Service in a manner which would
facilitate evaluation of remote sensing applications. Secondly, an
attempt was made to determine the ways in which currently operational
remote sensing techniques might be used to provide information pertain-
ing to current multiple use planning, as well as the possibility of
devising land classification systems particularly suited to aerial photo
interpretation, while still satisfying multiple use planning needs.
Finally, the feasibility of incorporating more exotic techniques currently
under development into multiple use mapping operations in the future was
considered.

B. Multiple Use Management

As a first step in investigating the use of small scale remote
sensing imagery as an input into a multiple use management plan, the
study must ascertain exactly what information is essential or desireable
in developing such plans. The multiple use concept, as described in

most policy statements, is quite general in nature. Therefore, the

investigations reported herein of necessity concentrated on interviews

with practicing land managers and others intimately associated with the

formulation of actual resource and land use plans, as well as reviews

of operational management directives. Thus an insight as to the

actual needs of those managers for information pertaining to the

resources of an area was gained. Furthermore an attempt was made to

place these informational needs in a well integrated form: i.e. not

simply pertaining to the individual resources, but rather to the various

interactions of the resources pertinent to multiple use decisions.

C. Use of Conventional Techniques

The second phase of the investigation consisted of a survey of

currently operational remote sensing techniques, and entailed the use

of color infrared photography at large to intermediate scales, as such

photography might be better used to provide the kinds of information

discussed in the previous section. This phase concentrated primarily

on the NASA Bucks Lake Test site in the northern Sierra Nevada Mountains

of California. This area has been imaged, at least in part, with nearly

all types of operational remote sensing systems, and has been the focus

of five years of detailed remote sensing experiments. In addition,

periodic aerial photo coverage of the entire test area taken over the

past thirty years is available, as are considerable data resulting from

various resource research projects carried out in the area. The test

site comprises the bulk of the American Valley Working Circle* on the

Plumas National Forest. This working circle forms the basic managerial

*A "working circle" is defined as: the primary unit of forest management, with well-defined boundaries, usually based on topography, large enough to furnish a sustained yield of forest products sufficient to support dependent industries or communities.

unit for which multiple use planning on the Plumas National Forest is for-
mulated by the U. S. Forest Service. (The multiple use concept, which seeks
to find an optimum combination of uses of each part of an area, is discussed
in detail in the next section). Because of this fact, coupled with the
wealth of information available pertaining to the Meadow Valley area and
the willingness of the Forest Service personnel to cooperate by providing
additional data, it seemed that this area would be the most appropriate
test site for such a study.

D. Consideration of the Effects of Probable Future Developments

The third phase of the project investigated the utility of extremely
small scale photography and other techniques currently under development
for meaningful multiple use zoning and planning, drawing in part upon
those techniques developed in the previous sections. Imagery investi-
gated include that obtained from very high flying aircraft as well as
from earth-orbital satellites. Test sites studied include the NASA-Bucks
Lake Test Site, the southern Lake Tahoe Basin, the coast ranges of
Southern California, and selected wildland areas in Southern Arizona.
The potential sites for such an investigation are limited by the small
amount of such photography that currently is available of appropriate
areas. In selecting areas for study, great weight was given to the fact
that the Southern California and Arizona sites have been photographed
with the S065 multiband camera system by the Apollo 9 Astronauts in
March, 1969. All of the above-mentioned test sites are the subject of
a current program of very high altitude (e.g. 70,000 feet) multiband
photography from aircraft. Furthermore, the sites are now being subjected
to multiple use management by the Forest Service, at least in part. As
previously indicated, this study seeks to determine the extent to which

17

remote sensing techniques can aid in the development of multiple use

management plans. Thus, an excellent opportunity is afforded in these

sites to compare multiple use plans, as devised through remote sensing,

with multiple use plans currently being implemented by the Forest Service

in the same areas.

III. Multiple Use Management: Policy and Information Requirements

    A. Definitions of Multiple Use

        The Multiple Use Act, passed by the 86th Congress on June 12, 1960,

defines "Multiple Use" as: "The management of all the various renewable

resources of the national forests so that they are utilized in the

combination that will best meet the needs of the American people; making

the most judicious use of the land for some or all of these resources

or related services over areas large enough to provide sufficient latitude

for periodic adjustments in use to conform to changing needs and condi-

tions; that some land will be used for less than all the resources; and

harmonious and coordinated management of the various resources, each

with the other, without impairment of the productivity of the land, with

consideration being given to the relative values of the various resources,

and not necessarily the combination of uses that will give the greatest

dollar return or the greatest unit output."

        Presumably this definition was worded in its relatively loose and

ambiguous form for a specific purpose--i.e. so as not to be overly re-

strictive on those persons charged with carrying out the dictates of

the act under the varying conditions which would be met in the operational

situation. While this might be viewed as an advantage, it has presented

a number of problems as well. In many cases, the public and those not

directly involved in wildland management grossly misunderstand the

meaning of multiple use as practiced by public agencies, thus giving
rise to criticism that might not have been forthcoming if less complex
management schemes were being implemented. Also, those governmental
agencies which have endeavoured to conduct multiple use management
have been faced with a dual problem--first to define the act in practi-
cal workable terms, and secondly to devise techniques to actually imple-
ment the concepts.

In an attempt to clarify the meaning of multiple use, the Forest
Service Manual, in specifying the need for regional and distric multi-
ple use management plans has stated that multiple use can be defined
variously as:

'1. The deliberate and carefully planned integration of various
uses so as to supplement each other as much as possible, and to inter-
fere with each other as little as possible.

2. The skillful adjustment of land resources and uses into a
pattern of harmonious action to achieve overall objectives for the area
being managed.

3. The coordination of existing and potential uses and acti-
vities with a resultant benefit to people that is greater than the sum
of the individual uses if they were not coordinated.'

In analyzing these definitions, the Manual states that, while the
definitions exhibit certain differences, each definition prescribes the
following elements inherent in multiple use management.

'1. It requires an anlysis of the inherent capability of land
to produce a sustained yield of the several resources or, services with-
out impairment of the site.

2. It requires conscious planning and management.

3. It is based primarily on satisfying the needs or desires of people, within the capability of the site, rather than the full development of a resource.

4. Its end objective is an increased yield of products and services from a given area while maintaining resource productivity."

The implications of these definitions and guidelines on actual Forest Service practice will be discussed in the following section. However it is appropriate at this point to examine some less official interpretations of the meaning of multiple use which might serve to clarify the problems involved in its application.

Clawson and Held (1957) differentiate between various kinds of land use situations, each of which can be considered to be multiple use management under specific sets of circumstances. Thus one might encounter land with one dominant use with one or more compatible secondary uses; several co-dominant compatible uses on the same plot of land; or a number of small interspersed plots, each managed for a single dominant use, but with the whole managed for its multiple uses.

A somewhat more general definition is given by Dana and Kreuger (1958) as "planned management with due regard to all of the various values involved. It does not mean the use of every acre or even of an entire tract for all possible purposes, but rather the combination of uses that will yield the most satisfactory results in the management of any given administrative unit from the standpoint of the owner."

Finally, Zivnuska (1961) warns of the danger of relying too heavily on slogan terms with popular definitions which may be over simplified. In essence, he feels that the term "Multiple Use" refers both to 1) an economic concept concerned with multiple products

resulting from common or interrelated production processes, and
2) an administrative and management philosophy closely linked with
the U. S. Forest Service which holds that all values and costs must
at least be considered when allocating land use.

By combining these three concepts it is possible to develop a
definition of multiple use as: the allocation of lands to various
uses such that the combination of uses best meets the needs of those
for whom the land is being managed, provided that in the process of
developing this allocation, values and cost of each of the many possi-
ble patterns of exclusive uses and compatible co-uses are at least
taken into consideration. In some instances, depending on the circum-
stances, several uses may be derived simultaneously from the same par-
cel of land, while in other cases a particular area may be allocated
to only a single use but managed as a portion of a greater whole com-
posed of many such exclusive-use parcels.

B. Actual Forest Service Multiple Use Practice

The implementation of multiple use management on the national
forests begins with the Regional Multiple Use Guides specified by the
Forest Service Manual. Essentially, the regional guides establish a
system of associations or zones possessing similar resource values and
management problems into which all National Forest lands in the region
can be categorized. For each zone, general management directions are
given, thus assuring that Forest Service multiple use policies are
uniformly applied in each planning unit. In some cases multiple use
guides are prepared for subdivisions of a region if, because of physical
and economic conditions, a single region-wide zoning procedure is not
feasible.

The guides, while varying somewhat from region to region, in general follow a somewhat similar format. First a general description of each zone is given to enable the national forest administrators to adequately map their lands according to the regional criteria. However the descriptions are broad enough to allow for the variability that is likely to exist in local conditions. Secondly, a general statement of management direction is provided which specifies the management philosophy which should prevail in the zone. Finally, more specific coordinating instructions are given for each zone, describing more specific management pertinent to each possible use in the zone. As an example, the following are the specific coordinating instructions for the Crest Zone of the Westside Sierra Subregion of California, in which the Bucks Lake Test Site is located. (U. S. Forest Service, 1956):

A. SOIL
1. Inventory areas of accelerated erosion. Initiate and maintain an action program with priority on critical areas to achieve control of unacceptable erosion.
2. Locate and delineate areas where proposed or existing use may cause unacceptable erosion and provide for prevention measures in project planning.

B. VEGETATION
1. Study need and feasibility of extending blister rust control and other protective measures to this zone.

C. WATER
1. Inventory sites where lakes may be created or developed for water power, flood control, recreation, or fish life.

D. RECREATION AND OCCUPANCY
1. Inventory and where necessary reserve sites suitable for winter sports and campgrounds.
2. Lay out road and trail system that will serve to distribute recreation use.
3. Establish allowable limits of fire loss.
4. Inventory and, where possible, relocate roads which traverse meadows.

E. TIMBER
1. (See Vegetation)

F. WILDLIFE
1. Inventory potential wildlife habitat improvement projects including lakes where levels may be raised for maintenance of streamflow.

      2. Develop habitat improvement programs for approval and
           allocation of funds. Proceed with work as funds and
           opportunities permit.

G. GRAZING
      1. Delineate areas where commercial packers will be required
           to import feed.
      2. Select and delineate areas suitable for sustained grazing
           use within the framework of subregion direction.
      3. Inventory existing and proposed physical improvements.
      4. Reseed current burns in delineated areas where soils are
           best adapted for forage production and management.

H. MINERALS
      1. Continue appropriate action in event of abuse of the mining
           law.

I. LANDS
      1. In accordance with overall management direction, specify
           the private lands which have priority for inclusing in
           consolidated exchange.
      2. List rights-of-way needed and establish priorities.

J. FIRE
      1. Fire control will aim to meet burned area objective for
           the zone.

The final, and most critical level at which multiple use planning

is carried out is the individual ranger district. Each district is

required to prepare a Multiple Use Plan outlining the specific management

procedures to be followed, within the directions of the Regional Guides,

and each plan must be approved at the Regional level. Typical Ranger

District plans contain maps illustrating the zoning of the district as

well as written management direction for each zone. The district plans

follow a format similar to that of the regional guides, but are more

detailed, and they reference the specific areas and problems of the

District in question. A specific multiple use plan will be investigated

in detail in a later section devoted to the case study of the Meadow

Valley area of the Plumas National Forest.

It may seem that these multiple use plans do not really touch at

the root of the multiple use management problem, i.e. the optimization

of the multi-product, multi-producer function, in basic economic terms.

However it should be realized that the functional plan is at least an

operational compromise which attempts to carry out directives and philosophies for which even theoretical economists have not yet developed practical solutions. In fact, this operational system has been praised (Martin, 1969) as a "system maintenance mechanism" which serves quite well to "resolve conflict at the organizational level where a decision is being made". Thus by subdividing the management unit into zones possessing specific physical and geographic characteristics bearing directly on their possible uses, at least one of the basic tenets of multiple use management is adhered to--i.e. that land managers should be cognizant of the various possible uses and co-uses of the land, and strive for some degree of optimum use allocation.

C. Criteria for Zoning and Planning:--Decision Making Models

In order to adequately investigate the applications of remote sensing to multiple use management, two related studies must be undertaken. First, an attempt must be made to ascertain the degree to which present zoning procedures can be facilitated through the use of aerial photos or other types of remote sensing data. Secondly, classifications especially designed with mapping from remote sensing imagery in mind, and which also satisfy the needs of multiple use management must be considered.

Basic to the study of applications to present systems is an understanding of precisely what criteria are used in multiple use zoning at the present time. Zoning as practiced in the Westside Sierra Subregion of California is essentially accomplished in two phases. Initially, land is categorized as Valley Front, Westside Intermediate, or Crest, depending primarily on its elevation which, in this area, is closely correlated with climate and vegetation. These factors, in turn,

are gross determinants of the range of possible uses. Thus the cri-
teria for this general zoning are fairly simple, being based on easily
identifiable gross characterics. Within each of these general zones
the procedure is somewhat subtractive in nature, i.e. the final West-
side Intermediate Zone consists of all lands within that area not
further zoned as Waterfront, Streamside, Roadside, or Special. At
this stage the zoning criteria become more specific, and are dependent
not only on the physical characterics of the land, but also on local
social and economic factors such as need for watershed, frequency of
travel, etc., as well as intangibles such as expectation of future use
or scenic value. Thus, among the factors which must be considered are
fishing potential in streams and lakes, location of municipal and
regional watersheds, effects of logging operations on both soil erosion
and aesthetic qualities of the landscape, extent of wilderness areas, and
local requirements for grazing, mineral rights, and summer homesites.
In essence, therefore, the decision making seems to operate on the
assumption that there is plenty of land for use primarily in timber
production, and hence priority is given to other uses, particularly as
they pertain to recreation, aesthetics and watershed.

IV. Use of Conventional Techniques

    A. Discussion of Aerial Mapping Problems

    1. Mapping in General

        The production of a map from aerial photos can logically be sub-
divided into two operations: 1) that which involves the identification
and location of points, lines, or areas of interest on the image, and
2) the transfer of these features from the individual images onto a flat
sheet of paper of suitable size and shape, and at a uniform scale, so

that all of the features appear in their true plan positions relative
to each other. The second of these procedures has been widely·discussed
in photogrammetric literature, and will not be dealt with here. The
first, however, represents the link between the disciplines of photo
interpretation and photogrammetry, and a discussion of the physical
and philosophical problems involved, as well as the evaluation of
mapping techniques can serve to shed some light on the more specific
problems encountered in the use of aerial photos for multiple use plan-
ning.

The initial problem encountered in mapping meaningful types on
aerial photographs of wildland areas consists of deciding on the cri-
teria to be used. This decision is, of course, based both on the
ultimate use of the map, and the limitations imposed by the character-
istics of the image. Thus this step must of necessity involve persons
knowledgeable in the field of ultimate application as well as in photo-
interpretation procedures. Mapping jobs range from those which may be
extremely simple and for which the interpreter can supply even more
detailed information than is needed, to those which cannot be performed
on aerial photos or which would prove to be too costly or time consum-
ing to be practicable. Usually the result is a compromise between
what is desired and what can be readily and accurately performed. In
practice, mapping criteria are generally developed by means of an infor-
mal procedure analagous to the selection of independent variable for
multiple regression estimation--i.e. environmental factors are selected
which can be identified or measured on the image and which either
singly or in combination are highly corellated with those attributes
of the environment which are to be mapped. Thus it is the job of the
interpreter to classify the area on the basis of image characteristics

26

which in a sense allow an _estimation_ of the actual environmental parameters of interest. Only occasionally can these specific parameters be evaluated directly on the aerial image. Finally, if the criteria are to be of practical use to the interpreter, they must include such factors as the amount of variability that will be accepted within a mapping unit and the minimum size of the unit.

Once the mapping criteria have been chosen, the next step consists of inspecting the image, drawing boundary lines between appropriate "types", and accurately classifying each type. Essentially the processes of delineation and classification must of necessity progress concurrently, as each is dependent to a certain extent on the other. This is not necessarily true if the environment consists entirely of discrete uniform conditions with sharp, well defined boundaries. However nearly all wildland environments are composed of extremely complex mosaics of conditions, usually with gradual transitions from one to another, and do not possess sharp boundaries.

Thus the interpreter is faced with making continual compromises as to where delineations between types must be drawn. He must decide where within the gradual transition the delineation will be made. This is dependent upon the accuracy with which he can classify or identify the type being delineated, as well as adjoining types, and the variability within a type which is allowed by the mapping criteria. On the other hand, the classification of a type is dependent on the placement of the boundaries of the type and the amount of variability and "transition zone" which will be included: this is an important consideration because the classification is generally based on an average of all conditions included within the type. Naturally all of the foregoing

27

are dependent upon the ability of the interpreter to recognize the requisite image characteristics--a consideration which should be taken into account during the selection of mapping criteria.

In summary then, the job of performing the first stage of mapping on photo images can be considered to consist of four steps: criteria selection, recognition, delineation, and classification, all of which are intimately related and interdependent.

Fundamental to the development of a specific mapping technique and its application on a large scale to operational problems is the preliminary testing of the procedure to ascertain its accuracy, effi- ciency, and reliability. When one seeks to evaluate the accuracy with which mapping of wildland conditions has been performed, he encounters some unique problems not always present in the testing of more straight- forward interpretation tasks. Basically, testing consists of a compari- son of the mapping results with what is commonly referred to as "ground truth". However, often for relatively wild, vast, and poorly accessible areas, the acquisition of ground truth is nearly impossible by means other than remote sensing. Thus a common practice is to compare the interpreter's findings with those of a panel of experts who draw upon their experience and familiarity of the test area to produce the "best possible" map. Obviously such a procedure may not always adequately reflect the capabilities of an experimental technique which may actually produce a map which is different than but superior to that produced by the experts. This may hold true for both the location of delineation lines and the correct classification of types. The same problem may arise if the comparison is made with maps produced by methods other than remote sensing but which might actually be inferior

to the technique being tested. Often such situations cannot be avoided,
but cognizance of the possible bias in the test can lead to a more
objective evaluation.

In addition to a decision as to how to obtain ground truth,
the investigator must also give a great deal of consideration as to
the actual characteristics of the map upon which to base the test. In
certain instances, depending on the ultimate use of the map, the exact
location of boundary lines may be the critical factor. In other cases,
an accurate determination of the area included in each type constitutes
the measurement of interest, while the location of individual boundary
lines is of relatively little importance. In some instances the correct
classification of types may be extremely critical, while in others,
classification may be unimportant as long as the area has been deline-
ated into relatively homogeneous units. The latter statement commonly
is true, for example, with respect to the use made of aerial photos in
stratified sampling systems.

Finally, when evaluating a mapping procedure, one must be care-
ful to keep clear the distinction between "mapping" on the one hand, and
"identification" or "discrimination" on the other. Tests which require
the interpreter to simply identify isolated objects or conditions or to
discriminate one thing from another may be perfectly valid for certain
applications. However to draw conclusions from such tests as to the
feasibility of mapping (which, as has been stated, involves considerably
more than identification) may in many instances be quite unjustified.

If it is possible in a given situation to provide a well founded
quantitative basis for comparison between interpretation results and
ground truth, many techniques exist for making a quantitative, statis-

tical evaluation of the interpretation technique and for comparing

various techniques. Certainly if at all possible, such evaluations

should be made, as they provide the most straightforward, objective

basis for selection of a technique. If, however, the nature of the

problem is such that only more subjective evaluations are possible.,

they may be entirely meaningful provided that the limitations and

possible bias are clearly understood and honestly stated.

2. Multiple Use Mapping

The preparation of a multiple use map from aerial imagery

entails not only the delineation of particular landscape characteristics

which are readily seen on the image, but in addition involves a thor-

ough understanding of the multiple use zoning criteria. Also of impor-

tance is an ability to deduce the significance of environmental features

based on a knoledge of these criteria. Clawson (1965) points out that

if information is to be of optimum value, a distinction must be made

between the classification of the natural qualities of land and man's

present or potential activities. He further states that while these

are often interrelated, a classification of "activities" should be

kept pure, with as little inclusion of "natural qualities" as possible.

Certainly multiple use planning is concerned with both present and

potential activities, thus often necessitating deduction and conver-

gence of evidence in the interpretation process rather than the simple

classification of land based on its physical appearance.

As will be apparent in the Meadow Valley case study which follows,

the existing zoning criteria fall into three categories in regard to

their potential for aerial mapping. Some zoning, (that falling in the

first category) can be based purely on the physical appearance of the

image. In a second category is zoning which requires a familiarity
with the local needs for various kinds of land use and with the rela-
tionships that exist among various environmental factors which govern
land use. Finally, some criteria may be based to so great an extent
on factors not apparent on the image that it is impossible to perform
meaningful zoning using only images. A major intent of this study is
to ascertain these limitations in one area (the Meadow Valley Area)
and to determine what degree of other knowledge is required to perform
meaningful multiple use mapping in that area.

B. Case Study: Meadow Valley

1. Use of existing multiple use criteria

In this study, the first step in determining the feasibility
of mapping multiple use zones using the standard criteria was as fol-
lows: Zone boundaries as delineated on existing multiple use maps of
the area were transferred onto aerial photos. A photo-interpreter
experienced in typing of wildland areas was asked to make an evaluation
of the delineations thus produced to determine whether they could have
been derived using only the photos and the written official zoning
criteria.

Quite negative findings resulted--i.e. the interpreter felt
that in only a few cases could he have produced delineations resembling
those on the multiple use map. Certainly this cannot be adjudged to
be a fault of the system, because each area had been zoned on the ground
by personnel intimately acquainted with the land involved and its char-
acteristics, and also with the special local needs and situations.

The following is a synopsis of the zone descriptions and pro-
posed management practices as prepared by the staff of the Quincy

Ranger District--one of the districts falling within the study area.
It will be noted that four major zones are recognized (General
Forest Zone, Travel Influence Zone, Water Influence Zone and Special
Zone) and that numerous sub-zones are recognized within each of these
major zones.

QUINCY RANGER DISTRICT MULTIPLE USE ZONES

A. General Forest Zone

    1. GF-1 Scenic Backdrop Areas

        a. Description:

            1) Consists of many irregularly shaped and varying shaped
                parcels.

            2) Provides scenic backdrop for the Travel and Water
                Influence Zones.

        b. Management:

            1) Logging and road building designed to minimize the
                impact upon the viewer.

            2) Land uses confined to those that do not detract from
                scenic beauty.

    2. GF-2 Municipal Watershed Areas

        a. Description:

            1) Includes any watershed that provides a municipal
                water supply that requires an individual watershed
                management plan.

            2) At present, Quincy Municipal Watershed is the only
                watershed involved in this district. It includes
                6352 acres, 78% of which is managed by USFS.

        b. Management:

            1) The use and harvest of resources are accomplished

only when compatible with water production.

2) Logging operations are to follow guidelines indicated by erosion hazard ratings.

3) Public use and occupancy are to be limited.

4) No livestock grazing is to be allowed.

5) With reference to fire hazard, this area is to be given the highest priority for pre-attack planning and implementation.

3. GF-3 Butterfly Botanical Unit

   a. Description:

      1) Consists of 262 acres, 142 of which are under USFS management.

      2) It is comprised of springs, bogs, and mixed conifers.

      3) There exists on this site the largest concentration of Darlingtonia californica (a rare insectivorous plant) in California.

      4) There is a close proximity to contrasting plant communities.

   b. Management:

      1) Prevent pollution and contamination through proper sanitary facilities.

      2) Encourage use as related to botanical attraction.

      3) Limit campground and picnic area.

      4) Encourage use by scientifically oriented organizations.

      5) Maintain roads so as not to disturb bogs.

      6) Use of herbicides is prohibited.

      7) Large scale publicity is to be avoided.

4. GF-4 Lee Summit Seed Production Area

   a. Description:

1) This area was established in 1963 for production of coniferous seed from naturally occurring timber stands.

b. Management:

1) Expand the production as it becomes economically feasible.

2) Harvesting plans are to be modified to eliminate danger to seed production.

5. GF-5 Proposed Rock Creek Dam and Reservoir Area

a. Description:

1) The proposed reservoir is to have an estimated area of 610 acres.

b. Management:

1) The harvesting of timber and the designing of roads are to be accomplished so that a near natural appearance is retained.

2) All slash in potential campgrounds is to be disposed of.

3) No special use permits are to be issued.

6. GF-6 Scenic Roadside Areas

a. Description:

1) The roadside strip (not Travel Influence Zone) borders logging roads of scenic value (including Slate Creek, Deanes Valley, Snake Lake, and the proposed Jacks Meadow roads).

2) The strip is not to exceed 200 feet on each side of the road.

b. Management:

1) All slash in the unit is to be eliminated.

2) Timber harvest and cultural practices are to be

34

adjusted to maintain scenic values.

      3) Vegetative cover is to be established on newly disturbed sites within one year.

7. GF-7 Red Hill, Mt. Hough, Claremont, and Spanish Peak Electronic Sites

    a. Description:

      1) These sites offer the best positions for TV relays between the Sacramento Valley and the American Valley.

    b. Management:

      1) All fixed-installation electronic operations are restricted to these sites.

      2) Neat appearances are to be maintained in these areas.

B. Travel Influence Zone

  1. T-1 Quincy-Keddie Community Expansion Area

    a. Description:

      1) Those areas bordering the towns of Quincy and Keddie, suitable for expansion by those communities.

    b. Management:

      1) Aim toward disposal of this unit by land exchange.

      2) No additional special use permits are to be issued unless to be succeeded by exchange.

  2. T-1 All paved roads

    a. Description:

      1) All paved roads are considered to constitute a travel influence zone.

    b. Management:

      1) Areas will be managed to preserve aesthetic qualities

C. <u>Water Influence Zone</u>: This zone includes the canyon bottoms of the
North Fork of the Feather River and of Indian Creek, Spanish Creek,
American Valley, Silver Lake, Snake-Smith Lakes, and Rock Creek.
Approximately 60 percent of the District's mining claims are in
this area.

1. Snake-Smith Lakes

    a. Description: see above

    b. Management:

        1) These lakes support warm-water fish and are open to
fishing all year.

        2) Investment for site development should be proportional
to the feasibility of aquatic weed control.

2. Rock Creek

    a. Description: see above

    b. Management:

        1) Two fee campgrounds are located on Rock Creek.

        2) High power transmission lines are to be constructed to
corridor in North Fork canyon from Caribou to Rock Creek.

        3) Aesthetics of the hydroelectric installations are to be
improved through the use of camouflage paint and vege-
tative screening.

3. W-1 Silver Lake Micro-Wilderness

    a. Description: see above

        1) Silver Lake was created by a dam for mining in the late
1880's.

        2) Provides domestic water for a portion of Meadow Valley
residences.

3) Limit development to foot trails and wilderness improvements except around Silver Lake.

4) Revise the area plan to eliminate a proposed public service site for pack and saddle stock at Jacks Meadow.

4. W-2 Rich Bar Historical Site

  a. Description:

    1) Rich Bar was one of the earliest gold settlements in Plumas County.

    2) A portion of the site is private land and the remainder is under the administration of the USFS.

  b. Management:

    1) Acquire the necessary private land.

    2) Develop a visitor information program.

    3) Limit development to parking, sanitation, visitor displays, and trails.

5. W-4 Ben Lomond High Lakes

  a. Description: see above

  b. Management:

    1) The site is to be managed for the preservation and enhancement of water quality and quantity and for aesthetics

    2) Construct an observation point at Ben Lomond look-out site.

    3) Construct helispots for fire protection to eliminate the need for roads.

37

D. The Special Zone--Middle Fork of the Feather River. This river
    has been designated a "Wild-Scenic River" under PL 90-542 on
    October 2., 1968. This classification extends 20 chains to both
    sides of the river bank. A management plan for this area is due
    in October 1969 in compliance with PL 90-542.

    As can be seen from the preceding descriptions, the major limita-
tion to the use of aerial photos for zoning purposes is that the zone
descriptions are not always in terms of features discernible on the
photos. For the most part, the descriptions are adequate for one
personally familiar with the area but not for one who is not. Of
course an interpreter could not be expected to delineate special use
areas such as GF-3 (Butterfly Botanical Unit), GF-4 (Lee Summit Seed
Production Area), W-2 (Rich Bar Historical Site), and U (Unclassified
Private Land), since these areas have no visible boundary that would
indicate an area of special interest. Other areas, however, could
perhaps be delineated with consistency on aerial photographs if the
descriptions of the zones were more explicit.

    As an example of some of the difficulties encountered, the follow-
ing are comments recorded by an experienced interpreter asked to deline-
ate the zones on an Ektachrome Infrared mosaic.

        GF-1 Scenic Backdrop: This zone provides the scenic back-
        drop for the travel influence and water influence zones. It
        consists of many irregularly shaped parcels. Frequently it
        is not evident for which travel and/or water influence zone
        the parcel provides a backdrop. Also, when this zone borders
        the water and/or travel zones there is no guideline for
        drawing the separating border between them.

        GF-2 Municipal Watershed: This zone includes the watershed that
        provides the water supply for the community of Quincy. The bound-
        ary for this zone can be delineated easily only if specific in-
        formation concerning the required watershed area is known.

GF-6 Scenic Roadside: These roadside strips border some, but
not all, of the existing roads, depending on whether the roads
are deemed to be of scenic value. The strips, by definition,
should not exceed 200 feet on each side of the road. It is
not clear which roads should be considered to be of scenic
value. Usually a scenic road is one that leads to an area of
high recreational value such as Deanes Valley, Snake-Smith
Lakes, or The Silver Lake Micro-Wilderness. If the scenic
roadside definition is changed accordingly, this zone can be
delineated consistently on aerial photographs.

Travel Influence: This zone borders all paved roads under
Forest Service jurisdiction in the District. No strip width
is given to border the roads and there is confusion as to
where the travel influence zone ends and where the scenic
backdrop area begins.

2. Development of remote-sensing oriented criteria

In view of the difficulties described above in applying photo inter-

pretation to existing zoning procedures, it was decided that much

could be gained by attempting to develop a multiple-use zoning process

particularly amenable to the use of aerial photography. Initially,

the question arose as to whether any new system should be tied to the

zoning concept, or whether some totally different way of integrating

potential land uses should be investigated. It was decided, however,

that despite its many apparent drawbacks, the concept of wildland zoning

probably best meets the needs of those asked to practice multiple use

land management in this area now. Perhaps in the future more refined

techniques for quantifying benefits derived from various uses and

arriving at benefit-cost solutions for land allocation may render the

zoning approach obsolete, but at the present time no such practices

appear to be fully operational.

A remote sensing oriented system, classifying lands in the Meadow

Valley Area should, in all probability, resemble the present system.

The primary difference would be the absence of reliance on an intimate

knowledge of the area in question and on criteria that can be gathered only on the ground. In other words, the land classification based on remote sensing should be viewed as an initial broad-scale planning aid, and not as a final map of the type needed for developing plans. It is likely that any operational use of small scale imagery for land planning would utilize interpreters trained in image interpretation and in the general requirements of multiple use planning, but who would not be extremely familiar with each plot of land to be zoned. This would be particularly true of any operation designed to uniformly zone large, widespread wildland areas, and would be even more true if it included areas previously little managed on an intensive basis. At the same time, it is felt that any general mapping system should be designed such that later modification and adjustment would be possible based on on-the-ground checks of areas with specific local requirements, thus providing the needed flexibility to move from the regional planning phase to actual unit management without a total reappraisal being necessary.

Thus the remote sensing oriented zoning system which follows was developed under the following assumptions and constraints:

1. It should provide the general kinds of information necessary for multiple-use planning as practiced by the U.S. Forest Service.

2. It should be amenable to subsequent refinement based on more specific information that might be obtained either from ground observation or through the use of more sophisticated remote sensing techniques.

3. It should be general enough to apply to rather diverse

·wildland environments.

4. It was assumed that the identification of (not to be confused with the interpretation) of specific wildland conditions is no more limiting than would be encountered using Ektachrome Infrared film at a scale of approximately 1:25,000. The determination of tone signatures and visual appearance of features on aerial images of various types is a separate problem not to be investigated in this study.

5. It was assumed that the interpreters would be reasonably experienced with the image types used, the general ecological relationships encountered in the area, and the broad requirements of the land use planners, but not intimately familiar with the particular area to be zoned or specific socio-economic factors which might affect land use decisions.

a) Selection of Zones

Based upon a thorough investigation of the various zoning procedures being followed on the National Forests of Northern California, a compilation of desireable zone categories to be included in the photo interpretation system was prepared. It was felt that the selection was general enough to apply at least to the bulk of the Westside Sierra Subregion, the Northeast Plateau Subregion, and the northern half of the Sequoia Eastside Subregion, as they are designated by the U.S. Forest Service. The list is in essence, a combination of the zoning systems used by each of the three Subregions, as it was found that some variability existed depending on the vegetation types occuring in each subregion and the date of preparation of the particular set of guidelines.

For reasons that will become apparent in later sections deal-
ing with the actual mapping procedures to be followed, the zones were
lumped into two groups: 1. General Zones, which are based on the
broad climatic-vegetation-topography factors prevailing in the area,
and 2. Use or Occupancy Zones, which are based on specific charac-
teristics of the local environment likely to influence ultimate use.
The determination of the final management to be applied to an area
is subtractive in nature. For example, all land classified as West-
side Intermediate is subject to the management directives of that
zone unless it is specified as constituting a Use or Occupancy Zone,
in which case the more restrictive directives will apply.

The following is a list of the zones with accompanying descrip-
tions and appropriate management guidelines. However two points should
first be emphasized: 1. Much of this material is not wholly original,
but is an amalgamation of descriptions and directives contained in the
Forest Service Management Guides for the three subregions mentioned
above. Much more detailed management directives can be found in those
Guides. 2. Further refinement of the directives for some Use and
Occupancy Zones will be held independent of the surrounding General Zone.

I. General Zones

    A. Valley Front

        Description: Generally lower elevation areas below the inter-
        mediate zone, and fronting on the Sacramento Valley. Vegeta-
        tion consists of grass, oak-woodland, or brush, with scattered
        low-elevation conifers in some localities.
        Management: Primary emphasis will be placed on the preserva-
        tion, maintenance, and improvement of the plant cover so as

to furnish optimum conditions for wildlife and livestock grazing. This includes an active awareness of the potential for fires, and both on-site and downstream needs for watershed protection. Recreational use will not be encouraged. Few timber management practices are necessary.

B. Westside Intermediate

Description: Generally heavily timbered areas lying in mid-elevations (range approx. 2000' to 7000') between the Valley Front Zone and the Crest Zone. Vegetation consists primarily of conifers and occasional dense stands of middle elevation brush species.

Management: Primary emphasis is placed on maximum production of forest products on a sustained basis, with concurrent maximum production of water from snowpack in higher elevations. Secondary emphasis is on the maintenance or improvement of forage production for wildlife or livestock on areas unsuited for timber production. Transitory forage types should be utilized in a manner consistent with ultimate timber production. Recreational use will usually be limited to peripheral activities originating in other high recreational use zones.

C. Crest

Description: A high-altitude zone, characterized by rugged peaks, rocky slopes, plateaus, lakes, meadows, and sub-alpine tree species.

Management: Primary emphasis is placed on the value of this zone as the principal watershed for most major rivers of the region. Thus activities which adversely affect the quality,

timing, or quantity of water flowing from the zone will be
avoided. The second important use for the zone is mountain
type recreation, and the need for such use will be met to the
limit of available resources without impairing watershed or
scenic values.

D. Eastside Intermediate

Description: A mid-elevation zone lying generally east of
the Crest Zone, and bordered to the east by the Basin Front.
Vegetation is primarily coniferous, sometimes intermingled
with brush and other semi-arid forage species.

Management: Primary emphasis is on maximum production of
timber on a sustained basis. Secondary emphasis is on the
maintenance of forage values for wildlife and livestock.
The arid nature of the zone precludes a high emphasis on
watershed management needs.

II. Use of Occupancy Zones

1. General Occupancy

Description: All lands which are presently in an "improved"
state rather than in the undisturbed wildland state. Includes
primarily built-up areas and lands obviously in private
commercial agriculture and ranching.

Management: While these lands do not fall under the direct
jurisdiction of public wildland management agencies, some
adjustments may be necessary in adjacent wildland areas.

2. Streamside

Description: Includes all live streams (including intermit-
tent streams) and associated riparian areas. Also includes a

44

border fringe of vegetation of sufficient width to protect

the channel, and scenic canyon walls where applicable.

Management: Objectives are to minimize siltation, channel

blockage, channel alteration, and temperature increases.

Merchantable trees may be cut within the streamside border on

an individual selection basis, but only when such cutting will

not adversely affect the stream or desireable residual growth.

Cutting in general forest zones up-slope from streamside

zones should be carefully planned such that erosion, sliding

logs, etc. do not adversely affect the stream environment.

3. Water Influence

Description: Areas of varying width along <u>specific</u> streams

or lakes which due to their scenic values and/or accessibility

promise particularly attractive potential for recreational use.

Should include an area large enough to protect the water and

near view scenery, as well as provide for necessary recreational

developments.

Management: Emphasis is on the preservation of the aesthetic

environment, including the quality of the pertinent lakes

or streams. Development of recreational facilities as neces-

sary should be undertaken, with appropriate concern given to

protection against water pollution, damage to the environment,

and protection against fire. Timber cutting should be limited

only to high-risk trees and that necessary for construction of

roads, campgrounds, and other developments.

4. Travel Influence

Description: Areas of varying width which border main highways

and roads. The area should be wide enough to protect
the near-view aesthetics.

Management: Timber cutting within this zone will be limited
to high-risk trees or those necessary for construction of
rights-of-way, scenic overlooks, adequate fire protection
breaks, and other necessary developments. Emphasis is on
maintaining the natural appearance of the zone.

5. Scenic Roadside

   Description: Areas of varying width along secondary roads
   of particular scenic value. Generally these will be roads
   providing access to special scenic zones or water influence
   zones.

   Management: The aim will be to remove trees on an individual
   selection basis while maintaining a near-natural appearance in
   the roadside strip.

6. Distant View areas

   Description: This zone provides scenic backdrop to the Water
   Influence, Travel Influence, and special recreation zones, and
   is located beyond near-view areas, either above or below the
   elevation of the travel route or recreation use area.
   Management: Activities should closely parallel those of the
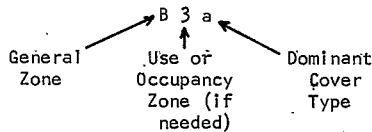   surrounding General Zone, with the proviso that the shape, size,
   and timing of patch or group cutting and construction of roads
   should be such that a pleasing backdrop is maintained for the
   recreational or travel use zones.

   Finally, it was felt that some indication of the dominant cover
type would be helpful for planning the ultimate use of each area.

46

Consequently twelve cover type designations were selected for inclusion
in the final zone description code.

b) Zone Description Code

It was anticipated that when zoning maps were finally completed,
a simple coding system would be needed which would indicate the zone
description assigned to each area. Hence a three character code was
adopted as follows:

```
                    B 3 a
                    ↑
        General    Use or    Dominant
        Zone       Occupancy  Cover
                   Zone (if    Type
                   needed)
```

    I. General Zones
      A. Valley Front
      B. Westside Intermediate
      C. Crest
      D. Eastside Intermediate

    II. Use or Occupancy Zones
      1. General Occupancy
      2. Streamside
      3. Water Influence
      4. Travel Influence
      5. Scenic Roadside
      6. Distant View Area
      7. No use or occupancy designation

   III. Dominant Cover Type
      a. Dense mature conifer forest
      b. Sparse mature conifer forest
      c. Dense young conifer forest
      d. Sparse young conifer forest
      e. Dense chaparral
      f. Sparse chaparral
      g. lush herbaceous vegetation
      h. dry herbaceous vegetation
      i. riparian hardwood vegetation
      j. dry-site hardwood vegetation
      k. semi-arid shrubs
      l. bare rock or soil

Thus the example code, "B 3 a", indicates an area in the Westside Intermediate Zone which, in terms of use or occupancy, is of importance primarily as a Water Influence area, and which has a dominant cover consisting of dense mature conifers. Obviously, if no use or occupancy zone were involved, the code would consist of a code such as "C 7 1", indicating a Crest Zone with predominant bare rock or soil cover.

A source of confusion could arise, however, if when mapping use or occupancy zones, one discovered that more than one designation applied to the same piece of ground. The degree of "restrictiveness" of the management to be applied to the zones helps to remedy this situation--i.e. if there is a conflict, the more restrictive zoning will apply, as indicated in the following table.

Conflicting Designations	Designation to be Used
1,2	1
1,3	1
1,4	1
1,5	1
1,6	1
2,3	3
2,4	4
2,5	2
2,6	2
3,4	3
3,5	3
3,6	3
4,5	4
4,6	4
5,6	5

V. · Planned Completion of Study

It is planned that the multiple use study described above will be completed within the next several months. Among those sections which are scheduled for inclusion in further reports are the following:

1. The development of mapping criteria amenable to the use of image interpretation techniques for multiple use planning. Prime consideration will be given to such factors as amount and kind of supplementary information needed in addition to the images themselves, the minimum size of land area that merits its own classification, and the number of classes that should be recognized.

2. The development of image interpretation keys and guides applicable to the mapping system developed in (1) above.

3. A classification of one or more test sites using the criteria and guides described above, and a subsequent objective evaluation of their usefulness.

4. An analysis of the potential applicability to multiple use planning of advanced techniques presently being developed. Included in this analysis will be specific applications of satellite photography, automated interpretation techniques, color enhancement of multispectral and sequential imagery, and capabilities of sensors operating in other than the photographic portion of the spectrum.

Future Research Activities

A number of projects, either currently in progress or soon to be undertaken by the unit are listed ·below. The list is presented here as an indication of the types·of investigations. that are considered to be appropriate undertakings of the unit.

A. In order to adequately determine those areas of earth resource management to which remote sensing techniques might most usefully be applied, interviews with resource management personnel responsible for making. policy decisions are being undertaken. Hopefully such interviews wil·l provide a basis for further benefit-cost studies.

B. A survey is bei·ng made of current state-of-the-art procedures for determining benefits der·ivable from operational remote sensing systems.

C. A compilation, on a continuing bas·is, of ·the results of actual tests of image interpretation and data extraction, using various sensor types and interpretation methods is being made, as are appropriate evaluations of the validity and significance of such tests.

D. Following completion of each of the successive compilations in 3 above, recommendations will be prepared regarding the need for and type of tests of image interpretation which are needed to supply the necessary inputs for benefit-cost calculations.

E. Investigations of the operational requirements by foresters and other managers of wildland resources for a large scale system of image acquisition and data distribution as envisaged by proponents of earth resource satellite programs could be

undertaken. These studies would include image specifications, distribution procedures, and types of interpreter training (to be carried out in cooperation with the Training Unit).

F. Tests are being developed to quantitatively evaluate various interpretation techniques in terms of the ability of each to satisfy specific operational needs. The Multiple Use study currently being conducted by the unit is an example of this type of activity. (Details of that study are presented in a later section of this report).

G. Periodic cooperative undertakings with the Training Unit in the form of seminars, discussion groups, and training pro-grams are planned. In addition to the dissemination of infor-mation, the inputs from representatives of various sensor and application disciplines will be collated, discussed, and included in surveys of both technical feasibility and user needs.

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SPECTRAL CHARACTERISTICS OF FEATURES AND CONDITIONS

Edwin H. Roberts

Introduction

This unit is responsible for investigating and characterizing the spectral properties of wildland resource features and conditions. The data should provide criteria for discrimination of features of interest and for the understanding of sensor returns. In addition, the unit will seek to determine those parameters which significantly affect the spectral characteristics of features and conditions of interest, and investigate the manner in which they operate. Test site ground intrumentation and consultation with experts from other fields will be utilized in investigation of these parameters. Knowledge of the spectral properties of features is necessary for effective interpretation of multispectral sensor returns and specification of necessary ground truth data.

A. Studies conducted within the unit.

1. Develop operational procedures for gathering meaningful spectral reflectance and emission data in a wildland environment through the use of portable equipment to observe radiance phenomena of natural features *in situ*.

2. Characterize temporal variations in the spectral returns of features of the wildland environment and investigate the parameters responsible for these variations.

3. Determine those time periods and those parts of the spectrum to be utilized for greatest discrimination between features of interest.

4. Monitor incident radiation and reflectance from selected
   neutral targets at the time of photographic overflights
   in order to facilitate calibration of the resultant imagery.

B. Studies involving interactions with other units.

   1. Operational Feasibility.   Determine that type of spec-
      tral data which can best be utilized to satisfy ultimate
      user requirements and devise and recommend procedures and
      methods by which the pertinent data can be most efficiently
      obtained.

   2. Image Interpretation and Enhancement.   Collect and
      analyze spectral ground truth information in order to
      explain sensor returns as necessary for effective image
      interpretation. Help determine what types of ground truth
      information that are necessary to establish feature conditions.
      By analysis recommend those film-filter combinations most
      likely to result in images which are easily interpreted
      or enhanced for identification of specific features or
      conditions by spectral signatures.

   3. Automatic Image Classification and Data Processing. Examine
      relationships between automatic image classification and
      the spectral characteristics of the features being classi-
      fied in order to help determine the actual on-the-ground
      factors responsible for differentiation of classification
      units.

   4. Training.   Provide training material and examples for
      understanding of spectral characteristics and their utili-
      zation in remote sensing. Provide classroom and field
      instruction for this aspect of remote sensing.

Current Research Activities

Introduction

A study was initiated in order to assess the feasibility of making _in situ_ spectral reflectance measurements of wildland vegetation and to compare. the radiance levels from the resulting data with optical density as measured from multiband photography. A portion of the NASA Bucks Lake test site was used as a study area and several brushfield species common to the area were used as targets for the spectroradiometer measurements.

Mature brushfields are often impenetrable and topography frequently limits ground visibility. Consequently, ground inventory of the interior of large brushfield areas is virtually impossible. Since a knowledge of brushfield species composition is important for many types of management planning, it was of interest to determine whether several of the prevalent brush species could be identified from their tone. signatures on multiband aerial photography.

As a point of departure in making this determination it was considered desirable to attempt a systematic analysis of factors affecting the photo images of plants, as in the following section. Then, in view of that analysis, a meaningful experiment could be performed to determine the feasibility of identifying important brush species. Such an experiment is described and the results of it are presented and analyzed in subsequent sections of this chapter.

Factors Affecting the Photo Images of Plants

The appearance of a plant on aerial photography of a given scale is influenced by several factors including (1) its morphological characteristics, (2) its spectral reflectance characteristics

56

`(3) its seasonal state or state of maturity, (4) the sun angle, (5)
the spectral sensitivity of the film and (6) the spectral transmit-
tance of the photographic filter. It is difficult to discuss each
of these factors separately since the effect or relative importance
of each is often determined by the particular combination of all
factors. With these limitations in mind, the following brief summary
of the effects of each factor is presented.

1. The morphological characteristics of the plant include size,
shape and orientation of the leaves, plant height and foliage density.
These factors affect the textural appearance of the plant and also
determine the proportion of reflectance from leaf surface and from
stems, other plant parts and underlying litter and soil. As applied
to a photographic image, "texture" may be defined as the frequency of
tone change within the image.

2. The spectral reflectance characteristics of a healthy
green plant are governed primarily by its foliage. In a broader
sense, however, a plant's reflectance represents an integration of
the reflectance contributions from its leaves, stems, flowering parts,
and fruits and may even be influenced by spectral characteristics
of the underlying soil and litter.

3. The seasonal state or state of maturity may change the
spectral reflectance of a plant by altering the proportion of plant
parts mentioned above. Flowering, for instance, usually occurs during
a short period of each year; deciduous plants, of course, are leaf-
less during a period of each year and present a dramatically different
appearance than during their leafy stage. Furthermore, the fall
coloration of some deciduous plants is distinctive enough to be

an identifying characteristic. Because of these factors, the "spectral signature" of a plant species may vary during the season and during its life.

4. The <u>sun angle</u> affects the amount of shadow present in the photographic image and the depth to which the plant canopy is illuminated. When the sun is at the zenith, the illumination of the plant interior, i.e., stem and dead material, and of the underlying soil and litter is greatest. As the angle from the zenith increases the proportion of reflectance from the outer leaves increases while that from stems, litter and soil decreases as they are immersed in shadow.

5. <u>Spectral sensitivity of the film</u>. The "tonal response" with which a plant is recorded on an aerial photograph is a function not only of the intensity of the reflected energy returned from the plant but also of the sensitivity of the film to this energy. Both the intensity of reflected energy and the sensitivity of the film vary according to wavelength; thus, the appearance of a plant will vary according to the type of film used.

6. The <u>spectral trasmittance of the filter</u> governs the wavelengths of light allowed to strike the film. Filters used in the acquisition of aerial photography preferentially absorb some wavelengths of energy and transmit others. Many filters are available, each allowing passage of a different band, or wavelength interval of energy. Since both the energy return from the plant and the sensitivity of the film vary with wavelength, it is often possible by selecting the appropriate combination of film and filter to utilize those wavelength intervals which result in maximum response differences between one particular plant species of interest, and all other species with which it might be confused.

58

Reflectance Phenomena of Plant Parts

From the foregoing discussion it becomes apparent that, in order to exploit the benefits of multispectral techniques as an aid in the absorption and transmission phenomena of plant structures, particularly leaves, should be known and understood.

Although radiant energy striking a leaf surface can be absorbed, reflected, transmitted or scattered, a downlooking photographic system detects only the radiant energy reflected from the scene below. The greater the reflected energy from a plant or other fea-ture, the brighter the tone with which that feature will be registered on a positive photograph. There are basically two types of reflectance, specular or direct, and diffuse or scattered. The total reflectance from a material is equal to the sum of the specular and the diffuse reflectance fluxes.

Specular reflectance occurs when the incident energy falls on a surface which has only small irregularities compared with the wave-length. For such surfaces the angle of incidence equals the angle of reflection, as from a mirror. Among natural objects, smooth water surfaces and some rock outcrops exhibit specular reflectance.

Diffuse reflectance occurs from a surface having irregulari-ties that are large with respect to the wavelength of the radiant energy. The diffusely reflected energy tends to be scattered equally in all directions irrespective of the angle of incidence. Among natural surfaces displaying essentially diffuse reflectance are blown sand (Romanova 1964) and some vegetated surfaces.

Mixed reflectance occurs most frequently in nature. In this case the reflecting surface returns radiant energy both diffusely and specularly. Depending on which type of reflectance predominates, the

59

various kinds of surfaces found in nature display reflectances encom-
passing the entire gamut from one extreme to the other. The reflec-
tance properties of surfaces can be represented graphically in the
form of polar diagrams where the length of any particular radius
vector corresponds to the reflected radiant flux in that direction.

Leaves vary from those with an extremely glossy cuticle where
reflectance is largely specular, to those with essentially matte sur-
faces where reflectance is almost entirely diffuse and approximately
follows Lambert's cosine law (Myers and Allen, 1968). Most leaves
exhibit a mixture of specular and diffuse reflectance. At grazing
angles the specular component from the upper surface of a leaf may
be large; however, as the incident angle decreases the specular
component rapidly decreases and the reflection becomes more diffuse
due primarily to multiple internal reflections. Howard (1966),
working with eucalypts in Australia, found that at small incidence
angles, the reflection pattern of those leaves does not greatly dif-
fer from the pattern of well-known matte surfaces. At larger angles
the pattern was of the mixed reflectance type.

Most leaf constituents are relatively transparent, and with the
exception of the pigments found in the chloroplasts, do not absorb
significant amounts of energy in the visible and near infrared wave-
lengths (400-900nm) used in aerial photography. The typical leaf
anatomy (Figure 3.1) is such that there are many air-water interfaces
between the cell walls and the intercellular spaces. The change of
index of refraction from 1.33 for water in the cell walls to 1.00 for
air in the interspaces provides for efficient internal reflections
at these interfaces (Gates et al, 1965). Although there may be many
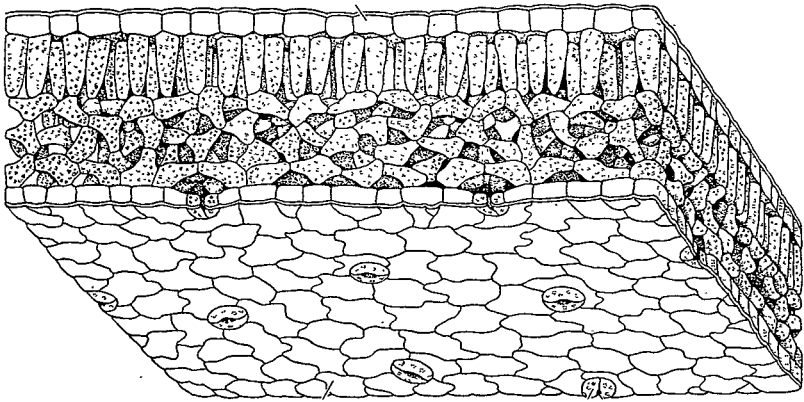
Figure 3.1 This drawing of a typical leaf anatomy (from Gates, 1965)
emphasizes the large amount of air space present. The great number
of air-water interfaces at the cell walls are effective reflectors
of radiant energy. Chloroplasts in the cells absorb at the blue and
red wavelengths, but otherwise cell materials are quite transparent;
therefore, most of the infrared and much of the green energy escapes
the leaf as reflected or transmitted light, as indicated by the
curves in Figure 3.2.

such reflections, if there is little absorption, much of the radia-
tion which would have otherwise passed through a leaf is instead
returned as a component of the reflected radiation.

The radiant energy leaving a leaf from the side opposite the
illuminating source, i.e., the shaded side, is defined as the trans-
mitted component. Usually this transmitted energy emerges only after
multiple internal reflections and, except for direction, is completely
analogous to its counterpart emerging from the illuminated side.

Figure 3.2 shows that qualitatively the spectral distribution of
radiant energy from a leaf is very similar to that reflected from it.
Only energy that is absorbed by a leaf can be used by it in photo-
synthesis and other biological processes. Consequently, the radiant
energy transmitted through a leaf and that reflected from a leaf to-
gether comprise that part of the radiant energy incident upon the leaf
which has been unused.

Although most leaf components are relatively transparent, plants
abs~rb energy very efficiently at those wavelengths required for pho-
tosynthesis. The predominant leaf pigments, chlorophyll a, chlorophyll b,
carotene, and zanthophyll all absorb in the vicinity of 445nm in the
blue part of the spectrum. In addition, chlorophyll absorbs in the
vicinity of 645nm in the red part of the spectrum. A small part of
the energy which is absorbed by chlorophyll (Figure 3.3) undergoes a
wavelength change and is emitted as fluorescent energy. Most impor-
tantly, another part is converted photochemically into stored energy
in the form of organic compounds which are then available as sources
of energy to the plant itself and to other organisms which can not
utilize light energy directly to synthesize food, but can utilize
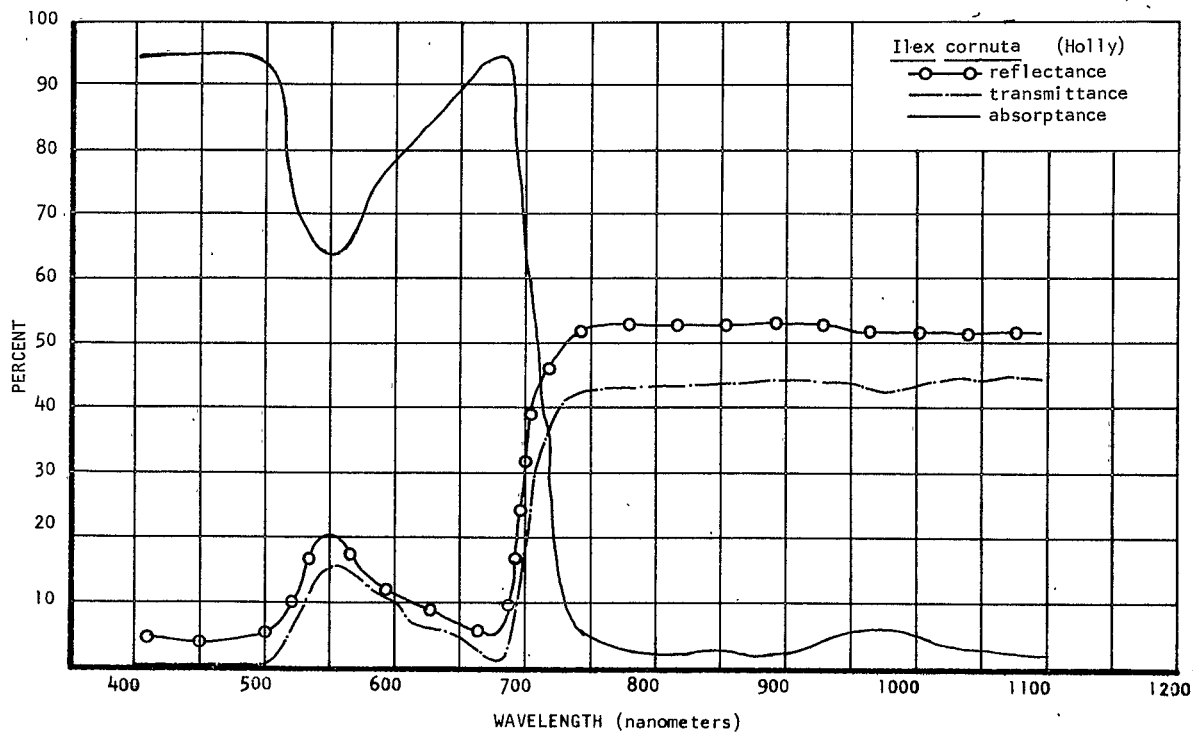
Figure 3.2 Curves showing the relative amounts of energy reflected, transmitted and absorbed in the visible and near infrared regions of the electromagnetic spectrum by leaves of holly (Ilex cornuta) as a function of wavelength of the incident energy. (After Gates et al, 1965)

63
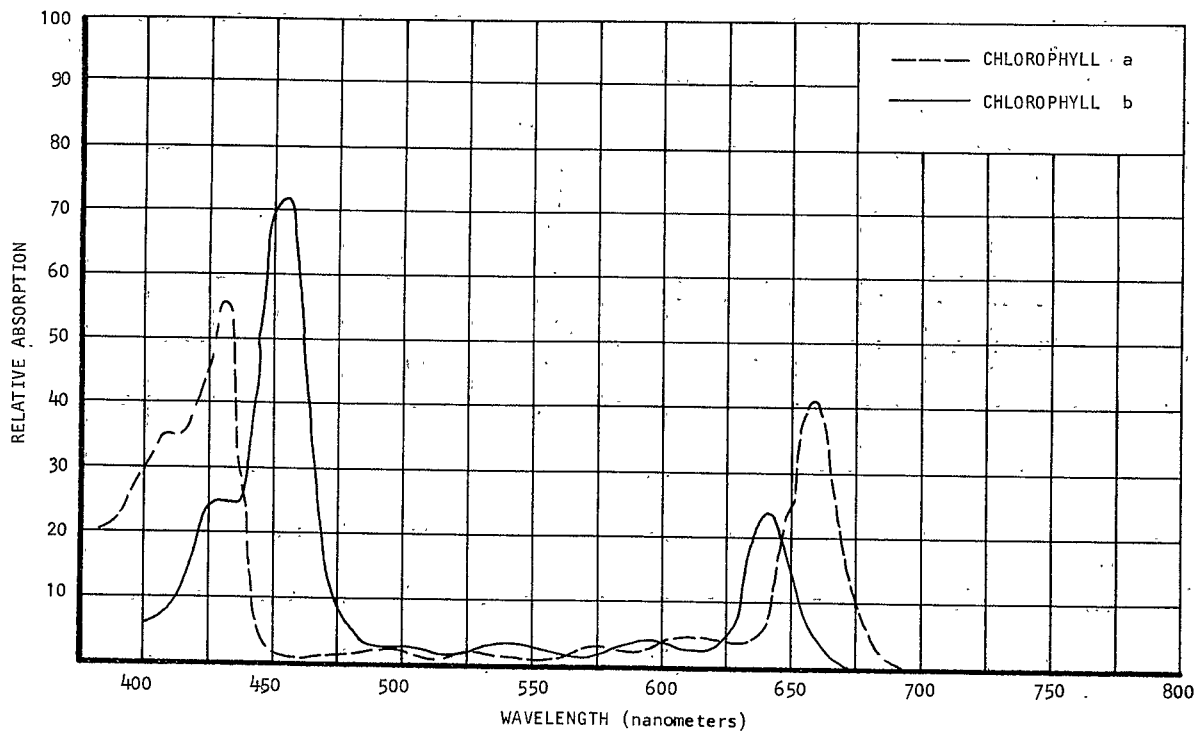
Figure 3.3 Curves showing relative absorption of chlorophyll a and chlorophyll b as a function of wavelength. The combined absorption would be a summation of the two curves at each wavelength.

light energy directly to synthesize food, but can utilize plant mate-
rials as food.

Laboratory Measurements of Spectral Reflectance

Spectral reflectance data for plant species have most often been
obtained using laboratory spectrophotometers to obtain measurements
from severed leaves mounted as flat samples. The following para-
graph outlines the use of one such instrument, a General Electric
recording spectrophotometer.

In order to obtain a reflectance measurement, the sample and a
reflectance standard (MgO) are both mounted against openings in the
integrating sphere of the spectrophotometer. They are illuminated at
an angle of five degrees from the vertical by essentially monochro-
matic light which is alternately directed at the sample and the
standard by a rapidly rotating prism and a decentered lens.

The illuminating energy is varied in wavelength from 400 to
1000 nanometers by a monochrometer system. The reflectance is alter-
nately measured from the standard and sample by a photocell mounted
on the integrating sphere. The reflectance from the sample is recorded,
wavelength-by-wavelength, as a percent of the reflectance from the
standard, the latter having been chosen because it gives essentially
100 per cent reflectance at all wavelengths, within the range recorded
by the instrument. The data are commonly expressed in graphical form
with reflectance plotted on the ordinate and wavelength on the abscissa.

Laboratory measurements of reflectance from surfaces are help-
ful in choosing filters that pass wavelength bands in which there
are maximum differences in reflectance levels between subjects for

which discrimination is desired. However, laboratory measurements of reflectance from leaf surfaces have three major limitations when used to estimate the reflectance that will impinge on an airborne sensor from an entire plant canopy: (1) The spectral reflectance from such a canopy may not be the same as the reflectance from individual leaf samples. Furthermore, plant reflectance is a composite of the reflectances from variously oriented and variously illuminated leaves, stems and underlying soil and litter. (2) The density of a plant's foliage and the orientation of its leaves with respect to both the sun and the sensor may have a great influence on the spectral reflectance of the plant as recorded by the sensor. (3) Laboratory measurements are obtained with artificial illumination. The resulting data are plotted for a constant spectral intensity source, whereas in a natural scene as recorded by an airborne sensor the intensity of the illuminant, (consisting of direct sunlight, diffuse skylight and reflectances from nearby objects) varies greatly as a function of wavelength.

Field Measurements of Spectral Reflectance

Field measurements of spectral reflectance overcome many of the limitations inherent in the laboratory. Measurements are made with the plant illuminated by sunlight, skylight and light reflected from nearby objects, as it is when recorded by a remote sensing device. In addition, it usually is possible for the field of view of the instrument to encompass an area of plant canopy large enough to integrate the reflectance from leaves, stem, soil and litter. However the making of field measurements entails certain other difficulties.

66

Field measurements are more prone to variation than laboratory measurements because of the less controlled conditions usually prevailing. Changeable conditions, such as weather, illumination and terrain, make replication of experiments difficult. It may be expected, then, that there should be somewhat greater variability in the reflectance data reported for a species when such data are gathered by field measurement as compared with laboratory measurement.

The field measurements of spectral reflectance used in this study were made with an E.G.&.G. spectroradiometer model 580/585. This instrument measures spectral intensity in absolute radiometric units. (watts/cm^2/nm) through a spectral range of 350-1200 nanometers. When the instrument is used as configured for this study, the bandpass around any central wavelength in its spectral scan is 20nm in the visible and 40nm in the IR region. For field use, the unit is powered by a self-contained, rechargeable battery capable of operating the unit for several days before requiring recharging. The instrument is of modular construction consisting of the beam input, optics monochromator housing, a detector head and an indicator unit. The complete instrumentation package weighs approximately 35 pounds.

For measurement of spectral reflectance from brush plants, the instrument was mounted on a heavy-duty tripod which allowed it to be raised as much as eight feet above the ground. This put the instrument three to four feet above the top of the brush in most instances. (Figure 3.4) The instrument has a nominal field of view of fourteen degrees. At the usual viewing distance of three to four feet, the reflectance from an area of crown canopy nine to twelve inches in diameter is received by the detector. This size roughly corresponds with

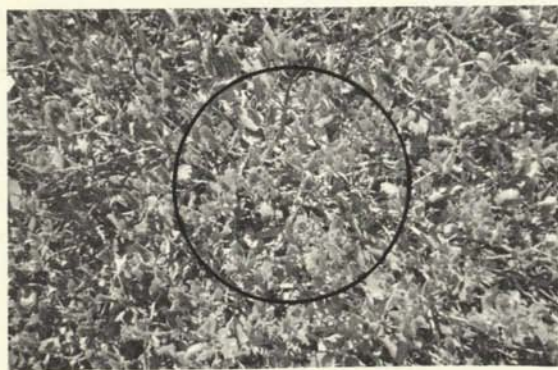67

Figure 3.4 The spectroradiometer is shown here being used at the NASA Bucks Lake Test Site to make spectral reflectance measurements from brush plants. In this example, reflectance from snowbrush (<u>Ceanothus velutinus</u>) is being measured. The circle on the lower photo shows approximately the area from which the spectroradiometer accepts reflectance, i.e., the instrument's field of view.

the resolution of the aerial photography used in this study; there-
fore, the integrating effect of the photograph and the spectroradiometer
should be about the same.

Preliminary testing indicated that specular reflectance was an
insignificant factor at instrument angles of less than forty degrees
from the vertical at the time of year when the field data were obtained.
(August and September) The data acquired for this study were at instru-
ment angles of less than ten degrees. In order to further ensure that
specular reflectance would not pose a problem of variability, the
instrument was always oriented at right angles to the shadows when-
ever it was necessary to deviate from the vertical.

It was felt necessary to take these pracautions because very
little work had been done on field measurement of plant reflectance.
The Russian worker, Krinov (1947), did some excellent preliminary
work in the late 1930's on reflectance from natural formations, but
this apparently was never pursued farther. In the present study,
only limited tests could be made of the effects of various angles
of inclination of the instrument from the vertical, in relation to
sun angles and azimuths. However, these tests indicate that the
reflectance data reported here do not suffer significantly from vari-
ability due to these factors.

The process of obtaining a reflectance reading for a brush
plant involved first selecting an "average" plant in a location which
was favorable for setting up the instrument. In order that data
from several plants could be acquired each day, only a limited area
was covered. Because data were acquired only with relatively high
sun angles, that is, during midday, only a short time each day was

69

available for collecting data. The time required for instrument set-up and data recording at each spot was about thirty minutes for one man working alone.

The instrument, elevated above the brush on a tripod head, was operated through its spectral range by first fitting a grating mono-chrometer functioning in the 350-800 nanometer range, and an accompany-ing detector head sensitive in this range; then, after irradiance had been read at intervals through this range, monochromater func-tioning was switched to the 700-1200 nanometer range and a detector sensitive in these wavelengths was used. The signal from the detec-tor head was read on the indicator unit and recorded on a data sheet.

This raw data thus obtained were adjusted in the office to com-pensate for the spectral sensitivities of the detector heads. The adjusted data in units of watts/cm^2/nm were displayed as graphs show-ing irradiance at the detector as a function of wavelength.

Multispectral Photography of the Study Area

Photography that had been taken with each of the following eight film-filter combinations at an original scale of 1/5, 100 on June 25, 1968, was available for study:

Film	Type	Filter	Viewing Form
Plus-X Aerographic	2401	Wratten 25	Opaque Print
Plus-X Aerographic	2401	Wratten 61	Opaque Print
Infrared Aerographic	5424	Wratten 89b	Opaque Print
Infrared Aerographic	5424	Wratten 47b	Opaque Print
Ektachrome Aero	8442	No Filter	Transparency

Cont.	(film)	(type)	(filter)	(viewing form)
	Ektachrome Aero Infrared	8443	Wratten 12	Transparency
	Ektachrome Aero Infrared	8443	Wratten 12 + CC30B	Transparency

This multispectral photography was taken with a specially con-
structed aerial camera capable of simultaneously photographing a
scene on two separate rolls of 70mm film. On each roll of film
two frames are simultaneously exposed through separate lenses, and
each lens is separately filtered. This results in four film-filter
combinations of a scene being simultaneously exposed. The result-
ant spectral sensitivities for the four black-and-white film and fil-
ter combinations used in this study are shown on the following pages .
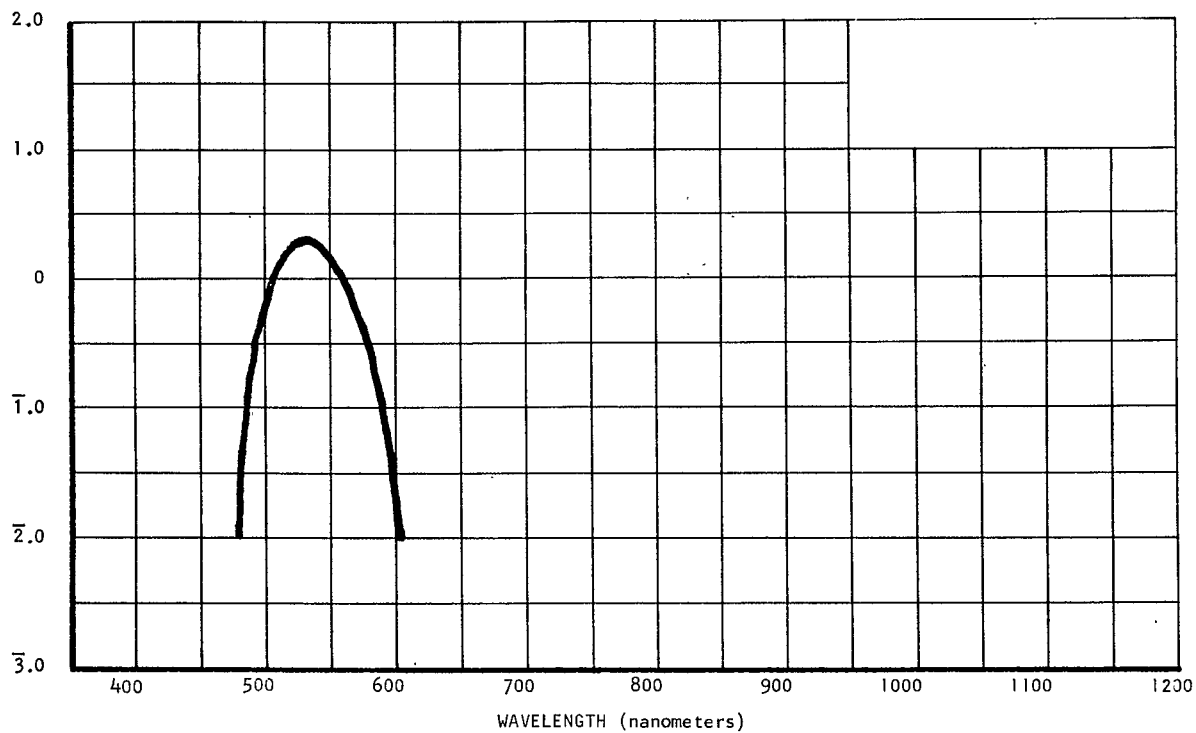
Figure 3.5 Resultant spectral sensitivity of Plus-X Aerographic film used with a Wratten 61 filter.
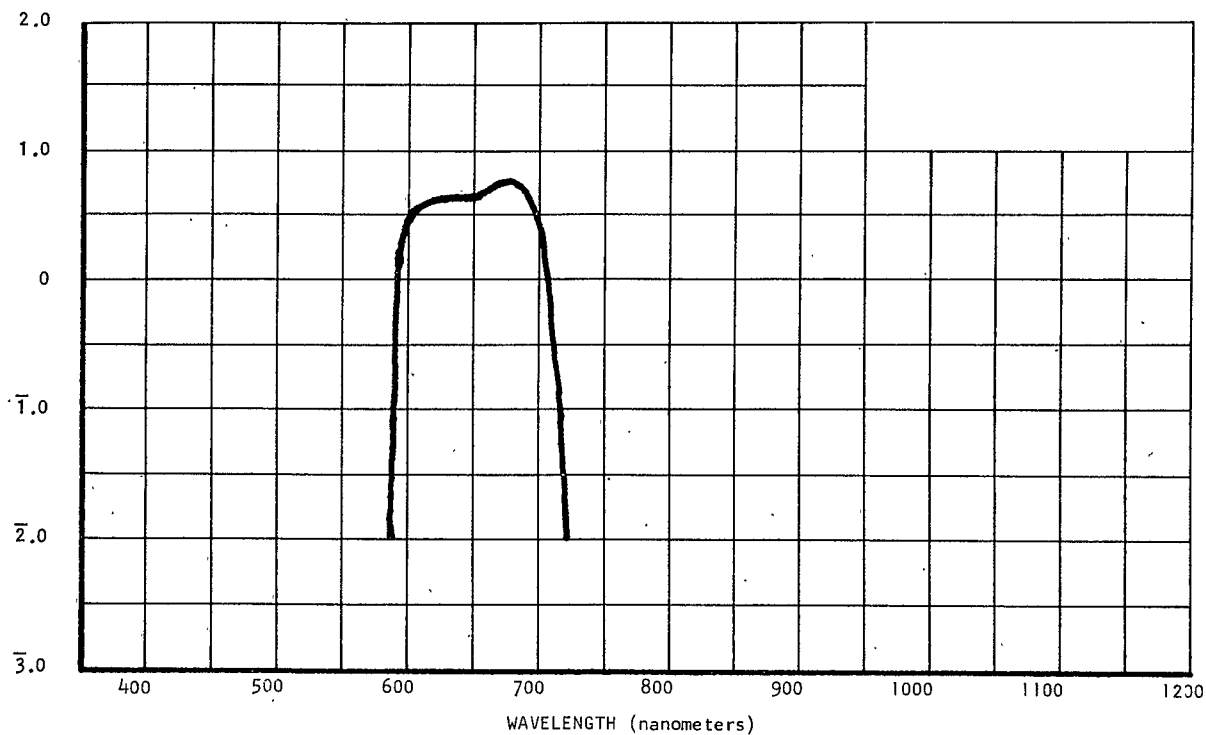
Figure 3.6 Resultant spectral sensitivity of Plus X Aerographic film used with a Wratten 25 filter.
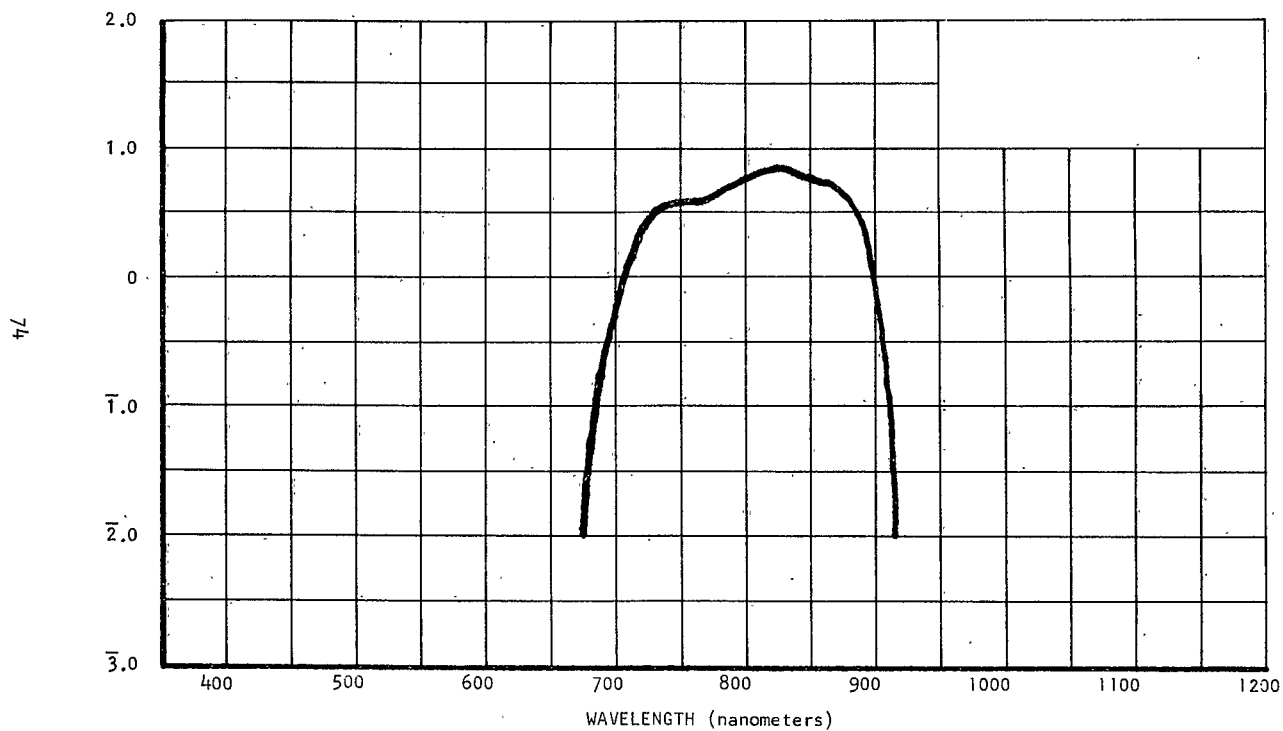
Figure 3.7 Resultant spectral sensitivity of Infrared Aerographic film used with a Wratten 89B filter.

74
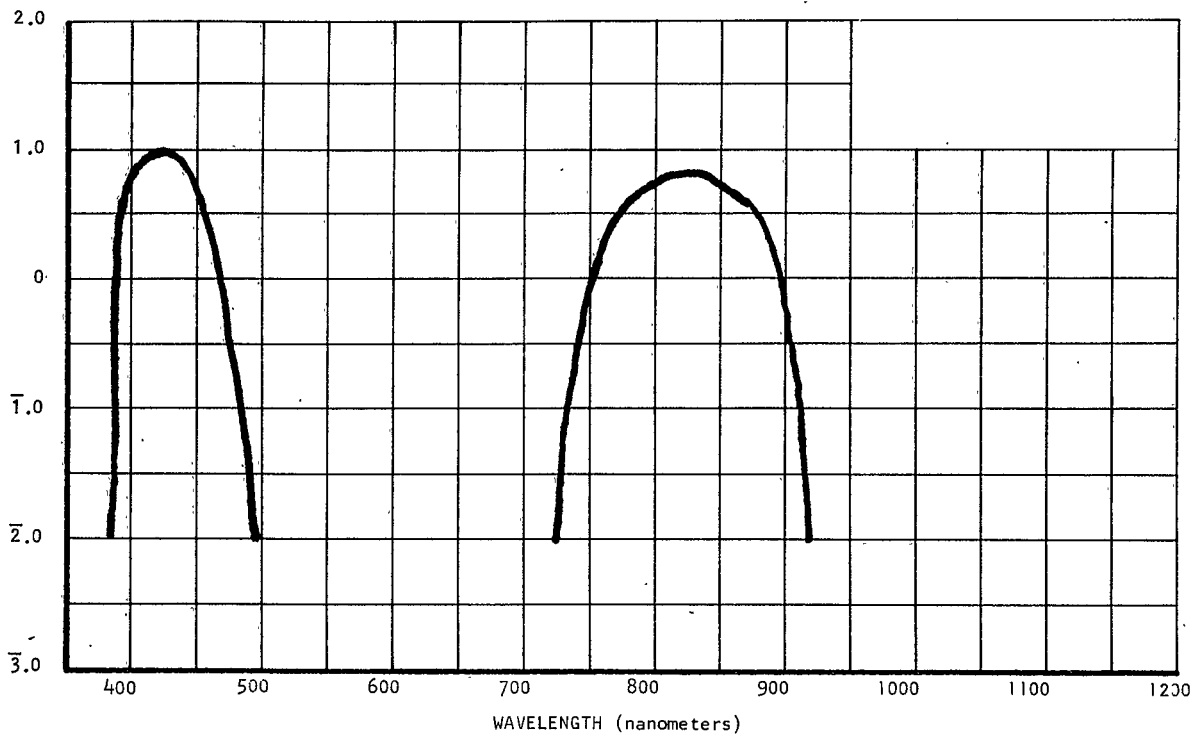
Figure 3.8 Resultant spectral sensitivity of Infrared Aerographic film used with a Wratten 47B filter.

Collection of Ground Truth Data

The area covered by the multiband photography was visited on the ground by a two-man crew during September. Individual brush plants were identified on the ground and then located on 1/1000 scale vertical color photography in the form of paper prints. The location was marked by pinpricking the image and the plant identity was annotated on the back of the photograph for future reference. In this manner several hundred individual plants and groups of plants were identified and located.

The area covered by the photographs contains primarily mixed brushfields, that is, brushfields which contain several species of plants in a heterogeneous admixture. Because of this it was unusual to find even a small area covered by only one species of brush. At the scale of the color prints used in the collection of ground truth it is possible in most cases to resolve individual brush plants as large enough images to have distinguishable color characteristics. However, at the 1/5000 scale of the multispectral imagery this is not usually the case.

Comparison of Spectral Reflectance Data and Photographic Image Tone

The aerial photo images are uncalibrated data and, therefore, comparisons of absolute quantitative values between images from different spectral bands are not valid. However, comparisons between species on any given film-filter combination and relative ranking of species between film-filter combinations can be made.

A Welsh densitometer was used to make measurements of optical
density on the negatives for images of the following four brush types:
snowbrush (Ceanothus velutinus), manzanita (Arctostaphylos patula),
whitethorn (Ceanothus cordulatus), and alder (Alnus rhombifolia). The
measurements were made for each of the black-and-white film-filter
combinations, and thus optical densities for images of each of the
species can be compared in each of three broad spectral bands--namely
green, red and near-infrared. (By inspection of the data, relative
difference in the blue part of the spectrum may be inferred.)

Optical density is a measure of the opacity of the negative
image formed in the film emulsion after it has been exposed and pro-
cessed. The higher the numerical value, the greater the negative
density, or opacity. On normally processed photography obtained with
any given film-filter combination, density on the negative is governed
by: (1) the total amount of radiant energy striking the film in the
wavelength interval that is being sensed for and (2) the net sensiti-
vity of the film within that same wavelength interval.

The ranking of species on an optical density scale for any given
film-filter combination can be compared with a ranking of their reflec-
tances as obtained from spectroradiometer readings for the wavelength
interval to which the particular film-filter combination responds.
At the time of this writing a comparison of optical densities cannot
be made between film-filter combinations because the density measure-
ments for this set of photography have not yet been normalized.

If the spectral reflectance measurements for the brush species
are valid analogs of the spectral irradiance at the film as reflected
from those brush species, then there should be good correlation between

the rankings of species by optical density data and spectral re-
flectance data.

Results

Comparison of the data tabulated in Figure 3.9 for four plant
species, and the summary curves shown in Figure 3.10 for the same four
species reveals that, for the spectral regions shown, there is a
good correspondence between the optical density of the film emul-
sion as exposed in the aerial camera and the spectral reflectance
as measured in situ by a field spectroradiometer.

The tabulations of optical density in Figure 3.9 show a range of
values obtained from fifteen measurements of each plant species. The
optical density values for the plant species can be compared only
within spectral bands. For example, values for whitethorn and man-
zanita can be compared for the spectral interval to which the Plus-X
Aerographic film and Wratten 61 filter combination (Pan 61) is
sensitive, but the optical density value of whitethorn for the Pan 61
film-filter combination cannot be compared with its value for the
IR89B film-filter combination. The reason for this is that differ-
ences in exposure or processing can raise or lower the absolute value
of optical density for the film negative. Processing differences
can also change the film gamma so that the effect of a change in film
irradiance is stretched out or compressed on the optical density
scale. While the absolute optical density values are thus changed,
none of these factors will change the relative positions of the plant
species on the optical density scale for a given photograph.

The curves of spectral reflectance shown in Figure 3.10 are averages

78
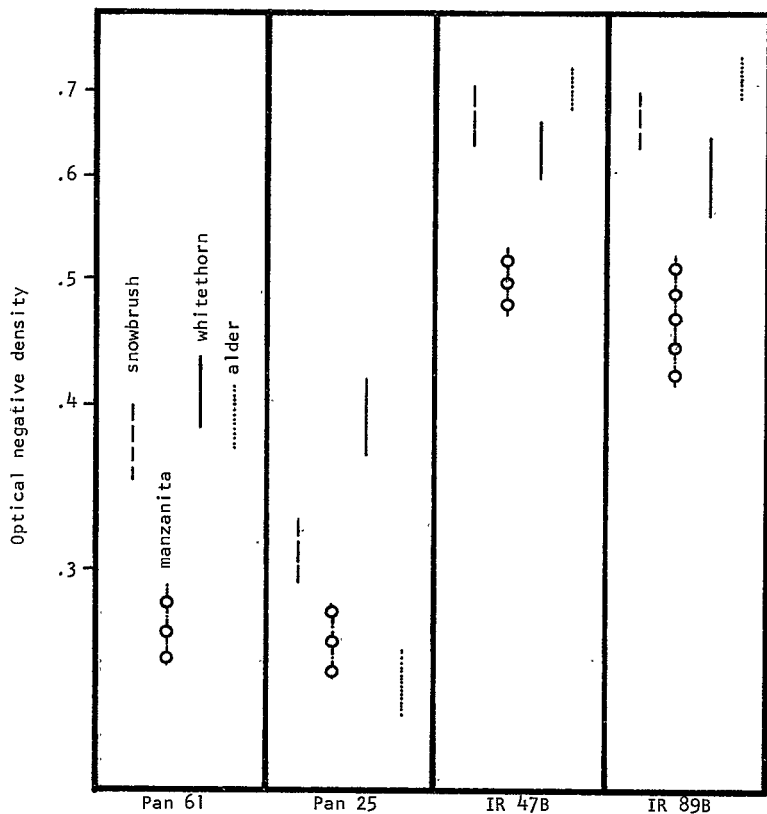
Figure 3.9 The summary of data shown above for four brush species indicates the range of optical density values measured on each film-filter combination. Comparison with Figure 3.10 shows the good agreement in ranking with these film density measurements and the spectral reflectance measurements made in the field with a portable spectroradiometer.
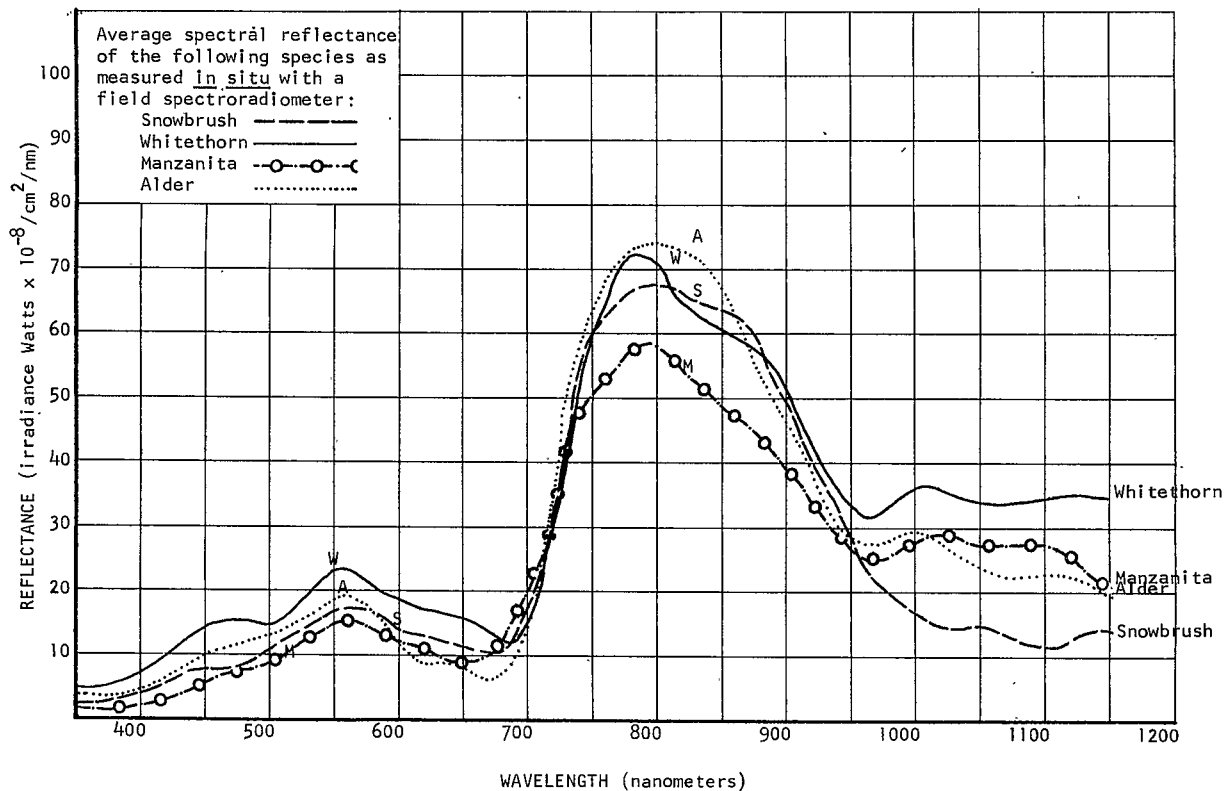
Figure 3.10 Field spectroradiometer measurements of average reflected energy as a function of wave-length for the plant species shown in the legend above.

of from two to five individual curves from each species. The "within species" variability of spectral reflectance readings is great enough to preclude identification of a species on the basis of reflection from one spectral region alone. However, when the reflectances from several spectral regions are examined in concert, the chance of species identification becomes considerably better.

It is difficult and tedious to interpret black-and-white images simultaneously. One solution may be to optically combine the black-and-white images into a color composite such as that shown in Figure 3. This procedure has the advantages of color presentation and selection of optimum wavelength bands. Potentially, such a procedure would result in the formation of a composite image containing more information relevant to species identification than is contained in present color films. At the same time, it would be more interpretable than its black-and-white components.

The gelatin absorption filters that were employed for the photography used in this study are relatively broad-band filters. That is, they allow a broad wavelength interval of light to pass. In this case, the green, red and near-infrared spectral regions were separately utilized, but the blue and infrared were combined. A plant species can display very obvious differences in relative tone value when photographed with these combinations. For example, alder, which is intermediate in tone on the Plus-X Wratten 61 photograph, is the darkest vegetation feature among those studied when viewed on the Plus-X Wratten 25 combination and the lightest when viewed on the infrared combinations.

The optical density values summarized in Figure 3.9 shows grey

Projection   Multiband   Colored   False-color
System   Images   Filters   Enhanced Image
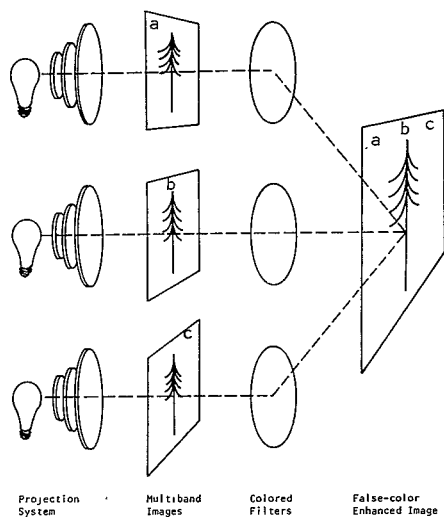
(after Lauer, 1967)

Figure 3.11 To produce multi-color image enhancement, transparencies acquired with different film-filter combinations are projected in common register, each through a different colored filter, onto a screen. The information content of the composite image is the sum of the information from the individual images as suggested by the letters a, b, and c at the top of the images.

scale rankings for four species. If they were ranked according to grey-scale tone with "1" the lightest and "4" the darkest, and then were presented in the order that the spectral bands are presented in that figure, each could be identified according to its unique "signature" as follows:

snowbrush	3-2-2-2
whitethorn	1-1-3-3
manzanita	4-3-4-4
alder	2-4-1-1

However, notice that on any given film-filter combination the range of optical density readings for one species may overlap that for another species. Consequently, identification cannot generally be made on the basis of one spectral band as might at first appear possible.

Conclusions

The results of this study indicate that, for the species of brush plants investigated, there are sufficient differences between spectral reflectance signatures to permit species identification through comparison of optical density values on multispectral aerial photography. The spectral reflectance characteristics of these species when gathered in situ with a field portable spectroradiometer agree in ranking with the optical density of the image as measured on the negative. Although it was not the intent of this study to predict the relative density levels of brush species on the film-filter combinations used, it appears that this could have been done. In situ measurements show more promise for these predictions than laboratory measurements of leaves only because the in situ measurements can provide an integration of all the factors which contribute

to the reflectance of a plant or plant association as seen from the aerial view.

In this experiment it was necessary to obtain all spectral measurements under cloudless sky and within a limited angle of solar elevation in order to ensure that the illumination would be as uniform as possible for all measurements. It would be desireable in future work to monitor the intensity and spectral characteristics of the illumination so that spectral measurements of plant reflectance could be obtained under a variety of conditions and adjusted to a "standard" illumination. Such a procedure would allow direct comparison of data obtained under different conditions; the effectiveness of a program for in situ spectral reflectance measurements would thus be greatly enhanced, even though meaningful results were obtained in the present test despite a lack of such monitoring.

Future Research Activities

The unit anticipates acquisition of equipment for monitoring the spectral intensity of incident illumination. The use of this, together with present equipment, will allow meaningful in situ spectral reflectance data to be obtained for natural features under a variety of illumination conditions and then be standardized so that valid comparisons can be made among all the data.

A variety of data recording systems are being evaluated in order to provide faster data acquisition in the field and efficient interfacing with the data handling facilities within our Forestry Remote Sensing Laboratory. The adaptation of such a system would allow many more reflectance measurements to be made at each location and provide

a better statistical base for the analysis of data.

Studies are planned to characterize the change in spectral reflec-
tance of selected wildland features as a function of detector-target-sun
angles for changes in both azimuth and elevation.

A study will be implemented to define natural features which are
of sufficient size and spectral stability to be used as natural cali-
bration targets for multiband photography.

In order to determine the type of ground truth necessary to define
a natural resource and its condition for remote sensing purposes, a
study to define the effect of several ground truth parameters on the
spectral reflectance of various wildland features will be instigated.
The results should indicate what kinds of ground data are important
and with what degree of precision each needs to be measured for various
levels of interpretation accuracy.

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CHAPTER 4

IMAGE ENHANCEMENT AND INTERPRETATION

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Introduction

A primary role of the Forestry Remote Sensing Laboratory is to demonstrate
the overall value and feasibility of collecting useful earth resource data
from aircraft and spacecraft. In order to carry out this important responsi-
bility, it is imperative that we continue to utilize state-of-the-art sensors
and the latest image interpretation and enhancement techniques. The basic
function of this Laboratory Unit is to develop a thorough understanding of
the components of the image interpretation process. This effort involves a
continuation of on-going research in several forest and range environments
and centers on two major objectives: (1) evaluation of human/psychological
factors (i.e., color-tone perception, photo interpretation skill, fatigue,
etc.) and technical/physical factors (i.e., film-filters, resolution, expo-
sure, processing parallax, distortions, etc.) influencing the interpreta-
bility of imagery, and (2) developing a methodology for extracting useful
resource information from imagery (i.e., feature description, key preparation,
interpretation tests, enhancement equipment, sampling procedures, etc.)

The following sections of this chapter describe in detail three case
studies. The tests performed at the Klamath Falls site demonstrate the
value of small scale aerial photography for stratifying valuable homogeneous
forest stands. Such forest stratification information can then be used as
the first stage in a multistage sampling scheme whereby more detailed forest
inventory data can be obtained. The study done at the Bucks Lake site shows,
when proper image interpretation techniques are employed, ultra-high altitude
photography is useful to the wildland manager for mapping ground cover types,
for monitoring changes in ground cover with sequential coverage and for

87

selecting primary sample units for more detailed study in multistage sampling. Work done at the Mississippi/Louisiana site evaluates the potential for land use mapping on Apollo 9 photography. The degree of image detail, the synoptic view and sequential coverage are among the parameters studied which affect the interpretability of land use categories on space photography.

Literature Review

Depending upon the kind of forest survey information needed, photographic scale specifications can vary widely. Studies that have been conducted in a variety of forest environments support the conclusion that certain broad mapping objectives can be met adequately through the use of photography flown at a scale of 1/30,000 or smaller. For acquiring detailed information regarding species composition and timber stand volume, however, it is generall· recognized that larger scale photography must be used.

Kummer (1964) reports that panchromatic photographs, scale 1/60,000, were successfully used on Weyerhauser timberlands in southwestern Washington to determine the presence or absence of timbered land and to ascertain how these lands were situated with respect to the existing road network. Photo map enlargements (4X) were prepared for coordination with existing logging progress maps and to extend map coverage to scattered holdings where existing maps were not available. These photographs served many other purposes: They provided the basis for preparing fire report maps and maps that could be used to portray plans for aerial seeding, spraying or planting; they facilitated the location of areas in which snag-falling operations should be conducted or where road maintainance and construction should be undertaken. Wind damage from the hurricane of October 12, 1962, was quickly assessed from such photographs taken within 30 days following the damage. Previous photography was compared with the new photography to isolate the newly-

damaged areas and to make damage appraisals and salvage plans. These appli-
cations indicated that a number of practical uses can be made of very small
scale photography by commercial timber managers.

Forest inventory studies were carried out in Maine by Young, et al.,
(1963) using a combination of aerial and ground techniques. It was deter-
mined that essentially the same information could be derived on photos flown
at a scale of 1/31,680 as on those flown at a scale of 1/15,840. In this way,
costs of flying, mapping and interpretation were substantially reduced.
Eight classes of pulpwood stands were typed on the photography, with four
vegetation classes and two categories of merchantability for each vegetation
class. Field sampling in strips resulted in changing only 1% of the type
delineations.

Small scale (1/30,000) panchromatic aerial photographs have been used
to improve the management of many resources of East Africa. Howard (1965)
indicates that nine important vegetation types could be identified on the
basis of tone and texture, and sometimes shadow. This information was used
to program timber cruises and to locate areas for permanent forest reserves.
Using these same photographs, areas suitable for new agricultural settlement
could be identified, and other areas best suited to grazing by livestock
could be located. Information regarding existing management of settled areas
could be derived from the photographs, thereby indicating where adjustments
should be made in the balance between forestry, agriculture and grazing uses.

An interesting timber volume estimation study has been reported upon
by Swellengrebl (1961) for "greenheart" (Ocotea rodiaei) timber in British
Guinea. The assumption that greenheart volume per acre is constant has been
proved to be correct by correlating timber volume, measured in the field,
with the areas of Greenheart-bearing forest types, measured on type maps pro-
duced from photo interpretation. Of the five forest types which could be

distinguished, two classes--Mixed Rain Forest and Greenheart Forest--were found to contain Greenheart trees. For this study, the error of estimation in a land area containing a year's production harvest was 15%, which was deemed adequate for the purposes of the inventory.

The success of interpretation on small scale panchromatic photographs (1/50,000) has also been documented in a forest survey of 3,400,000 hectares of the Caspian forests of Iran which was begun in 1958 (Rogers, 1960, 1961). Four forest types were identified: beech, oak, mixed hardwoods and cypress. Within these types, it was possible to recognize three density classes (poor, medium and well stocked) and four stand height classes (seedling and sapling; pole trees; young sawtimber, and old sawtimber). As has been mentioned for other studies of this kind, the photographs themselves served as map substitutes and were used for field planning and guidance. Estimates of forest growth and volume on a per hectare basis were made using multiple regression techniques and data from ground surveys.

An indication of the range of success possible with vegetation classification using 1/40,000 scale panchromatic photographs is given by two studies in tropical forest environments. Dillewijn (1957) has prepared a selective key for identifying vegetation types on aerial photographs of northern Surinam. Within five broad classes of vegetation (coastal, swamp, marsh, savannah and dryland forest) 28 distinct types were identified. The main identifying characteristic was the appearance of the stratum as a whole, i.e., the upper canopy as a continuous surface. In contrast to Dillewijn's success, Loetsch (1960) could recognize only two strata on the same type and scale of photography. Working in the uniform lowland Semangus forest of South Sumatra, he could distinguish only (1) the heavily exploited perimeters and (2) the undisturbed centers of forests. Complications in making distinct stratifications were caused by local differences due to topographic changes

and the complex mixtures of some species. A significant amount of variability
in ease of interpretation of small scale photography appears to be induced
by ecological factors and the complexity of the area being inventoried.

Encouraging success in inventorying extensive forest areas in the
Amazon basin of Brazil is summarized by Heinsdijk (1960). The objective
of this study was to obtain data about the composition of mixed tropical
rain forests as a base for better economic consideration of the resources
of this area. Trimetrogon photography was available at a scale of 1/40,000
on the vertical photograph. Using this imagery, the following tasks were
judged to be the easiest to perform: map artificial features; determine the
borders of rivers and seas where not obscured by vegetation; delineate the
boundaries between forest and scrub/grass savannahs. Of more importance,
photo interpretation techniques permitted several forest formations to be
mapped, including saltwater swamp, sweetwater swamp and marsh, and dryland
forests. Within the dryland forest formation, it was also possible to dis-
tinguish secondary forests (with a pattern of shifting agriculture) and
savannah (or caatinga) forests. Only when a formation contains unique tree
species (such as Rhizophora mangle and Avicennia nitida in saltwater swamp
forests) can floristic names be assigned. In such cases, identification of
particular species is inferred from recognition of the forest formation.

From Heinsdijk's work it was also discovered that with clear photog-
raphy the same forest formations could also be identified at the center of
the oblique trimetrogon photographs where the scale was approximately
1/70,000. If vertical photographs taken at this smaller scale has been pro-
cured, the cost of photography could have been nearly halved. And, perhaps
more importantly, almost twice as much area could be photographed on the
same few cloudless days. This latter advantage takes on increased signifi-
cance when one considers that, in a humid tropical area, very few days are

sufficiently cloud-free to permit the taking of aerial photography.

Another aspect of this study relates to the actual planning for exploitation of valuable tree species of tropical forests. If these particular trees to be harvested can be located with certainty, it would justify procurement of larger scale photographs and the preparation of stand maps for management purposes. This justification can also be warranted when one considers the difficulty of engaging in field work in the swamp and marsh areas. Photo interpretation results have been shown to produce more reliable results than ground sampling, and the time savings that result from reducing field work also can be very significant.

The advantages of large scale photos, on the one hand, and of small scale photos on the other, as highlighted in the preceding paragraphs, can be realized when both types of photography are combined in some form of sampling scheme. Conventional forest survey techniques have long used one scale of aerial photograph to stratify forest land prior to employing ground survey procedures to obtain inventory data. The advantages of using both large and small scale photographs in addition to ground survey methods can be exploited most fully when two or more scales of photography are integrated into a multistage sampling design. In an early article entitled, "Futuristic Photo Interpretation", A. J. Nash (1963) suggested that combining large scale sample photography with small scale coverage "shows promise for the future". He envisioned that small scale photos would be used to determine stand type, height, canopy density and acreage of stands. Photographs of large scale would be used to make detailed measurements and to complete more valid appraisal of stand conditions. Although he was considering small scale photographs, of scale 1/20,000, it has been demonstrated (Langley, et al., 1969) that for certain applications space photographs (scale 1/3,000,000) can serve satisfactorily as the first stage of the sampling design.

A. FOREST TYPE MAPPING - KLAMATH FALLS TEST SITE.

Studies conducted at the San Pablo Reservoir Test Site (Lauer, 1967) and the Flicker Ridge Study Area (Lauer, 1968) indicate that homogeneous forest stands can be identified and mapped on small scale (1/30,000) multispectral aerial photography. In each study, trained photo interpreters used photo interpretation keys and refer- ence materials prepared for the study area to perform the tasks. In both cases, Infrared Ektachrome film was judged slightly superior to other film types for interpretation purposes. In addition, substantial savings in interpretation time were noted for Infrared Ektachrome film.

As a sequel to these investigations, it was deemed necessary to evaluate the possibilities for performing the same mapping tasks on panchromatic (Wratten 25A filter) and Infrared Ektachrome (Wratten 12 plus EF-2200 filters) photographs of even smaller scale (1/30,000 to 1/100,000). For this purpose, a 72 square-mile area located 25 miles north of Klamath Falls in south-central Oregon was chosen (referred to as Klamath Falls Test Site) to test the relative interpretability of the two film types. Relatively homogeneous stands of the following forest species are found within the Test Site: (1) Ponderosa pine (Pinus ponderosa), (2) Lodgepole pine (Pinus contorta), (3) Mixed Conifer - consisting primarily of ponderosa pine, lodgepole pine, sugar pine (Pinus lambertiana), and white fir (Abies concolor), and (4) Quaking aspen (Populus tremuloides).

Of these forest types, ponderosa pine and the mixed conifer type have the greatest economic value to the forest manager. In the Test Site, lodgepole pine is of secondary economic value but is now being

harvested to provide pulpwood supplies for Oregon paper mills. Quaking

aspen is one of the more common riparian species that occurs in small

isolated stands and has little or no economic value in this area.

Because there are differences in the relative value of these forest tree

species, the preparation of an accurate forest type map is the first

step in the inventory phase of any extensive forest management project.

Improved photo interpretation techniques will reduce the costs of

completing such inventories.

On August 29, 1968, a commercial photographic firm flew the

prescribed flight lines using the following film, filter, and scale

combinations:

1. Complete coverage, 1/50,000 scale:

   Plus-X Aerecon (8401) with Wratten 25A filter
   IR Aerographic (5424) with Wratten 89B filter
   Ektachrome Aero (8442) with HF-3 filter
   Ektachrome Infrared Aero (8443) with Wratten 12 plus
       EF-2200 filters

2. Complete coverage, 1/25,000 scale:

   Ektachrome Aero (8442) with HF-3 filter
   Ektachrome Infrared Aero (8443) with Wratten 12 plus
       EF-2200 filters

3. Coverage of 25% subsample, 1/10,000 scale:

   Plus-X Aerecon (8401) with Wratten 25A filter
   Ektachrome Aero (8442) with HF-3 filter
   Ektachrome Infrared Aero (8443) with Wratten 12 plus
       EF-2200 filters

Ground surveys were made with the photography in hand to study

the forest types of the Test Site. Recently prepared maps of forest

types on lands of the Winema National Forest in the Test Site were

used as the base for preparation of a ground truth map. Type bound-

aries were updated by field checking, and the remainder of non-Forest

Service land in the Test Site was mapped using the same legend system.

Reference materials and a dichotomous key were prepared for administering the interpretation test. Photo examples of each forest type and representative density classes were prepared from photographs of analogous areas adjacent to the Test Site. The dichotomous keys for panchromatic and Infrared Ektachrome film types appear in Table IV-1A and IV-1B.

The testing procedure was administered in its entirety to two photo interpreters. Both were trained with the appropriate photo interpretation techniques and showed proper motivation and good judgment in performing the various tasks associated with completing the test. Each followed the steps as outlined in Table IV-2.

The information derived from photo interpretation was compiled in map form. Type boundaries from the photographs were transferred to a map sheet using a Kail plotter. Planimetric maps of equal scale (1/30,000) were produced in this manner. The ground truth map was reproduced at the same scale as the maps from interpretation results so that visual comparison for accuracy could be made. Photo reproductions of the finished maps appear in Figure 4.1.

An area calculation device was used to compare, stand by stand, the ground truth map with each interpreter's results for each film type. The results of these comparisons appear in Table IV-3. Summarized in chart form are the individual results for each interpreter and the combined results for both interpreters. Also given is the actual distribution of cover types. In each chart, the cover type categories are listed in rows, and each interpreter's results are arranged in the columns. For example, in chart #1, Interpreter 1's

Table IV-1A Dichotomous photo interpretation key for four Oregon forest
types. (Klamath Falls Test Site)

Film: Panchromatic (8401) with Wratten 25A filter
Season: Late summer seasonal state
Scale: 1/50,000

1. Small isolated stands having medium grey tone. <u>Populus tremuloides</u>
                                                                2.

1. Extensive continuous stands having dark to very dark grey tone.

    2. Stands of heterogeneous tone and texture which occur on moderately
        moist protected slopes which usually face north and east.
                                                   <u>Mixed conifer</u>

    2. Stands of homogeneous tone and texture which occur on flatlands or
        dry slopes which usually face south and west.   3.

3. Fine-textured stands which are dark to very dark grey in tone and occur
    on wet flats and/or imperfectly drained slopes.   <u>Pinus contorta</u>

3. Coarse-textured stands which are dark grey in tone and occur on dry well-
    drained south- and west-facing slopes.   <u>Pinus ponderosa</u>

Table IV-1B Dichotomous photo interpretation key for four Oregon forest
types. (Klamath Falls Test Site)

Film: Infrared Ektachrome (8443) with Wratten 12 + EF 2200
       filters
Season: Late summer seasonal state
Scale: 1/50,000

1. Small isolated stands having bright magenta color. <u>Populus tremuloides</u>

1. Extensive continuous stands having medium or dark magenta to purple
    color.   2.

    2. Stands of heterogeneous color and texture which occur on moderately
        moist, protected north- and east-facing slopes. <u>Mixed conifer</u>

    2. Stands of homogeneous color and texture which occur on flatlands or
        dry slopes.   3.

3. Fine-textured stands which are dark magenta to purple in color and occur
    on wet flats and/or imperfectly drained slopes.   <u>Pinus contorta</u>

3. Coarse-textured stands which are medium magenta in color and occur on
    dry, well-drained south- and west-facing slopes. <u>Pinus ponderosa</u>

Table IV-2   Instruction sheet for photo interpreters - Klamath Falls Forest
             type mapping study.

I.   Training Period #1 (panchromatic photography)

     A. Study each stand description in the photo interpretation key.

     B. Analyze each of the stand types as shown in the photo examples.

     C. Classify example forest stands (6 mi^2) with reference to the dichoto-
         mous key, tree description and photo illustrations.

         1. Identify species composition (numerator)

Symbol	Species
PP	ponderosa pine
LP	lodgepole pine
MC	mixed conifer
A	aspen
N	non-stocked

         2. Estimate timber density (denominator)

Symbol	Density	Percent of total ground space covered by crowns
1	Dense	80-100
2	Semidense	50-80
3	Open	20-50
4	Very Open	5-20
5	Unstocked	0-5

     D. Check results and review.

II. Interpretation Period #1 (panchromatic photography)

     A. Review each stand description in the photo interpretation key.

     B. Review example forest stands.

     C. Classify forest types within the 66 mi^2 test area

         1. Identify species composition (numerator)
         2. Estimate timber density (denominator)

III. Training Period #2 (same as #1, but with Infrared Ektachrome photography)

IV. Interpretation Period #2 (same as #1, but with Infrared Ektachrome
     photography)
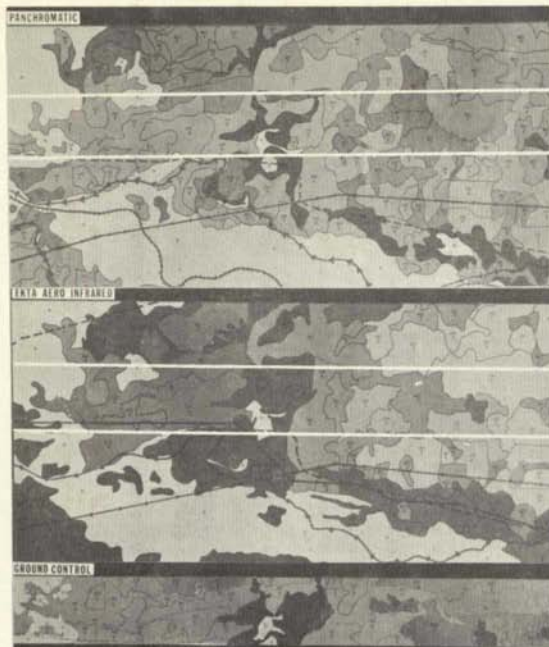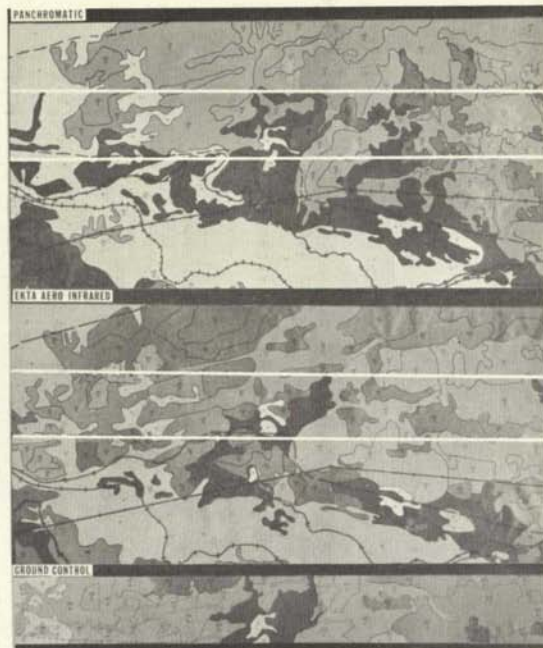
Figure 4.1 Reproduced here are forest type maps prepared by each interpreter for both panchromatic and infrared Ektachrome film types. The following key to each type is helpful in comparing results: tan=ponderosa pine; red=lodgepole pine; green=mixed conifer; yellow=non-stocked. The outlined strip across the center of each map is the area for which "ground truth" was available. A ground truth map for that strip is reproduced below each pair of maps for comparison.

Table IV-3 Interpretation results for Klamath Falls forest type mapping test. (Percent identifications for two interpreters using panchromatic and infrared Ektachrome films).

Interpreter #1

Percent Identified As

Cover Type	Total Area mi^2	PP	MC	LP	NS
PP	33.6	73.9	17.1	0.8	8.2
MC	19.1	17.6	79.6	2.8	-
LP	7.3	41.2	6.9	47.1	4.8
NS	6.0	14.1	1.1	5.4	79.4

Total % Correct: 72.6

Panchromatic

Percent Identified As

Cover Type	Total Area mi^2	PP	MC	LP	NS
PP	33.6	10.2	69.9	13.0	6.9
MC	19.1	62.3	36.2	1.5	-
LP	7.3	3.5	13.3	78.9	4.3
NS	6.0	-	10.9	5.9	84.0

Total % Correct : 32.0

Infrared Ektachrome

Interpreter #2

Percent Identified As

Cover Type	Total Area mi^2	PP	MC	LP	NS
PP	33.6	56.6	10.5	13.3	19.6
MC	19.1	70.4	26.0	3.6	-
LP	7.3	27.9	24.5	46.1	1.5
NS	6.0	2.0	-	7.0	91.0

Total % Correct: 49.2

Panchromatic

Percent Identified As

Cover Type	Total Area mi^2	PP	MC	LP	NS
PP	33.6	65.1	19.4	1.8	13.7
MC	19.1	62.6	30.2	6.9	0.3
LP	7.3	19.6	33.0	42.0	5.3
NS	6.0	25.9	1.9	1.9	70.3

Total % Correct: 52.6

Infrared Ektachrome

results are given for panchromatic film. The first row contains information regarding how well ponderosa pine was identified. Of the total area, 33.6 square miles, of ponderosa pine, 73.9% was correctly identified (first row, under PP). However, 17.1% was incorrectly identified as mixed conifer (first row, under MC), 0.8% was incorrectly identified as lodgepole pine (first row, under LP), 8.2% was incorrectly identified as non-stocked (first row, under NS). Percentages outlined in the boxes are correct identifications for each category. No data is presented for quaking aspen because all stands of this species were less than the 40 acre size minimum for mapping.

One of the most obvious results from the study is the relatively low accuracy achieved in overall correct identification of the various types for both interpreters. (Summary of results in Table IV-4). In only two cases (both for category NS) did the interpretation accuracy exceed 80%. In addition, there were better results for certain type categories on panchromatic film than on Infrared Ektachrome film.

Results with both film types for identifying ponderosa pine and mixed conifer types were generally poor. Since these types are economically more important than the others, the results are especially disappointing. However, much of the overall discrepancy occurs between these two types. If they are grouped into a single category, this category can be identified with much higher success (85.5% on panchromatic film, 86.7% on Infrared Ektachrome film) than as individual types. The justification for such grouping lies in the fact that both types have similar commercial value; thus, for certain purposes, a system employing only three categories (non-stocked, lodgepole pine, and commercial conifer) would be quite satisfactory.

100

Table IV-4 Summary of Percent correct identification of Oregon forest
types. (Data for PP and MC given individually and grouped.)

Interpreter #1

	Pan 25A			IR Ekta	
Type	%	%	Type	%	%
PP	73.9	} 93.2	PP	10.2	} 86.3
MC	79.6		MC	36.2	
LP	47.1	47.1	LP	78.9	78.9
NS	79.4	79.4	NS	84.0	84.0
Overall Accuracy	72.6	86.9	Overall Accuracy	32.0	85.2

Interpreter #2

	Pan 25A			IR Ekta	
Type	%	%	Type	%	%
PP	56.6	} 77.8	PP	65.1	} 87.1
MC	26.0		MC	30.2	
LP	46.1	46.1	LP	42.0	42.0
NS	91.0	91.0	NS	70.3	70.3
Overall Accuracy	49.2	75.4	Overall Accuracy	52.6	80.6

Average

	Pan 25A			IR Ekta	
Type	%	%	Type	%	%
PP	65.3	} 85.5	PP	37.7	} 86.7
MC	52.8		MC	33.2	
LP	46.6	46.6	LP	60.5	60.5
NS	85.2	85.2	NS	77.2	77.2
Overall Accuracy	60.9	81.2	Overall Accuracy	42.3	82.9

Without such grouping, average overall correct identification for panchromatic film (60.9%) is greater than for Infrared Ektachrome film (42.3%). Using the grouping for ponderosa pine and mixed conifer types, Infrared Ektachrome (82.9% correct identification) film provides slightly better results than panchromatic film (81.2%). Since the data are not consistent for both interpreters, it is difficult to determine from these results which film type is superior. In a forthcoming test of this same area, more interpreters will be used so that a statistical treatment of the data will be possible.

Data were collected regarding the time required for interpretation. A summary of the time needed to interpret each type of photography can be found in Table IV-5. Both interpreters completed their work in much less time using Infrared Ektachrome film (reduction of 32% in time required) than when using panchromatic film. This finding coincides with results from earlier tests (Lauer, 1968) regarding interpretation times. The implication of this conclusion is that, even though the difference in interpretation accuracy between Infrared Ektachrome and panchromatic film may not be great, the savings in time might warrant using Infrared Ektachrome film for mapping forest types.

Another factor which affects the accuracy of the results is that photographs were interpreted without the benefit of stereo coverage. This limitation was placed on the study because it is believed that stereo parallax will have negligible influence on satellite imagery of forested areas. In the Klamath Falls Test Site, the relationship between vegetation type and topography suggests that better interpretation results would be possible if stereo viewing were possible. An example of this point can be seen in Figure 4.2. On a single Infrared

TABLE IV-5

TABULATION OF INTERPRETATION TIME AND COSTS OF
PANCHROMATIC VS. INFRARED EKTACHROME PHOTOGRAPHY

INTERPRETER 1	PANCHROMATIC (Time, hours)	INFRARED EKTACHROME (Time, hours)
Training	1	1/2
Interpretation	3 1/2	2 1/2
Total	4 1/2	3
INTERPRETER 2		
Training	1 1/2	1
Interpretation	3	2
Total	4 1/2	3
AVERAGE (1 and 2)		
Training	1 1/4	3/4
Interpretation	3 1/4	2 1/4
Total	4 1/2	3

COST DATA - AVERAGE (1 and 2)

Hourly wage	$3.25	$3.25
Interpretation cost	$14.60	$9.75
Total area mapped	66 mi.^{2}	66 mi.^{2}
Cost/sq. mile mapped	$0.22	$0.15
Cost ratio	100%	68%
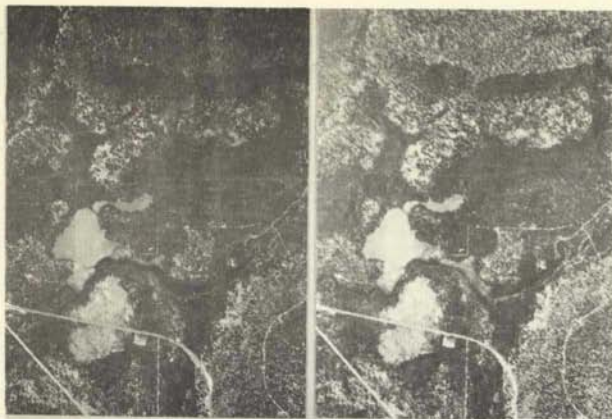
(a) Plus-X Aerecon (8401)
     Wratten 25A filter
     August 29, 1968
     Scale: 1/50,000
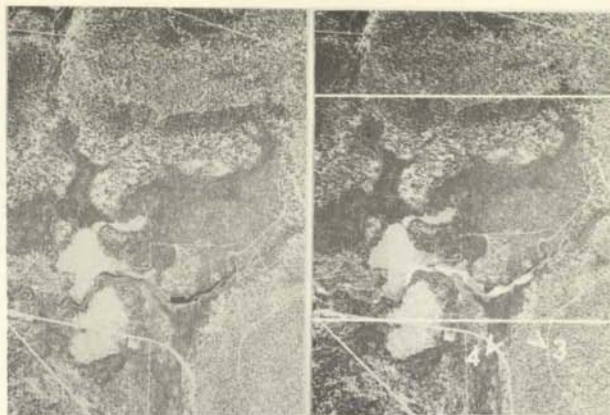
(b) Ektachrome Infrared Aero (8443)
     Wratten 12 + EF-2200 filters
     August 29, 1968
     Scale: 1/50,000

Figure 4.2 Photo examples of the two film types used in the inter-
pretation tests. Although interpretation was performed without bene-
fit of stereo viewing, stereo coverage is reproduced here to provide
the reader with a better impression of the relationship between for-
est type and typography. By comparing the ground control map with
the outlined area above, it can be observed that, in this example,
lodgepole pine occupies imperfectly drained lowland sites while pon-
derosa pine occupies the surrounding better-drained sites. As dis-
cussed in the text, the association of vegetation with relief is not
so apparent on a single photograph as when two overlapping photo-
graphs are viewed stereoscopically.
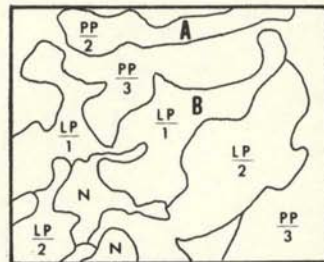
Ground control map for area out-
lined above.

Ektachrome photograph ponderosa pine at "A" (see map) can be distinguished from lodgepole pine at "B" on the basis of the color difference. However, on the adjacent panchromatic photograph, this difference is not apparent (non-stereo viewing). If the interpreter realizes that ponderosa pine is more common to well-drained slopes and that lodgepole is frequently found on low lying areas, he can use information about relief obtained through stereo viewing to aid in vegetation identification.

Figures 4.3 and 4.4 contain ground photographs which correspond to portions of the area depicted in Figure 4.2. They help to illustrate the statements just made regarding relationship of vegetation and relief.

Errors in map preparation continue to add to the inaccuracy of the results. The Kail plotter, while simple to operate, does not provide the accuracy necessary to transfer type boundaries faithfully from a photo overlay to a map sheet. A more sophisticated mapping system is needed to ensure that differences in type boundary locations from one map to another are due only to differences in interpretation and not to mapping error.

A final word regarding the use of the key is necessary. It was sometimes difficult to differentiate between certain types because of their similarity in tone and texture. Perhaps the dichotomous key and example photographs can be reexamined to determine if changes might be made to improve their usefulness for discriminating subtle differences between species.

To ensure that future studies of this type will produce meaningful results, the following recommendations are made: 1) Use several

Figure 4.3. Ground photograph indicating relationship of various forest types. (See Figure 4.2b for photo location -- at 3). Note ponderosa pine in immediate foreground, lodgepole pine along Spring Creek (two densities), and ponderosa pine on the better-drained slopes in the background. Compare with type map (Figure 4.1) to determine which boundaries are distinguishable.

Figure 4.4. The boundary between young lodgepole pine on the low-lying flat (foreground) and ponderosa pine on the better-drained slopes (background) is evident on this ground photograph. (See Figure 4.2b for photo location -- at 4.) Distinct boundaries such as this one, in which there is a unique association between topography and vegetation, are consistently delineated by the interpreters. By referring to the map of interpreters' results (Figure 4.1) it can be seen that the boundary was correctly delineated and the types correctly identified in all but one case.

photo interpreters to produce more data so that an adequate statistical
analysis of the results can be made. 2) Prepare reference materials
so that they present in clearest form the most important recognition
characteristics. 3) Take pains to prepare accurate maps from overlays
or other interpretation material. 4) Choose type classes to be recog-
nized so that they constitute all of the important classes for the
particular objective. Thus, a large or small list of types may be
specified, depending upon the amount of information required.

An opportunity to view the Klamath Falls Test Site at smaller
scale was provided this year when the NASA-based RB-57F aircraft
obtained imagery of the Klamath Falls area. Mission 100 was flown
on July 18, 1969, over NASA test site 189, the Klamath Falls Test
Site. Figure 4.5 contains an example of that photography, scale
1/120,000. A portion of the area seen in that figure also appears
in Figure 4.2. Although the scale of the NASA photography is more than
twice as small as the photography used in the tests reported here, much
of the same kind of information regarding forest type composition is
discernible (compare Figure 4.5 with Figure 4.2). Although crown
detail is less apparent at the smaller scale, there are texture simi-
larities which can be seen on both scales of photography. In addition,
there are similarities in color signatures for various forest types on
both types of photographs. It thus seems possible that the same
criteria used for type mapping from 1/50,000 scale photographs (tone
and texture) could be used for interpretation of 1/120,000 scale photo-
graphs.
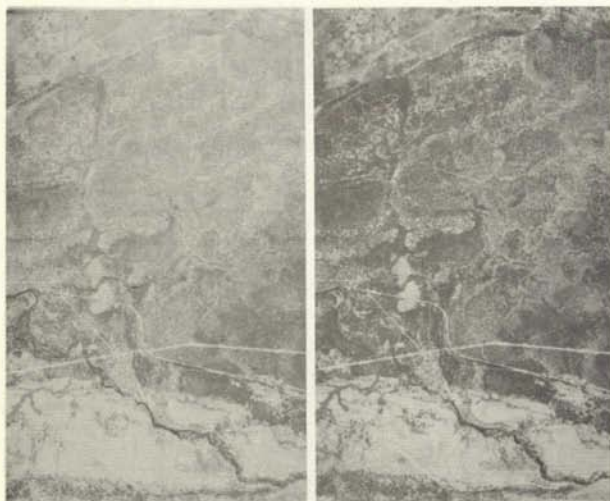
Figure 4.5 Infrared Ektachrome stereogram (scale 1/120,000) of a portion of the Klamath Falls Test Site obtained from the NASA RB57F aircraft on July 18, 1969, on Mission 100. The central part of this stereogram appears in Figure 4.2 at a scale of 1/50,000. Comparison with that figure reveals that color similarities exist between the two scales of photography, and that many of the same identifications that are possible on the larger scale photographs could also be made on the smaller scale photographs.

B. EVALUATION OF WILDLAND RESOURCES - BUCKS LAKE TEST SITE

The 100,000 acre NASA Bucks Lake Test Site, located on the westside portion of the Sierra Nevada Mountains of California, has been studied extensively by the Forestry Remote Sensing Laboratory of the University of California for the past five years. The site contains a wide variety of wildland resources including timber, which is the primary factor in the economy of the area; brush, which provides the habitat for wildlife but which, in some instances, might profitably be replaced by timber; forage suitable for grazing by domestic livestock; water, which is rapidly becoming the most important resource of the area; and both present and potential recreation resources. Elevations within the test site vary from 3600 to 7000 feet, thus providing a number of climatic regimes which are reflected in the differing soil and vegetation types found in the area (Draeger, 1967).

High altitude photography can aid the wildland manager in evaluating his resources in the following ways:

1. Mapping types of ground cover (vegetation).

2. Monitoring changes in the ground cover with sequential coverage.

3. Selecting primary sample units for more detailed study in multi-stage sampling.

Conventional low altitude photography also can be used for the above tasks, but since fewer high altitude photographs are needed to cover a given area, these tasks can be simplified. For example, the entire Bucks Lake Test Site was covered with one flight line of four high altitude photographs (60% overlap); similar coverage with 9 x 9 inch low altitude photographs (1/20,000) would require at least three flight lines of 10 photographs each.

GROUND COVER TYPE MAPPING

For the purposes of ground cover typing, three types of high altitude photography were used and compared: Infrared Ektachrome, Infrared-89B and Panchromatic-25A. The original 35mm photography was enlarged to produce 5 x 7 inch prints having a scale of 1/150,000. The photography obtained with each film-filter combination was viewed stereoscopically, and the cover type boundaries were drawn. The delineations were transferred to an Infrared Ektachrome mosaic (Figure 4.6, Overlay 2) and single photographs (Figures 4.7 and 4.8) for comparison. The delineations of the high altitude Infrared Ektachrome photography were compared with similar delineations made on low altitude Infrared Ektachrome photography that had been taken in June, 1966 (Figure 4.6, Overlay 1).

Ground cover was typed in the following six categories (160 acres minimum area):

1. Brush-dry site hardwood
2. Medium-high density conifer
3. Low density conifer
4. Rock-bare soil
5. Meadow-riparian hardwood
6. Water

The advantage of using high altitude photography for delineating these categories is quite apparent. Because so few photographs are required to cover the entire area, the photographic tones and textures used in identifying any given type of ground cover tend to be consistent throughout most of the area, and the number of photographs to be handled is small, thereby facilitating the mapping of ground cover types. In an area like Bucks Lake, the mapping of ground cover types on photographs of conventional scale (e.g., 1/20,000) would introduce much greater variability in photographic tones and textures of any given type of ground cover, and would require the shuffling of 30 or more photographs. This is not only time consuming but

Figure 4.6 This mosaic of the NASA Bucks Lake Test Site has been made from 35mm Infrared Ektachrome photography which was flown at an altitude of approximately 71,000 feet on August 4, 1969. Overlay 1 shows ground cover boundaries that were originally delineated on low altitude photography of June 11, 1966. Overlay 2 shows ground cover boundaries as delineated on the high altitude photography. Two major boundary discrepancies occur on the overlays at areas A and B. See text for discussion.

LEGEND

1. Brush-dry site hardwood
2. Medium-high density conifer
3. Low-density conifer
4. Rock-bare soil
5. Meadow-riparian hardwood
6. Water

Figure 4.7 Infrared-89B photography taken on July 15, 1969, from an altiude of 71,000 feet. This type of photography proved to be of little use for ground cover typing. Except for bodies of water and riparian hardwoods, most of the above delineations and identifications are of questionable accuracy, as indicated by comparing this figure with the preceding one (Figure 4.6).

LEGEND

1. Brush-dry site hardwood
2. Medium-high density conifer
3. Low-density conifer
4. Rock-bare soil
5. Meadow-riparian hardwood
6. Water

<u>Figure 4.8</u> Panchromatic-25A photography taken on July 15, 1969, from an altitude of 71,000 feet. Ground cover typing can be done fairly consistently on this photography although not as readily as on the Infrared Ektachrome photography of Figure 4.6. Some difficulty occurs, for example, when one attempts to distinguish between categories 2 and 3, and also between 3 and 4.

LEGEND

1. Brush-dry site hardwood
2. Medium-high density conifer
3. Low density conifer
4. Rock-bare soil
5. Meadow-riparian hardwood
6. Water

interrupts the concentration of the interpreter.

Of the three types of photography used, Infrared Ektachrome proved to be the most satisfactory for cover typing (Figure 4.6). Each category for the most part is easily distinguished from the others. Some confusion can occur between dry site hardwoods and riparian hardwoods. This confusion can be resolved when the photographs are viewed stereoscopically, for the lowland topography occupied by riparian hardwoods is quite different from the upland topography of dry site hardwoods. Because of its high infrared reflection, coniferous reproduction can be confused with brush, particularly when the former is emerging from beneath the latter. Such reproduction is only distinguishable on large scale photography where the tips of the emerging conifers can be seen. It was this very condition that resulted in the only major error in mapping cover boundaries on the high altitude photography (Figure 4.6, Overlay 1, area A). However, in most cases the details on the Infrared Ektachrome high altitude photography are good enough to allow more detailed typing than was done here.

Judging from this study, Infrared-89B photography (Figure 4.7) is of little use for cover typing. Bodies of water, water courses, wet meadows, and riparian hardwoods are the only cover types that can be delineated consistently. However, brushfields cannot always be distinguished from rock-bare soil and/or low density conifers. In addition, the road network is not visible so that the land manager gets no indication of the location of his resources with respect to existing roads.

Cover typing can be done satisfactorily with Panchromatic-25A photography (Figure 4.8). While cover type features are not as easily discriminated as on Infrared Ektachrome, typing can be done fairly consistently. The gray tones of meadow and riparian vegetation are quite similar to those of brush and dry site hardwood vegetation, but, just as with the Infrared

114

Ektachrome photography, when viewed stereoscopically the topography can be used to differentiate the two categories. While bare soil is easily identified, there can be some confusion between areas of bare rock and areas containing low density conifer.

MONITORING CHANGES IN COVER PATTERNS

Sequential high altitude photography gives the land manager a permanent record of changes in ground cover. The most evident example of this can be seen at B (Figure 4.6, Overlay 2). The overlay made from June, 1966 photography shows no bare soil at this point, whereas the outline of a brushland conversion site can be seen on Overlay 2. Perhaps if photography of this area were to be taken approximately 10 years hence, a comparison of it with the present photography would give an indication of the consequences of this vegetation manipulation by man.

High altitude sequential photography is ideal for monitoring changes in snow resources. The frequency of photography required for such an evaluation varies with the time of year. Comparing the snowpack on the May 21, 1969 high altitude photography (Figure 4.9) with high altitude photography obtained on July 15, 1969 (Figure 4.8) indicates that the two-month interval is too long to be of maximum use for snow surveys. Biweekly photography from December 1 to June 1 would be desirable. During the periods of maximum runoff, weekly photography might be more desirable (Willow Run Lab, 1966). The sequential photography, when coordinated with pertinent ground data, would provide a permanent record of snow accumulation and melt patterns for a given area. This, when combined with data from previous years, would enable the land manager to predict timing and relative quantity of water yield from the area (Draeger, 1968).

Accumulation patterns, when compared with ground cover patterns, slopes and aspects, give the land manager an indication of the consequences, with
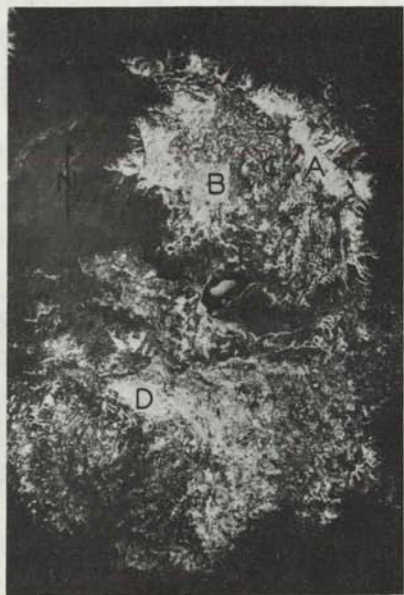
Figure 4.9 Panchromatic-58 photography taken on May 21, 1969, from an altitude of 71,000 feet. Relative accumulations of snow with respect to aspect, slope and ground cover can be discerned on this photograph.

    A. Steep (50%) north-facing slope devoid of vegetation. High snow accumulation.
    B. Gentle south-facing slope with low density conifer cover. High snow accumulation.
    C. Moderately dense conifer cover on gently rolling topography. Low snow accumulation.
    D. Moderately steep north-facing granitic outcrop. High snow accumulation.

regard to snow accumulation, of vegetation cover manipulation such as brush field reclamation and heavy timber harvesting. Comparison of Figure 4.9 with topographic maps and with Figure 4.6 (Overlay 2) provides the following examples of these relationships:

A. This steep (50%) north-facing slope is devoid of vegetation. Snow accumulation is relatively high.

B. Snow accumulation is high in this area also. This south-facing slope has a very low density conifer cover since timber harvesting was undertaken ostensibly with the idea of converting the land from timber production to future vacation home sites.

C. This area has the same slope and aspect as area B, but the vegetation cover is more dense. Snow accumulation is low.

D. While this granitic outcrop is predominantly north-facing, its snow accumulation is less than at area A since the elevation is lower and the slope is less steep.

In addition to the use of high altitude photography, a certain degree of ground work is required to determine actual snow volumes. High altitude photography can only give the areal coverage and the relative accumulation of the snowpack. As of now, determination of water content of snow with the use of active remote sensors is still in the experimental stage (Meier, 1968); and while snow depths can be determined photogrammetrically, the optimum photographic scale for this is 1/6,000 (Cooper, C. F., 1965).

APPLICATIONS FOR MULTISTAGE SAMPLING

In an Apollo 9 case study (Langley, et al., 1969) space photography was used for the selection of primary sample units for determining the timber volume in a 6-million acre portion of Mississippi and Louisiana. This photography was used in conjunction with 1/60,000, 1/12,000 and 1/2,000 scale aerial photographs in a stratified five-stage probability sampling

design. The design gives unbiased estimates that are independent of the quality of the imagery, but sampling errors are governed in large measure by the quality of the photography.

Such a design could utilize high altitude photography instead of satellite photography for selection of the primary sample units. Since more detail can be seen on the high altitude photography, the sampling errors could be expected to be lower than if satellite photography were used. More study is needed to determine if, with high resolution high altitude photography, this particular design need only consist of three or four stages.

This particular sample design can be used when inventorying almost any wildland resource including timber, forage, water and snow. Depending upon the resource being inventoried and its distribution (clustered or homogeneous) a mosaic such as Figure 4.6 can be partitioned into squares of arbitrary size, perhaps one or two miles on a side. These squares then become the population from which the primary sampling units are to be selected. The resource is delineated on the entire mosaic and the proportion of each square occupied by it is estimated by the interpreter. The primary samples are now selected with probability proportional to the prediction with the use of random number tables.

CONCLUSIONS

High altitude photography can be extremely useful in evaluating wildland resources. Because so few photographs are needed to cover a given area as compared to conventional low altitude photographs, evaluation is simplified. Infrared Ektachrome was judged to be the best kind of photography for delineating ground cover boundaries, although Panchromatic-25A was satisfactory for delineating several cover types. Except for delinea-

ting bodies of water, water courses, and riparian hardwoods, Infrared-89B
proved unsatisfactory for overall ground cover typing. Sequential photog-
raphy, if taken over a number of years, will yield valuable information
concerning the consequences of vegetation manipulation and the yield of
snow resource. Future study is needed, however, to determine how high
altitude photography can best be used in conjunction with conventional
photography and/or space photography to help inventory various wildland
resources.

C. LAND USE CLASSIFICATION - MISSISSIPPI/LOUISIANA STUDY AREA

Investigations regarding some of the parameters which affect the
interpretation of space photography were recommended in the 1968 Annual
Progress Report on Forest Tree Species Identification (Lauer, 1968). An
evaluation of the potential for land use mapping on space photography was
undertaken with the intention of studying certain of these parameters
which were recommended in that report, namely the degree of photographic
detail discernible, usefulness of the synoptic view, and influence of the
sequential factor. In addition, it was deemed important to determine the
consistency with which land use categories can be consistently identified.

It is presently agreed that one of the most important uses of space
photography in earth resource survey work will be for the delineation of
broad land use categories. The synoptic view of the earth from space
affords land managers the opportunity to recognize broad regional resource
associations that cannot be seen in their entirety on conventional aerial
photographs. Such information can be valuable for two purposes:

(1) The preparation of a map of land use classes for unmapped land
(never before inventoried) will provide the initial basis for ascertaining
the location of each important type of natural resource. For example, the

differentiation of hardwood forest, conifer forest, chapparal and grass-
land types provides an indication of the relative quantity and location
of major vegetation types and constitutes the first step towards the in-
tensive management of such resources.

(2) Broad delineations on a space photograph can be used to strati-
fy a large land area which is being inventoried. Estimates of specific
parameters made on the space photograph can be used to develop probability
distributions for the selection of subsamples. The most rigorous example
to date of this technique is the work by Langley, et al. (1969). Working
with Apollo 9 space photography of the Mississippi River Valley, he was
able to reduce the sampling error by 58% by using information from a
space photograph in the first stage of a multistage design.

SYSTEM OF CLASSIFICATION

A classification system for land use mapping on Apollo 9 photographs
of Mississippi and Louisiana has been devised which includes the following
categories:

1. Deciduous forest (D)
2. Pine forest (P)
3. Mixed deciduous and pine forest (M)
4. Cultivated land
    a. Vegetation-covered (CV)
    b. Bare (CB)
    c. Fallow (CF)
5. Open bodies of water (lakes, reservoirs, etc.) (WO)
6. Rivers and canals (WR)
7. Roads (R)
8. Urban and industrial areas (U)

This system was judged to be of suitable detail for broad land use
mapping in the Mississippi River Valley area. Expansion of the list to
include more detailed categories is not warranted for two reasons. First,
the opportunity for error is greater if an interpreter must search for
subtle differences between categories. Also, the additional time is not
warranted at this level because the objective of mapping on space photographs

is to stratify the terrain for sampling at larger scale in selected areas. Thus, within each stratum, more detailed information will be gathered at the next stage, and the added effort on the space photograph is unnecessary.

Recognition characteristics have been determined for these categories and are summarized in Table IV-6. The following brief descriptions will help the reader to become familiar with the classification system. Color characteristics are given for Infrared Ektachrome film type only. (Photo examples of the categories appear in Figure 4.10).

1. _Deciduous forests_ occur in pure stands of large size and homogeneous appearance. In the lowlands of the Mississippi River Valley, extensive deciduous forest area has been removed to clear land for agricultural cropping, leaving forest stands with linear boundaries in many cases. In other areas the deciduous forests occupy lowland areas along river courses, where they can be recognized by their sinuous appearance and dark blue to black color. Deciduous forest stands can easily be discriminated from evergreen stands at the time of year when Apollo 9 was obtaining earth photographs due to the absence of foliage on deciduous trees in contrast to evergreen trees.

2. _Pine forests_ in this study area have a unique pink to red color, depending on density and age of the stand. However, stands must be sufficiently large before they can be discerned on the space photograph. Pine forest stands occur only in the rolling hills of the upland areas which adjoin the floodplain of the Mississippi River.

3. _Mixed deciduous and pine forests_ are found in several areas of the rolling uplands but do not occur in the floodplain area itself. Since the reddish tone which characterizes pine stands is difficult to detect when pine trees occur in small groups mixed with deciduous trees, it is often difficult to distinguish mixed forests from deciduous forests.

Table IV-6 Recognition characteristics for land and vegetation categories in the Mississippi/Louisiana
Study Area on Apollo 9 space photography.

Land Use or Vegetation Type Category	FILM-FILTER COMBINATION		
	Infrared Ektachrome	Panchromatic-25A	Infrared-89B
Deciduous Forests - in large blocks along rivers and on flood plains	Dark blue to black (variable tones)	Dark grey to black	Medium grey
Pine Forests - in small blocks on uplands	Dark reddish patches (variable tones)	Dark grey to black	Medium grey
Mixed Deciduous and Pine Forests - in uplands	Dark blue to black and occasionally red-dish (variable tones)	Dark grey to black	Medium grey
Cultivated Land - in flood plain and uplands	Bare: light tan to white Vegetated: light red to pink Fallow: light blue-grey (uniform tones in most fields)	Light grey to white	Light grey
Open Bodies of Water (Rivers and Canals)	Mostly uniform blue to black	Light grey to black	Medium grey to black
Urban and Industrial Areas - streets, buildings, airports and highways	Light-toned to black	Light grey to dark grey	Light grey to white
Major Roads - linear features with intersections	Tan to white	Light grey to white	Light grey to white

122

March 24, 1969
Infrared Ektachrome

November 11, 1969
Infrared Ektachrome

March 9, 1969 (Apollo 9 enlargement)
Infrared Ektachrome

Figure 4.10 An enlargement of a portion of Apollo 9 frame
AS-9-26A-3740 is reproduced above. Imaged on that photo-
graph is a portion of the Mississippi/Louisiana Study Area
for which a feature identification test was administered.
The area covered lies just west of Monroe, Louisiana. The
two aerial oblique photographs (at the left) cover the por-
tion of the Apollo 9 photo in which features 2 through 6
are annotated. These annotations indicate the locations of
examples of the land use categories which were chosen for the
test. These categories are as follows: (1) deciduous forest
(2) pine forest, (3) mixed deciduous and pine forest, (4) cul-
tivated land (bare), (5) cultivated land (vegetated) (6) cul-
tivated land (fallow), (7) open water, (8) major road (free-
way). The aerial oblique at the top was taken on March 24,
1969, two weeks after the Apollo 9 photographs were obtained.
Vegetation appears in the oblique photograph in essentially
the same condition as when photographed by the Apollo 9 astro-
nauts. The oblique photograph at the bottom was taken on
Nov. 11, 1969, at the time when the deciduous hardwood trees
were undergoing the fall color change. The value of obtaining
sequential photography for mapping vegetation is discussed in
the text.

4. Cultivated lands, whether in the lowland or rolling upland, can easily be differentiated from forests by their unique colors and more uniform texture. Three distinct conditions of cultivated land can be recognized: bare (light tan to white color), vegetated (light red to pink), and fallow (light blue-grey).

5. Open bodies of water can generally be identified with ease on space photographs. The color of a water body will depend upon the sediment load which it contains. Oxbow lakes along the Mississippi River appear black on Infrared Ektachrome film because they are clear (suspended matter has settled out). Examples of other water bodies which appear as blue or tan colors (due to different sediment content) on Infrared Ektachrome film can be found in the study area.

6. Rivers and canals are discernible as unique linear features. They can generally be distinguished from roads by their dark blue to black color on Infrared Ektachrome film.

7. Major roads can be recognized if they are sufficiently wide to be discerned and if their tan to white color contrasts with the background. The confluence of roads at urban centers can also be used as a clue to their identification.

8. Urban and industrial areas can be identified if they are of sufficient size and if they contrast with the surrounding terrain. Convergence of evidence can aid in identification of urban areas when one or more of the following features can be recognized: confluence of road systems, large airports or factory complexes, regular pattern of streets, and smoke and haze accumulation.

INTERPRETATION TEST

An interpretation test was designed to determine how well these categories might be identified on Infrared Ektachrome space photographs

by suitably trained and motivated interpreters. Since the added value of space photography to resource surveys depends upon how well broad land use categories can be delineated, such tests are necessary to determine the level of accuracy which can be achieved.

Interpretation was performed by viewing Apollo 9 transparencies (frames AS-9-26A-3740 and AS-9-26A-3741), 10X enlargement, on an Itek rear projection viewing screen. At this scale, a minimum area for identification of 100 acres was established. Such a minimum is deemed reasonable for the objective of the study (namely, the preparation of broad land use maps) and could easily be seen on the screen.

The interpreters were encouraged to become familiar with the classification scheme by studying two types of training material. Written descriptions of each type were prepared for their use, and several low-level oblique and vertical aerial photographs were annotated for study so that they might become familiar with each category and its relationship with the other categories. After studying this reference material, each interpreter was introduced to the space photography and given the table of recognition characteristics for Infrared Ektachrome film (see Table IV-6). A representative number of training examples (25 on each of the 2 images used), were encircled and presented to the interpreters to train them to recognize the various categories on space photographs. Care was taken to select training areas (and, later, to choose test examples) which represented the variety of tonal and textural characteristics which existed in the study area. In this way it was hoped that a feature recognition test might provide the kind of information which would indicate the probable success to be achieved in a full-scale mapping effort, without actually performing such mapping over large areas. For this purpose, ground truth information (obtained shortly after procurement of the Apollo photographs)

of representative areas could be used to maximum advantage.

Ten interpreters (all of which had had previous experience with tests of this type) were trained in the manner just described. Each was then asked to examine a total of 39 outlined areas (100 acre minimum) and to classify them as belonging to one of the test categories. The identification of each outlined area was confirmed by locating it on either the low level aerial oblique or vertical photographs obtained shortly after the Apollo 9 mission. Two aerial obliques of a portion of the test area are presented in Figure 4.6. There is sufficient detail (tree crown characteristics, field pattern, etc.) on these Ektachrome and Infrared Ektachrome photographs to permit each category to be positively identified.

The results from this test appear in Table IV-7. Tabulated in that table are composite results for all ten interpreters. The reader is invited to compare the results by interpreters (data along the rows) with actual ground truth (data down the columns). For example, a total of 60 actual deciduous forest plots were used in this test (total for first column under D). Of this number 49 were identified correctly by the interpreters (outlined by heavy lines in first column). Thus the percent correct for this category, as indicated below the composite results, is 81% (= 49/60 × 100%). Similarly, the outlined boxes which occur along the diagonal contain the total number of correct identifications for each category. These results are expressed as percent values at the bottom of the table. Other entries in the table represent commission errors in which a feature from a given category was incorrectly identified as belonging to another category. For example, the number 1 (first column, second row) indicates that in 1 case a deciduous forest stand was incorrectly identified as a pine forest stand.

Summarized at the bottom is the percent commission error for each

Table IV-7 Summary of interpretation results for test of recognition features in the Mississippi/Louisiana area.*

		GROUND TRUTH										TOTAL SEEN BY P.I.	COMMISSION ERROR
		D	P	M	C_V	C_B	C_F	W_O	W_R	R	U		
PHOTO INTERPRETER'S RESULTS	D	49		7				2				58	9
	P	1	27	13	4			1				46	19
	M	.5	2	28				1				36	8
	C_V				74						5	79	5
	C_B		1		2	20					3	26	6
	C_F						18				1	19	1
	W_O	1						36			1	38	2
	W_R								18	6		24	6
	R								2	34		36	2
	U	4		2			2				20	28	8
TOTAL ITEMS		60	30	50	80	20	20	40	20	40	30	390	
NUMBER INCORRECT		11	3	22	6	0	2	4	2	6	10		66

* Numbers in table indicate the cumulative number of areas identified by ten interpreters. Numbers in bold-faced diagonal boxes indicate the number of areas identified correctly.

	D	P	M	C_V	C_B	C_F	W_O	W_R	R	U
PERCENT CORRECT	81	90	56	92	100	90	90	90	85	67
PERCENT COMMISSION	15	41	22	6	23	5	5	25	5	28

category. These percentages reflect how often other categories were con-
fused with a given category. The calculation is given by:

$$\frac{\text{Total seen by P.I.} - \text{total correct}}{\text{Total seen by P.I.}} \times 100\%$$

For example, a total of 58 test items were identified as deciduous
forests by the interpreters. Of these, 49 were correctly identified.
Thus, in 9 cases, items in other categories were incorrectly identified
as deciduous forest. The percent commission is:

$$\frac{(58-49)}{58} \times 100\% = 15\%$$

The following statements can be made regarding the results in
Table IV-7:

. 1. Although interpreters can recognize pine stands with 90% accuracy,
they have some difficulty in identifying mixed and deciduous forests on
Infrared Ektachrome imagery taken at this time of year. Also, the commis-
sion error for pine is high (41%) indicating that other forest types are
often confused with pure pine stands.

2. If all three categories of forest cover are grouped in a single
category, it becomes possible to recognize forested land with 74% accuracy
from all other categories, and the commission error is only 6%.

3. Three categories of cultivated fields can be distinguished at
least 90% of the time.

. 4. Open bodies of water, rivers and canals, and roads are consistently
identifiable (90%, 90% and 85% respectively), especially if there exists
sufficient contrast between the linear feature and its background.

Thus it seems that, given the success with which these categories can be recognized, it is possible to conclude that broad land use maps can be accurately prepared using space photography of the type and quality of the Apollo 9 frames which were studied. Of course, complete correlation does not exist between identifying individual features in a test of this type and by mapping an entire area on a space photo. However, with the area minimum established here, and the manner in which the test examples were chosen to represent the variety of image characteristics, it seems reasonable to conclude that broad type mapping could be successfully accomplished on Apollo 9 space photographs.

SEQUENTIAL ASPECTS

The value of the time dimension for vegetation inventory using conventional aerial photography has been recognized for some time. Two major benefits can be derived by interpreting photographs taken on different dates. First of all, knowledge of the phenological patterns of the vegetation being studied permits specification of time(s) of year when plant species can be most easily separated one from another. When repetitive cover is obtained for a period of several years or more, changes in the vegetative cover can be monitored. The effects of manipulation (logging, clearing, burning, etc.) can be measured and treatments can be evaluated.

Low level aerial oblique photographs were obtained for the Study Area on two different dates during 1969 for comparison purposes. Shortly after Apollo 9 space photographs were obtained, the first of these low-level missions was undertaken to obtain additional information about the vegetation in the Study Area at the time when the deciduous hardwoods were not in leaf. This information was used to aid in the interpretation of the space photography. In November, 1969, the Study Area was revisited to

129

document the appearance of the forest cover during the fall color change
(when the deciduous trees lose their leaves). An example of the photog-
raphy obtained on these two dates for a portion of the study area appears
in Figure 4:10.

· Comparison of the oblique taken on March 24, 1969, with the oblique
taken on November 11, 1969, will support the conclusion that hardwood and
conifer forest types can best be distinguished on winter or early spring
photography. The dark red color of conifer stands contrasts sharply with
the blue-grey color of deciduous trees as seen on Infrared Ektachrome
photographs taken at this time of year. This distinction is not nearly
so evident during the fall. Of course, a particular hardwood species might
have a unique signature during the fall as a result of its color change
which would aid in its identification; but the overall value of winter
photography for distinguishing between two major classes of vegetation
(as we have indicated is our objective with Apollo 9 photo interpretation)
is quite clear.

·   ·Identification of the mixed deciduous and pine forest category is
also best made at this time because of the difference in infrared reflec-
tance of the two components. The difficulty in consistently recognizing
this category on Apollo 9 photographs lies in the resolution limitation.
Patches of hardwood and conifer trees are often difficult to resolve on
space photography, and a mixed stand is often categorized as a deciduous
forest stand. The dark red color of the pine trees is frequently not
detectable and the stand is incorrectly identified. This is merely a
problem of resolution, however, and the sequential aspects cannot be used
to improve identification.

<u>Future Research Activities</u>

1. The research completed and reported upon in this chapter has
exposed a single major problem--the quantification of image interpretation
results. In the near future emphasis will be placed on a critical examina-
tion of the facets of this problem by employing a variety of interpretation
tests which will include procedures for collecting ground truth, selecting
images for testing, developing feature descriptions, making training aids
and evaluating test design and results.

2. In addition, Unit personnel will examine the capabilities of
various image enhancement systems. A number of comparative tests will be
performed on the interpretability of standard black-and-white, color and
color infrared film types and composite images made by the various systems.

3. Continued efforts will be made that will examine and describe
image characteristics relating to the qualitative analysis of remote sens-
ing data. This work will include the investigation of image character-
istics seen on exotic types of imagery (ultraviolet, thermal infrared,
radar, etc.), sequential photography and color composites. Feasibility
studies will continue on the usefulness of new kinds of equipment and
hardware.

4. A major activity of this Unit will be to continue close coopera-
tion with the other four Units at the Forestry Remote Sensing Laboratory.
Cooperation between this Unit and the Automatic Image Classification and
Data Processing Unit is apparent when attempting to evaluate or derive an
image interpretation system combining the skills of both humans and machines.
Likewise, data collected on spectral properties of resource features and
conditions are invaluable to the image analyst when attempting to extract
from airborne or spaceborne imagery useful information about those same
features and conditions. Lastly, this Unit will actively participate in

preparing the necessary materials needed for training personnel from user

groups, a subject discussed in Chapter 6 of this report.

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CHAPTER 5

AUTOMATIC IMAGE CLASSIFICATION AND DATA PROCESSING

Jerry D. Lent

Introduction

A major portion of the material contained in this chapter con-
stitutes our second year's progress results of the study entitled:
"The Feasibility of Identifying Wildland Resources Through the
Analysis of Digitally Recorded Remote Sensing Data". This study,
which was started in January, 1968, has as its primary objective
the investigation of techniques for automatically classifying wild-
land resources. In addition, related discussions are included of
our other current research activities and future requirements in
wildland remote sensing data analyses and processing. These activi-
ties are organized under a recently reviewed and implemented struc-
ture as shown below which facilitates (1) the review of techniques

135
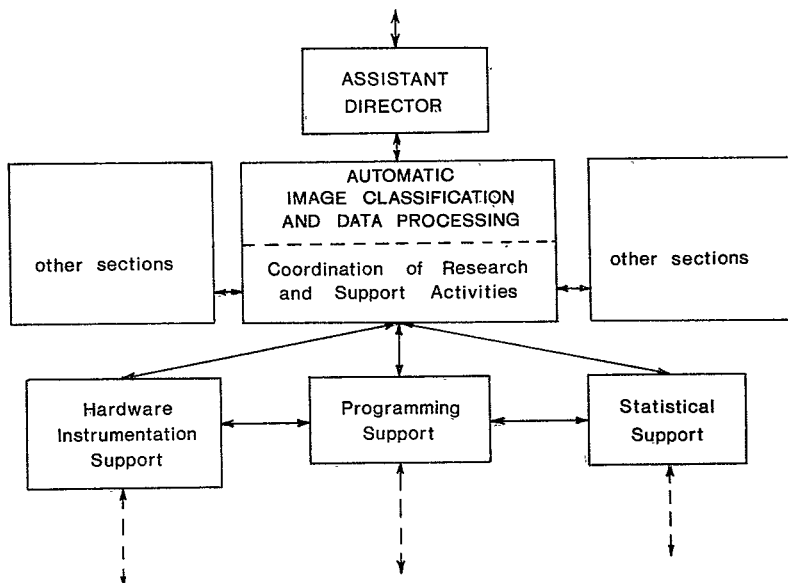
and the development of hardware to perform certain automatic image analysis tasks, (2) the development of the supporting "software" required, as well as (3) the supporting statistical algorithms for data display and analysis.

Current Research Activities

A. Annual Progress Report for the study entitled "The Feasibility of Identifying Wildland Resources Through the Analysis of Digitally Recorded Remote Sensing Data".

.The scope and justification for this study were documented in last year's Annual Progress Report to NASA's Earth Resources Survey Program Director (dated 30 December 1968). Briefly restated, that report pointed out the need for developing efficient data handling techniques to keep pace with the increasing amounts of information that are derivable from sensors operating at higher and higher altitudes above the terrain. Several approaches to automating the data handling and a large percentage of the interpretation of such sensor data were mentioned. The approach developed at Purdue University's Laboratory for Agricultural Remote Sensing (LARS) was more closely examined with the intent of evaluating their agricultural "pattern recognition" programs in a wildland condition. Figure 5.1 shows the area in interest--a portion of NASA's Test Site #20 in northern California. Some sixty miles of optical mechanical scanner imagery was acquired over this test site in May, 1966, using the University of Michigan (Willow Run Laboratories) M-5 Scanner, with the area indicated in Figure 5.1 being selected for digitizing and analysis at the LARS facility. The results of that analysis and
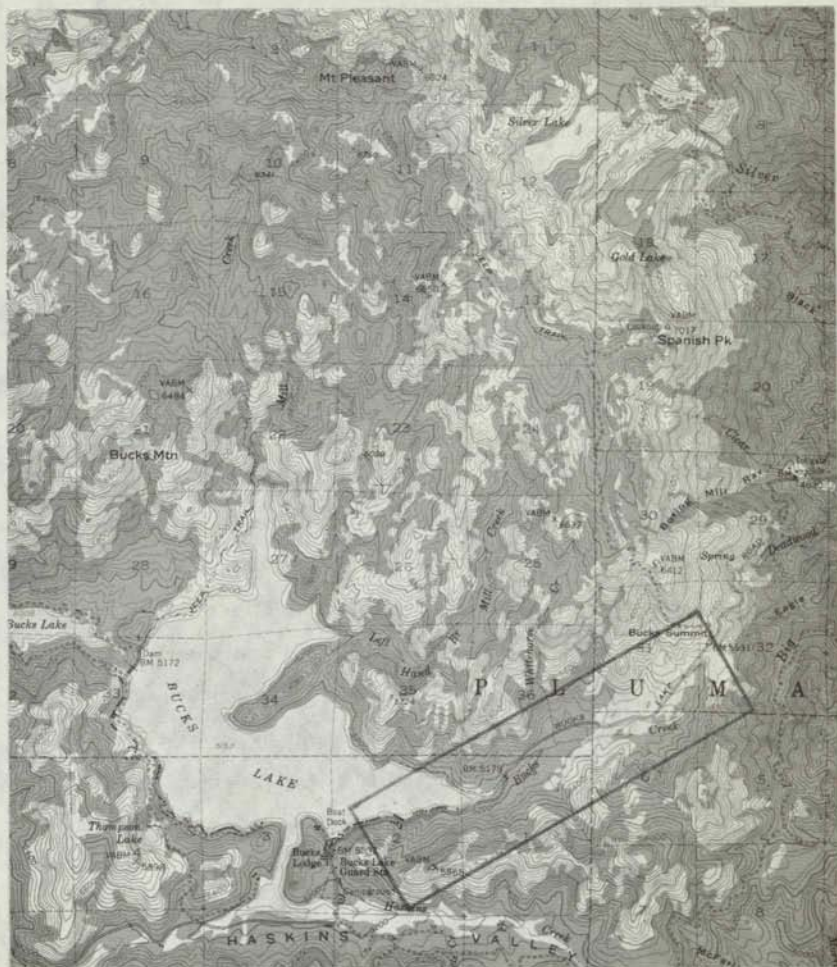
Figure 5.1 A portion of NASA's Forestry Test Site #20, located in northern California, is seen in the above map which has the area of interest in this study outlined in black. Other strips of data were recorded in the vicinity of this flight strip, but only the four mile strip recorded and studied in this feasibility investigation is delineated.

their discussion are herein presented.

Figure 5.2 shows the M-5 Scanner imagery (channel 9: 0.62-0.66 microns, in this case) of the selected study area appearing in Figure 5.1. The acetate overlay denotes the vegetation and land types which existed during the time of overflight in May, 1966. As the reader will note in examining this figure, the initial effort was to attempt automatic classification of broad categories rather than use a category breakdown which was too detailed. As will later be noted, however, some refinement of categories was possible which enabled a species differentiation to be made. Figure 5.3 shows all twelve channels of scanner imagery that can be analyzed in the LARS pattern recognition system. As noted in last year's report, while eighteen channels can be simultaneously recorded by the M-5 Scanner, ranging in sensitivity from 0.32 microns to 14 microns, only twelve of these channels are utilized for automatic classification purposes. This is because four separate detectors (and consequently four separate amplification systems) are used in the M-5 optical mechanical scanner such that congruency of data records between the four detectors is not maintained even though a single aperture scan is made for all eighteen possible wavelength intervals. As seen in Figure 5.3, the wavelength intervals for the twelve-channel detector data range from 0.40 microns to 1.0 microns (i.e., roughly equivalent to the sensitivity levels of photographic emulsions). A more complete description of the operation, advantages and limitations associated with optical mechanical scanners can be found in last year's text and references as well as in a recent article by Lent and Thorley (1969).

Figure 5.2 Photo reproductions of the twelve synchronous data channel filmstrips. On the following page are photo reproductions (printed contact size from 35mm negatives) of the twelve synchronous data channels recorded over the area of interest seen in Figure 5.1. Shown below is Channel 9 (0.62 - 0.66 microns) with the accompanying overlay showing the boundaries of features included in the classification scheme.
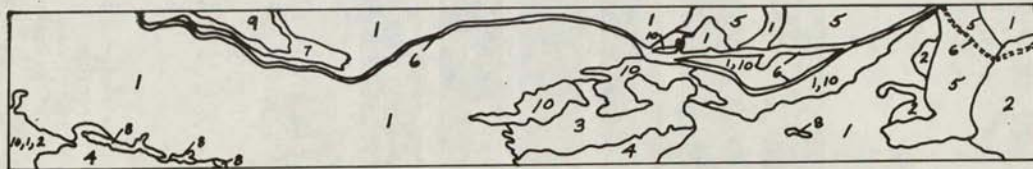
1 MIXED CONIFER STANDS
2 OPEN MIXED BRUSH SPECIES
3 DENSE SNOWBRUSH
4 DENSE MANZANITA
5 CLEARED BRUSHFIELDS

6 ROADS
7 LAKE SHORELINE
8 SNOW PATCHES
9 WATER SURFACE
10 BARE AREAS
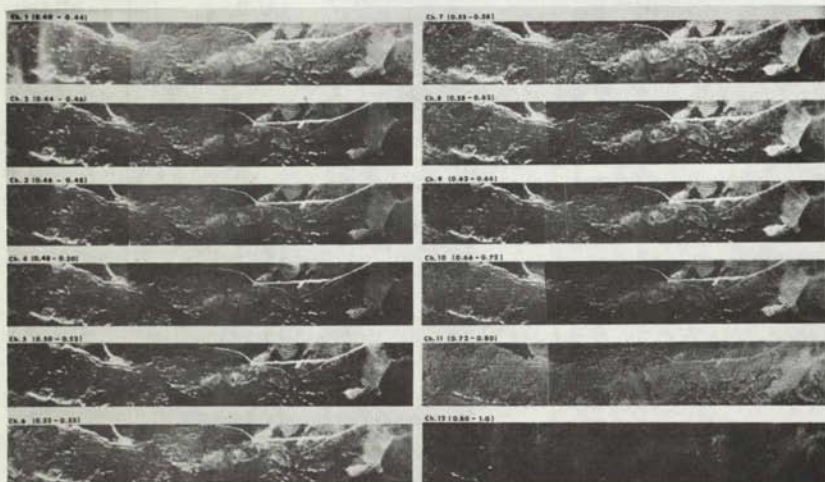
Figure 5.3 The twelve channels of M-5 Scanner imagery analyzed in this study are pictorially displayed in the above illustration. The "best" three channels and "best" four channels of data were used to produce the displays appearing in later figures.

Turning more specifically to the LARS pattern recognition con-
cept for automatically classifying recorded terrain signals, several
topics will be discussed with regard to evaluating that package of
computer programs for wildland data. These are the statistical
aspects and operation of the program and the specific application of
the program to wildland conditions previously described.

a) Statistical aspects and operation of the LARS pattern
recognition system. "Pattern recognition" is a term which denotes
different concepts to different readers. As used at LARS, the term
involves a decision-making operation which ultimately classifies a
pattern of signal responses on the basis of comparisons with responses
of a reference set of patterns. This reference set is highly depen-
dent upon the judicious selection of "training samples" chosen within
the various features of interest. Generally, the pattern recognition
designer must use subjective rationale in the selection of character-
istics which define a particular feature. This rationale is usually
based upon prior experience with the particular terrain types with
which the investigator is working. On the basis of these selected
characteristics, the problem of determining the "best" decision or
classifying scheme is subsequently examined. The input for the
pattern recognition program is the particular pattern (i.e., the set
of radiance signals within the data channels used in the analysis)
to be identified and classified. The output from the pattern recog-
nition program is a set of coded sheets which correspond to the best-
decision printouts of features examined. The statistical aspects
which lead to these best-decision classifications should be such that

modifications are possible in order to insure a flexible and meaning-
ful classification scheme.

The package of programs that produced the classification scheme
results which follow was developed by the personnel at LARS. This
package of programs, which are collectively labelled LARSYSAA, con-
sists of four interrelated sub-programs which are generally used in
succession. In discussing the function of these sub-programs, it
is assumed that the required preliminary data handling has been com-
pleted. This consists of digitizing the recorded analog line scan
records that were obtained with the M-5 Scanner, producing "greyscale"
printouts of certain data channels to enable the investigator to
select training samples, and finally the transcribing of the coordinate
references for the entire set of training samples for subsequent
processing.

The first sub-program, $STAT, is designed to compute the
statistics necessary to produce histograms of relative radiance ex-
hibited by the training sample data of all categories for all twelve
channels (wavelength intervals). Tables can be printed showing, for
each category in the classification scheme, the mean, standard
deviation, covariance matrix, and correlation matrix of signal re-
sponses comprising a category's training sample elements. Histograms
and spectral curves for the categories studied in the area shown in
Figure 5.1 are presented in Tables 5-1 and 5-2.   The data produced
by $STAT are used in subsequent programs.

The second sub-program of LARSYSAA, labelled $SELECT, performs
the function of "automatically" selecting the best set of data channels

142

with which to make discriminations between pairs of categories to be classified. The investigator can specify the number of data channels of recorded signals upon which the classification will be based, ranging from one to twelve. For the analysis performed in making the classification presented in this study, the best three data channels and the best four data channels were examined. The procedure for making the "best" decisions for an optimum set of data channels involves the use of the statistics previously computed in $STAT. Simply, the divergencies between the category density functions in an N-dimensional space (where N can assume values from 1 to 12 using LARSYSAA as previously noted) are calculated for all possible combinations of requested data channels. These divergencies between categories are determined as a function of both the distance between category means and the variation of signal responses about the category means. Consequently, the divergency data presented in Table 5-3 are readily used as indices of the "separability" between categories. For agricultural data studied around the Purdue Agronomy Farm, it is felt that divergencies in the neighborhood of 300 will result in near-perfect discrimination; divergencies approaching 30 or less yield classification results which are nearly impossible to discriminate. A continuum of "separability" exists between these arbitrary limits. How these limits perform for wildland terrain feature discriminations is as yet undetermined, since so little experience has been gained which might enable limits to be determined.

    The next step following the analysis to determine the best combination for a specified number of data channels which will discriminate between a set of categories is the classification of all

the recorded signal responses incorporated in the study. This is accomplished with the use of the third sub-program, labelled $CLASS, which statistically decides, for each recorded data point, to which category the point belongs. The statistical parameters computed by $STAT and the best combination of data channels determined from $SELECT are used in this classification scheme, which involves the scrutiny of each point, its classification, and its storage on magnetic tape files for future manipulations. The classification itself is made with the use of maximum likelihood ratios computed to enable the decision to be made as to which category a point most closely resembles. This statistical concept is reviewed next, briefly.

Let C_1 be the radiant output (i.e., the Characteristic signal response) of a particular feature (category) recorded in Channel 1, C_2 in Channel 2, ..., C_n in Channel n, where "n" in this study can be a maximum of twelve. The ordering of these features forms a measurement vector $C = (C_1, C_2, ..., C_n)$ and on the basis of this measurement vector, the decision is made as to which terrain feature vector it most closely resembles. There are several ways that the actual decision can be arrived at with respect to determining which category a particular pattern most closely resembles; the one employed at LARS, for lack of sufficient information regarding a more suitable function, is based upon normal probability density functions. For each category of interest, a set of likelihood ratios is computed which indicates the relative probabilities that a set of characteristics in question belongs to the category of interest rather than to any of the alternatives. For example, if X_1, X_2, ..., X_n constitutes a feature sample from a multivariate normal distribution, the maximum

likelihood estimates of the mean and covariance matrix can be shown to be the sample mean and sample covariance matrix. This would apply to each feature of interest being examined. The decision rule for classification is determined if the conditional probability of X, given X from the feature of interest, is largest. Stated in equation form:

$$L_{f(i)}\left[X\right] = -\left[X-M_{f(i)}\right]^T \cdot C^{-1}_{f(i)} \cdot \left[X-M_{f(i)}\right] - Log_e \cdot \left|C_{f(i)}\right|$$

where M is the mean, and T denotes "transpose".

The decision is made in favor of category "i" over category "j" if

$$L_{f(i)}\left[X\right] > L_{f(i)}\left[X\right], \text{ etc.}$$

A more complete discussion of this decision-making process and the rationale behind it can be found in the unpublished rough draft of the LARS 1966 Annual Progress Report.

Following the taping of the classification results, the investigator can display the classification using any computer printer symbols he desires to enhance particular categories from others. Some examples of different displays are included herein. The fourth subprogram in the LARSYSAA package controls the printout operations and is labelled $DISPLAY. It is at this time that "thresholds" can be assigned to certain, or all, categories for the purpose of reducing classification error by not designating a particular point in question to any of the possible categories because its spectral nature is "borderline" with respect to them. Points which have been thresholded out of the classification scheme are arbitrarily printed as blanks and a tabulation of all classifications, including those which are

thresholded, is printed for training samples and test fields. A more
complete description of LARSYSAA and some of the related data pro-
cessing programs is given in LARS Information Note 091968 (Landgrebe
and Staff, 1968).

b) <u>Application of the LARS pattern recognition program to</u>
<u>selected wildland features</u>. As noted in last year's report, several
problems were anticipated and possible solutions for them considered
prior to using the LARS automatic classification program. First, the
features to be identified and classified within the area of interest
were judged to be more complex in structure and appearance, from an
analytical standpoint, than the agricultural crop types for which the
LARS classification program was originally developed. These agri-
cultural resources (and related features such as fallow fields and
irrigation ditches) are sufficiently uniform <u>structurally</u> from point
to point within cultivated parcels that variation in radiant energy
signals--whether they be recorded on film emulsion or magnetic tape
as with the optical mechanical scanner--are generally felt to be less
than those from uncultivated terrain. When the signal variation for
a particular feature is small, the likelihood of its being discrimi-
nated from other neighboring features (or backgrounds) is increased.
While detailed <u>in situ</u> ground feature spectra were not recorded for
this study (primarily because it is felt that such spectra were not
meaningfully obtainable with the current "field" reflectance measuring
devices), it was observed that feature reflectance variation on
photographic emulsions of similar terrain conditions was relatively
high (see last year's report: Figure 21). This variation appears to
be largely attributable to shadows, undulating terrain and highly

varied terrain conditions.

Second, the problem of slope was considered, since the time of image acquisition by the Michigan aircraft was late afternoon and it was felt that this would affect signal responses on the steeper slopes. It was subsequently determined that this suspicion held true for only the steepest slopes and that imagery obtained under more optimum flying time would probably reduce this problem.

Following receipt of three different channels of "greyscale printouts" for the flight line studied in Figure 5.1, over one hundred training samples were selected among eight categories to be automatically classified. These original eight categories were:

1. Brushfields and related densely vegetated sites
2. Timber stands including some mixed hardwood types
3. Cleared land which is being prepared for seedling re-generation
4. Roads and trails
5. Lakeshore gravels
6. Water surfaces
7. Naturally bare areas containing little or no vegetation
8. Snow patches

The greyscale printouts have line and column coordinates on their borders for reference purposes in selecting training samples. Following study and selection of the training samples, they were transcribed directly to the greyscale printouts and subsequently keypunched onto EDP cards according to prescribed format prior to. starting the computer processing. Many more training samples than were actually needed were initially selected; this was because the original set of training samples was selected largely on the basis of arbitrary greyscale values in conjunction with known ground truth for the area of interest, and not specifically on any consideration. of spectral statistics. As previously mentioned in the discussion

of the four-part LARS program, LARSYSAA, an initial step in the data

processing leading to a successful classification scheme, involves

an examination of the statistics derived from each training sample.

In this and all remaining discussions, a "training sample" denotes

a rectangular set of digitized signal records, each point of which

is referred to as a Remote Sensing Unit (RSU). The histograms and

spectral curves were processed for each of the original training

samples. Where bi-modal distributions, or where very large variations

(standard deviations) were observed as a result of signal intensities

within individual training samples, these were pared entirely from

the original set or modified to eliminate some of the variation.

This was done until the final set of sixty-four training samples

remained. These sixty-four training samples, tabulated below, were

used in the final classification scheme. In studying the original

set of "brush" training sample histograms and related statistics,

it was apparent that species differentiation was manifesting itself

by producing three visually separable sets of histograms which agreed

with the ground truth information. Consequently, the original set

of brush training samples was regrouped to form three sub-sets of

samples: BRSHA, BRSHB, and BRSHC. The original category "bare" was

discarded entirely because of its distinct multi-modal character

which defied isolation for discrimination purposes. The final train-

ing sample listing follows: the category class labels for this list-

ing are:

BRSHA . . . . open, mixed species brushfields
BRSHB . . . . dense snowbrush, <u>Ceanothus</u> <u>velutinus</u>
BRSHC . . . . dense manzanita, <u>Arctostaphylus</u> <u>spp</u>.
CMIX . . . . .mixed conifer stands with some hardwoods

```
CLRD . . . . . . . . . . cleared brushfields
ROAD . . . . . . . . . . roadways and some bare areas
BANK . . . . . . . . . . lake shoreline
WATER . . . . . . . . . . water surfaces
SNOW . . . . . . . . . . snow patches
```

Training Sample	Class	First Line	Last Line	First Col	Last Col	Sample Pts. (RSU's)
1	BRSHA	441	449	127	139	117
2	BRSHA	359	375	83	101	323
3	BRSHA	357	373	29	35	119
4	BRSHA	997	1001	1	11	55
5	BRSHA	1059	1067	13	19	63
6	BRSHA	1237	1243	47	53	49
7	BRSHB	739	745	107	111	35
8	BRSHB	839	845	179	185	49
9	BRSHB	995	965	147	161	165
10	BRSHB	971	979	155	161	63
11	BRSHC	889	909	201	207	147
12	BRSHC	939	963	209	215	175
13	BRSHC	1001	1026	205	211	189
14	BRSHC	1457	1469	211	218	104
15	BRSHC	1481	1499	209	215	133
16	BRSHC	1513	1529	203	216	238
17	CMIX	23	31	89	93	45
18	CMIX	125	133	5	13	81
19	CMIX	391	399	95	101	63
20	CMIX	393	407	3	11	135
21	CMIX	415	421	31	37	49
22	CMIX	419	425	107	115	63
23	CMIX	599	604	121	125	35
24	CMIX	1059	1063	201	205	25
25	CMIX	1063	1065	189	195	21
26	CMIX	1281	1285	105	111	35
27	CMIX	1355	1361	167	173	49
28	CMIX	1462	1485	57	63	168
29	CMIX	1689	1699	29	39	121
30	CMIX	1683	1687	75	81	35
31	CMIX	109	113	95	103	45
32	CMIX	65	71	59	65	49
33	CMIX	699	711	5	9	65
34	CMIX	337	347	21	29	99
35	CMIX	1629	1637	73	83	99
36	CLRD	463	483	26	37	231
37	CLRD	477	493	59	75	289
38	CLRD	1255	1263	83	89	63
39	CLRD	468	478	152	156	55
40	CLRD	506	513	160	164	40

149

41	CLRD	531	539	178	181	36
42	ROAD	649	678	75	78	120
43	ROAD	767	827	79	81	183
44	ROAD	820	839	56	65	200
45	BANK	1285	1291	67	77	77
46	BANK	1297	1307	75	81	77
47	BANK	1305	1309	60	70	55
48	BANK	1333	1337	33	39	35
49	BANK	1351	1359	12	21	80
50	BANK	1419	1433	41	45	75
51	BANK	1445	1463	30	36	133
52	WATER	1361	1373	31	49	247
53	WATER	1407	1419	25	35	143
54	WATER	1439	1453	7	21	225
55	SNOW	1447	1450	200	203	16
56	SNOW	1483	1485	193	195	9
57	SNOW	1495	1502	186	189	32
58	SNOW	1514	1516	187	189	9
59	SNOW	1523	1528	185	187	19
60	SNOW	1536	1542	182	185	28
61	SNOW	1549	1551	176	179	12
62	SNOW	1555	1561	175	178	28
63	SNOW	1562	1571	172	175	40
64	SNOW	1571	1574	167	170	16

c) <u>Results and discussion</u>. The wildland feature classifica-
tion results presented herein were processed during the week of
January 19-24, 1969, at the LARS facility, West Lafayette, Indiana.
An IBM 360/44 Computer with peripheral tape drives, a keypunch, a
card reader, and medium-speed printer were used for on-line process-
ing of these data. The dual goal during the week spent at LARS was
(1) to become as familiar as possible with the LARS pattern recog-
nition system and its capabilities, and (2) to produce an automatic
classification scheme for wildland terrain features of a portion of
the 1966 Michigan M-5 Scanner imagery under study. The basic
operation of the LARSYSAA programs has already been outlined; the
results of the final classification scheme, from $STAT to $DISPLAY,
will now be presented.

$STAT: The coordinates of the sixty-four training samples used in developing the final classification scheme have been tabulated and each has been highlighted in the various $DISPLAY illustrations. Tables 5-1 and 5-2 list the statistical results of the combined training samples for each category included in the classification scheme. Initially, each individual training sample (numbering over 100 in eight original categories) was printed out and studied carefully in order to statistically determine how well it represented the category from which it was selected using the ground truth information. Once this original set of training samples was modified or pared down to the final sixty-four, the combined statistics for an entire category could be printed and stored for subsequent program use.

The four vegetation categories (i.e., CMIX, BRSHA, BRSHB, and BRSHC) generally exhibited very well-defined histograms and spectral plots. Channels 11 and 12 exhibited greater signal response variation than did the other ten data channels. This is probably due to the "near-infrared" response characteristics of healthy vegetation which is not exhibited as much in the lower wavelength regions.

Category CLRD was fairly well-defined by its set of training samples, though channels 7, 8, and 9 tended to exhibit rather large variations in signal response. This might be explained by the nature of the clearing operation in which the cut brush is piled in windrows to dry and disintegrate. Consequently, the net effect in terms of signal response of this category is rather unpredictable. The histograms tend to be less peaked and thus show wider variations

151

in certain data channels, especially in the yellow/green part of the spectrum.

Category ROAD proved to be rather poorly defined because of the terrain variability associated with this feature. Some parts of the road in the flight line were paved while other parts were not. Shadows and ruts also accounted for different radiant signals. The signal response variation for this category is seen to be rather large for most of the data channels.

Category BANK exhibited statistics which were very similar to category ROAD; these two categories, in fact, were nearly impossible to automatically separate, and were subsequently grouped into a single new category labelled SOIL for classification purposes.

Category WATER was well-defined, spectrally, as its histogram and spectral plot indicate. Interestingly, the classification displays show scattered signals of "water" in the area classified predominantly as mixed conifers where no standing water exists. It was suggested by LARS personnel that these signals were more than likely indicative of shadows, since they had similar experiences of water and shadow confusion in agriculture sites. The pattern distribution of these signals would conform to the likelihood of them being shadows, but it would have been extremely difficult and time-consuming to select a set of suitable shadow training samples to prove this point. In this case, the resultant classification errors are not deemed to be serious ones, because tree shadows are generally randomly scattered

in such a way and should not indicate a suspected water body.

Category SNOW was quite unique, spectrally, compared to the other categories in this classification scheme. Its radiant intensity far exceeded that of any other category and its histograms, because they are off-scale, appear "stacked-up" on the right side of the printout. This category proved most difficult to spectrally define for classification purposes, such that a number of signals are not classified into any category and are consequently thresholded out of the classification scheme, as the display illustrations reveal.

$SELECT: The classification results presented in this report were based on the optimum combination of four data channels that would "best" discriminate between the nine categories studied. In addition, the computer was programmed to print the thirty "best" three-combinations of data channels in order to determine what gains were produced by introducing the additional fourth channel for classification. In the three-channel combination results, photographically reproduced in Figure 5.4, it is noted that the combinations 3-5-12 yielded the greatest average divergency for the nine categories studied. Each category was assigned a single letter code to be printed with the paired divergencies:

```
CMIX    F
BRSHA   A
BRSHB   B
BRSHC   C
CLRD    X
ROAD    R
BANK    K
SNOW    S
WATER   W
```

FEATURES   INTERCLASS DIVERGENCE

No.	Features	Set		AB	AC	AF	AX	AR	AK	AW	AS	BC	BF	BX	BR	BK	BW	BS	CF	CX	CR	CK	CW	CS	FX	FR	FK	FW	FS	XR	XK	XW	XS	RK	RW	RS	KW	KS	WS
				(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)	(10)
1.	3 5 12	2.	2622	190	124	27	668	4554	3545	71	18646	26	48	76	936	687	371	6019	19	128	917	697	543	5008	144	998	765	171	7747	72	50	912	2778	2	5595	1212	4250	1109	25284
2.	3 9 11	4.	2616	196	127	32	1127	4991	3696	46	20192	25	49	136	803	544	440	6129	22	231	1056	724	650	4664	239	1117	803	237	6501	85	56	1403	1485	4	5525	420	4049	352	26029
3.	3 5 11	2.	2585	187	126	31	636	4287	3339	76	17681	24	48	74	920	677	411	6001	19	107	768	587	640	4694	128	854	654	236	7624	71	50	946	2739	2	5612	1090	4268	1072	26381
4.	3 9 12	4.	2557	191	131	29	1006	4517	3356	40	20096	25	46	133	794	541	398	6132	22	214	1031	714	549	5048	213	1061	771	174	6947	86	58	1365	1483	4	5469	286	4006	284	24849
5.	3 5 10	4.	2555	177	126	22	502	3143	2459	60	15283	10	41	79	922	683	332	6055	20	66	658	507	322	4643	108	836	654	78	7606	86	64	1150	2687	3	6162	1197	4617	1423	29212
6.	1 3 9	3.	2507	189	114	19	788	3218	2428	43	17025	13	47	132	759	507	202	8875	19	136	675	483	140	5431	182	841	624	33	8050	79	55	1276	2796	3	5635	538	4172	779	23942
7.	3 5 9	2.	2505	190	125	23	792	3442	2582	43	15960	4	42	132	901	638	210	6177	19	137	662	460	142	4904	176	816	594	26	7737	76	52	1334	2698	2	6625	797	4907	863	25791
8.	1 3 5	5.	2500	184	106	19	512	2938	2302	55	16285	15	48	67	903	630	148	9382	16	62	559	430	85	5206	108	692	534	18	8863	59	41	759	3351	5	5561	923	4272	1120	23760
9.	3 7 9	5.	2480	183	119	22	785	3203	2309	31	18979	7	44	126	760	533	206	6565	19	169	782	499	148	6418	217	999	683	24	8189	79	57	1269	1815	5	5518	242	4071	322	23892
10.	3 9 10	3.	2461	180	129	23	802	3452	2571	30	16209	10	42	130	767	531	351	6199	22	148	798	572	331	4510	189	984	729	76	6492	83	58	1512	1499	3	5910	193	4294	243	28521
11.	3 8 11	3.	2453	172	117	32	772	3838	2998	52	17363	23	47	140	885	648	457	6085	20	160	752	560	691	4828	156	815	614	245	7466	85	58	1245	1763	3	5183	479	3971	419	25165
12.	3 8 12	3.	2434	173	116	26	768	3880	3025	47	18121	25	46	138	896	650	395	6079	19	180	890	652	566	5104	181	941	708	176	7603	85	56	1155	1795	3	4994	512	3823	405	23389
13.	2 3 5	1.	2429	183	110	20	529	3107	2401	50	15464	5	47	71	896	655	164	6117	18	60	578	434	89	4714	118	799	604	12	7659	68	44	865	2694	1	6524	780	4910	927	25733
14.	3 5 6	1.	2422	208	144	28	579	3134	2458	47	15596	4	49	83	946	688	221	6172	24	55	576	417	188	4799	126	796	617	36	7720	60	38	1056	2695	1	6319	694	4911	899	24809
15.	3 8 10	5.	2420	161	117	20	525	2564	2017	37	15219	9	40	127	887	666	336	6185	20	103	624	485	328	4847	144	842	665	76	7526	82	60	1301	2731	3	5417	749	4087	952	27162
16.	2 3 9	2.	2409	194	122	21	820	3531	2619	38	16123	5	47	135	848	586	217	6291	17	140	686	480	141	4486	191	932	685	26	6018	98	66	1374	1505	2	6707	248	4392	222	26192
17.	1 3 8	2.	2397	176	101	18	551	2526	1996	46	15940	16	47	134	827	579	192	8882	17	97	547	422	131	5283	130	694	534	30	9066	82	55	1054	3429	2	5287	587	4115	813	21903
18.	3 8 9	2.	2393	179	117	21	773	3104	2307	24	16415	4	42	147	831	595	227	6163	19	132	655	456	160	5332	179	843	611	27	7713	79	53	1422	1761	2	6133	194	4563	269	24583
19.	3 5 7	1.	2391	178	116	24	503	2991	2280	41	16951	5	41	81	878	637	171	6741	17	57	572	411	122	5128	100	706	521	18	7919	73	44	853	2818	3	5613	695	4303	861	23590
20.	3 5 8	1.	2378	174	111	20	565	2907	2238	43	15350	4	40	138	892	641	194	6172	16	96	551	400	134	4820	130	697	521	23	7759	85	57	1097	2579	1	6156	875	4678	924	24421
21.	3 6 9	2.	2364	208	148	28	829	3330	2508	37	16179	4	48	136	849	594	254	6305	26	130	647	472	211	4627	200	929	695	41	6008	85	58	1449	1503	2	6321	117	4772	180	25113
22.	1 3 10	4.	2361	173	116	20	416	2136	1701	53	16005	21	47	61	564	399	304	8903	21	72	558	458	302	5199	111	736	577	82	8557	85	61	890	2013	4	3899	489	2964	306	25300
23.	2 3 8	1.	2352	177	107	19	575	2818	2162	40	15483	6	47	132	889	646	206	6246	19	96	581	429	135	4932	142	810	609	24	7548	94	62	1152	1799	3	6343	352	4789	408	24784
24.	3 6 10	4.	2305	190	154	28	479	2301	1821	46	15562	8	48	83	728	541	381	6222	28	59	491	364	399	4676	130	835	654	88	6584	90	65	1303	1230	4	5385	100	4269	150	27470
25.	1 3 6	2.	2303	195	121	22	489	2483	2012	52	16555	14	54	66	712	525	204	8349	24	65	557	435	185	5350	134	804	636	38	8151	61	41	903	2188	2	4657	486	3828	777	21123
26.	3 6 8	2.	2293	197	141	27	617	2707	2133	37	15583	4	48	135	897	654	240	6268	25	89	540	391	206	4986	152	792	612	43	7507	87	57	1236	1770	2	5828	183	4578	298	23468
27.	3 4 5	1.	2292	171	107	19	496	2903	2241	40	15354	3	40	66	853	621	140	6070	17	54	552	406	82	4953	104	704	531	9	7639	58	37	740	2671	1	5430	704	4109	877	23695
28.	2 3 10	3.	2291	178	125	21	452	2528	1926	49	15463	11	47	72	779	555	314	6150	23	66	600	448	303	5242	118	837	639	78	6604	96	68	590	1264	3	5063	234	3721	204	27903
29.	1 2 3	2.	2283	169	85	13	439	2581	2009	51	16609	12	50	52	785	545	113	9407	17	64	580	450	46	5244	121	808	613	13	8191	69	46	535	2072	2	4221	533	3196	780	21740
30.	3 7 10	3.	2283	164	123	24	416	2139	1707	47	16630	8	40	84	727	559	324	6731	20	59	496	384	328	5164	103	731	561	76	7323	86	59	1060	1809	3	4547	258	3490	329	25586

Figure 5.4 Three channel classification (unweighted); for an explanation of these values in relationship to Figures 5.5 and 5.6, see text.

Each pair of category divergencies is then averaged overall to obtain the listing of "best" combinations seen in Figure 5.4. The result revealed certain potential problems in discrimination between some of the categories, based on their calculated divergency index; namely, "AF", "AW", "BC", "BF", "BX", "XR", "XK", and "RK". Notice that some of the data channel combinations, while they appear further down the listing, may have greater divergencies for certain pairs of categories. Hence, it would be better to use that data channel combination which maximized the divergency between "important" features of interest, even though that combination appears lower in overall rating.

When a fourth data channel was included in the analysis (which requires twice as long to compute as does the three-channel combination) the following results were noted and photographically reproduced in Figure 5.5:

    1. Channels 3-5-9-11 were computed to have the greatest overall average divergency amongst the possible paired combinations of nine equally-weighted categories

    2. The difficulty noted for the three channel combination in discriminating between BRSHB and CLRD has been eliminated by the additional information provided by a fourth channel. The other eight pairs of categories which were noted as difficult to discriminate in the three channel combination were not much improved if at all by the additional channel.

    3. When weighting coefficients were assigned to certain pair combinations of categories deemed more important than others, the

FEATURES INTERCLASS DIVERGENCE

#	FEATURES	AB (10)	AC (10)	AF (10)	AX (10)	AR (10)	AK (10)	AW (10)	AS (10)	BC (10)	BF (10)	BX (10)	BRBK (10)	BW (10)	BS (10)	CF (10)	CX (10)	CR (10)	CK (10)	CW (10)	CSFX (10)	FR (10)	FK (10)	FW (10)	FS (10)	XR (10)	XK (10)	XW (10)	XS (10)	RKRWRS (10)	KW (10)	KS (10)	WS (10)
1.	3 5 9 11 4	2982.	229	137	35	1290	6372	4814 78	20730	26	53	147	1003 712	455	6206	22	241	1097	763	662	5195 242	1157	840	244	7891	89	61	1488	2839	4 6774 1129	5051	1075	28198
2.	3 5 9 12 4	2941.	224	139	31	1167	5964	4530 73	20824	27	51	144	1002 716	421	6225	23	226	1113	792	575	5398 220	1147	850	182	7927	92	64	1462	2859	4 6768 1217	5047	1141	27246
3.	1 3 9 11 5.	2929.	215	130	32	1149	5071	3801 69	21689	35	57	148	829 551	444	8886	23	242	1092	771	662	5765 246	1138	828	253	8873	89	60	1425	2821	5 5767 778	4305	838	26364
4.	1 3 5 12 5.	2891.	203	125	27	685	4592	3583 84	20376	36	54	83	1018 722	379	9596	20	140	907	742	548	5620 149	1022	779	179	9441	77	53	949	3361	3 5829 1263	4488	1254	25655
5.	1 3 9 12 5.	2872.	212	133	30	1034	4627	3490 63	21428	36	55	143	819 547	405	8950	23	226	1073	773	559	6056 221	1083	798	185	9345	90	62	1393	2952	5 5729 636	4277	812	25123
6.	3 5 10 12 5.	2853.	197	133	28	711	4575	3558 79	19258	26	49	96	981 718	487	6098	22	144	965	712	669	5109 157	1030	785	206	7896	92	68	1255	2787	5 6277 1314	4719	1507	(illegible)
7.	1 3 5 11 3.	2847.	200	127	31	651	4322	3380 91	19299	35	55	81	999 710	416	9461	20	120	807	642	648	5309 134	873	672	249	9113	75	53	974	3374	3 5821 1183	4488	1240	26820
8.	3 8 9 11 5.	2833.	211	129	35	1291	5660	4275 54	20342	26	53	169	940 676	480	6209	22	244	1072	748	697	5522 248	1125	811	248	7935	89	59	1598	1777	5 6329 533	4745	433	27185
9.	2 3 9 11 4.	2819.	224	136	33	1208	5564	4136 68	20531	27	58	149	911 625	451	6314	24	244	1113	771	654	4877 258	1248	905	249	6647	106	70	1505	1513	4 6780 561	4978	413	28145
10.	3 7 9 11 8.	2814.	212	130	33	1199	5396	4118 71	20770	26	52	141	855 614	455	6688	22	244	1085	728	685	6439 246	1141	807	247	8257	91	67	1427	1887	8 5682 500	4228	548	26200
11.	1 3 5 10 4.	2700.	192	126	23	527	3234	2559 76	16399	21	49	84	987 706	338	9453	21*	77	695	550	326	5281 115	867	674	87	8961	96	68	1178	3412	4 6378 1218	4836	1542	29622
12.	3 5 6 12 3.	2797.	225	162	36	757	4803	3774 79	19029	27	59	101	1064 792	443	6212	28	138	974	734	642	5217 185	1186	929	197	7953	77	57	1234	2854	3 6561 1267	5106	1171	26637
13.	2 3 5 12 2.	2794.	202	129	29	698	4668	3645 80	18856	27	54	84	982 729	402	6146	22	139	970	746	557	5142 159	1075	826	173	7841	83	58	1065	2818	2 6823 1310	5152	1166	27748
14.	3 6 9 11 5.	2793.	232	162	40	1205	5261	3952 63	20551	26	60	152	934 655	501	6343	29	237	1110	757	740	5007 277	1281	947	259	6731	95	64	1610	1513	5 6480 431	4926	369	27536
15.	3 5 10 11 4.	2791.	195	134	33	688	4315	3354 83	18389	25	50	94	962 710	526	6080	22	121	810	616	763	4757 135	922	713	270	7700	92	70	1285	2765	5 6296 1275	4739	1498	(illegible)
16.	3 5 9 10 4.	2790.	199	137	26	874	4269	3258 61	16322	11	45	143	993 722	363	6274	22	161	858	630	343	5024 194	1062	804	86	7800	88	65	1585	2991	4 7086 1260	5242	1456	(illegible)
17.	3 9 10 11 5	2790.	203	135	34	1140	5001	3707 49	20548	26	52	145	815 555	534	6228	24	237	1079	744	757	4749 242	1148	830	265	6716	90	62	1615	1508	5 5984 463	4374	390	(illegible)
18.	3 5 7 9 5.	2784.	201	128	25	861	3970	2871 47	19825	7	47	136	920 649	216	6825	20	176	857	554	153	6502 221	1047	715	30	8849	81	58	1341	2876	5 6656 877	4932	958	26575
19.	2 3 9 12 4.	2781.	217	140	31	1077	5020	3745 58	20399	27	55	145	910 628	428	6321	24	228	1096	769	567	5249 230	1168	855	178	7133	107	72	1502	1509	4 6837 426	5020	331	27593
20.	3 5 11 12 3.	2775.	196	130	34	703	4893	3816 91	19134	32	51	79	961 710	583	6056	21	136	939	717	989	5031 147	1001	768	360	7766	76	54	1093	2802	3 5812 1311	4424	1161	27807
21.	1 3 9 10 5.	2773.	200	131	24	838	3623	2763 54	17305	21	50	140	789 537	358	9020	23	159	833	617	340	5665 199	1013	763	89	8689	87	62	1536	2959	5 6156 565	4549	837	28825
22.	3 8 9 12 4.	2766.	198	125	28	879	4985	3890 72	18904	26	48	156	1006 730	416	6197	20	195	998	735	582	5146 191	1036	784	182	7884	95	65	1271	2864	4 6378 1223	4867	1204	26193
23.	3 5 6 11 3.	2765.	224	161	40	737	4596	3622 85	18156	24	59	98	1042 776	486	6198	27	118	827	630	739	4899 167	1030	808	263	7814	76	53	1272	2810	3 6584 1111	5130	1138	27746
24.	1 3 5 9 3.	2758.	203	126	24	812	3509	2657 60	17169	15	51	141	972 661	215	9502	20	147	694	492	150	5722 188	854	629	38	9029	82	56	1350	3492	3 6771 956	5064	1135	26291
25.	3 9 11 12 3.	2749.	202	134	36	1165	5261	3905 57	21382	32	51	139	825 557	591	6175	24	246	1159	784	975	5069 241	1142	817	359	6951	90	59	1492	1498	5 5592 504	4113	368	26945
26.	3 8 9 12 4.	2748.	204	132	30	1136	5078	3851 48	20252	26	49	163	933 673	430	6194	23	232	1071	758	584	5679 229	1081	795	182	7893	88	59	1548	1810	5 6240 517	4672	411	25854
27.	1 3 8 11 4.	2744.	192	121	32	798	3928	3108 74	18549	35	55	158	935 666	465	8918	20	176	817	639	700	5329 165	837	643	260	9272	90	61	1296	3445	4 5618 781	4389	871	25345
28.	3 5 8 11 3.	2744.	196	127	34	865	4784	3739 78	17928	24	49	158	993 726	467	6200	20	175	838	643	696	4874 167	886	669	253	7796	96	67	1334	2798	3 6450 1109	4926	1157	27468
29.	2 3 5 11 2.	2740.	200	130	33	671	4456	3477 89	17919	26	55	82	966 719	423	6137	22	120	838	648	641	4844 148	978	750	246	7726	83	58	1054	2789	2 6692 1189	5060	1162	28203
30.	1 3 7 9 6.	2735.	201	121	23	819	3349	2479 53	19714	19	53	135	782 540	213	9026	20	182	824	554	157	7137 228	1025	720	37	10131	81	60	1293	2891	6 5760 541	4327	825	24118

Figure 5.5 Four channel classification (unweighted); for an explanation of these values in relationship to Figures 5.4 and 5.6, see text.

list changed slightly, as seen in Figure 5.6. One of the optional features of the LARSYSAA programs is an ability to modify the "importance" of certain features by placing more emphasis on their signatures in the analysis. The weights which were assigned for the results shown in Figure 5.6 were: AF 3 times as important as the other; BC 2 times; BF 3 times; RK unseparable (i.e., they were made equal). Now only AW, BC, CF, XR and XK categories remained as problems for discrimination.

As mentioned earlier, these divergency ratings are best used as indices of separability between categories. The limits that account for "accurate" category discriminations vs. "inaccurate" category discriminations for wildland data are not yet known. The limits determined to be useful in <u>agricultural</u> classifications (i.e., 300 completely separable, 30 unseparable) were used for this study because no better limits are currently known. The final classification results showed that, in fact, in only one pair of categories were the two members consistently unseparable; namely, ROAD and BANK. Considerable difficulty in separating BRSHC from CMIX was encountered in the final automatic classification scheme. However, the displays of the final classification scheme seem to indicate that these two categories were not as difficult to separate as the divergency indices suggested.

$CLASS: The final four data channels selected for classification of the entire flight line were channels 3-5-9-11. The final classification, based on maximum likelihood ratio calculations, described earlier, produced a display of digits assigned one to each

FEATURES   INTERCLASS DIVERGENCE

#	FEATURES		AB (10)	AC (10)	AF (30)	AX (10)	AR (10)	AK (10)	AW (10)	AS (10)	BC (20)	BF (10)	BX (10)	BR (10)	BK (10)	BW (10)	BS (10)	CF (10)	CX (10)	CR (10)	CK (10)	CW (10)	CS (10)	FX (10)	FR (10)	FK (10)	FW (10)	FS (10)	XR (10)	XK (10)	XW (10)	XS (10)	RK (0)	RW (10)	RS (10)	KW (10)	KS (10)	WS (10)
1.	3 6 9 11	5.	237.	232	162	120				63		52	180	152				29	237					277			259		95	64			0				298	
2.	2 3 9 11	4.	235.	224	136	99				68		54	174	149				24	244					258			249		106	70			0					
3.	3 9 11 12	5.	234.	232	134	108				57		64	153	139				23	246					241					90	59			0					
4.	1 3 9 11	4.	234.	215	130	96				69		70	171	148				23	242					246			253		89	60			0					
5.	3 5 9 11	5.	233.	229	137	105				78		52	159	147				24	241					242			244		89	61			0					
6.	3 6 9 12	5.	233.	225	166	114				57		52	174	150				30	221					249			196		97	67			0					
7.	3 8 9 11	5.	233.	211	129	105				54		52	159	169				22	244					249			248		89	59			0					
8.	3 7 9 11	8.	233.	212	130	99				71		52	156	141				22	244					246			247		91	67			0					
9.	3 6 8 11	4.	232.	213	156	123				66		48	174	157				28	169					201			267		94	64			0					
10.	3 9 10 11	5.	232.	203	135	102				49		52	156	145				24	237					242			265		90	62			0					
11.	3 6 8 12	4.	231.	212	158	108				61		50	174	156				28	187					229			200		94	63			0					
12.	3 4 9 11	4.	231.	198	129	96				49		50	147	142				22	238					244			238		95	63			0					
13.	2 3 9 12	5.	231.	217	140	93				58		54	165	145				24	228					230			178		107	72			0					
14.	3 5 9 12	5.	230.	224	139	93				73		54	153	144				23	226					220			162		92	64			0					
15.	1 3 9 12	5.	230.	212	133	90				63		72	165	143				23	226					221			185		90	62			0					
16.	3 8 11 12	4.	230.	179	123	105				66		62	150	146				21	194					183					88	59			0					
17.	2 3 8 11	3.	230.	195	126	102				72		52	168	153				22	175					183			258		100	68			0					
18.	3 7 9 12	7.	229.	200	133	93				57		52	150	137				22	233					234			181		91	66			0					
19.	3 8 9 12	5.	229.	204	132	90				48		52	147	163				23	232					229			182		88	59			0					
20.	1 3 8 11	3.	229.	192	121	96				74		52	165	158				20	176					165			260		90	61			0					
21.	3 6 7 11	4.	229.	212	156	120				82		48	174	158				20	124					179			267		90	56			0					
22.	3 5 8 11	3.	229.	196	127	102				78		48	147	158				20	175					167			253		96	67			0					
23.	3 5 6 11	3.	228.	224	161	120				85		48	177	98				27	118					167			263		76	53			0					298	
24.	3 9 10 12	4.	228.	196	137	90				44		50	144	139				24	220					216			203		88	61			0				299	
25.	3 7 8 11	4.	228.	189	122	102				71		48	150	152				20	172					173			251		92	60			0					
26.	3 7 8 12	4.	228.	195	126	87				63		54	162	150				20	194					202			180		100	66			0					
27.	1 3 8 12	4.	228.	194	120	81				68		52	162	156				20	195					188			186		89	60			0					
28.	3 5 6 11	3.	227.	206	153	111				78		78	189	76				27	119					157			269		78	55			0					
29.	3 5 6 12	3.	227.	225	162	108				79		54	177	101				28	138					185			197		77	54			0					
30.	3 4 9 12	4.	227.	194	133	87				44		50	141	138				23	222					218			176		95	64			0				297	

Figure 5.6   Four channel classification (weighted); for an explanation of these values in relationship to figures 5.4 and 5.5, see text.

category in the study. For this classification scheme, ROAD and BANK were subsequently combined into a single category (since they could not be consistently discriminated one from the other) labelled SOIL. The classification results from $CLASS are illustrated in Figure 5.7. These digital data were simultaneously stored on magnetic tape for future reference or display manipulation.

$DISPLAY: Three displays were produced from the above listed classification scheme. All three are included in Figure 5.7 along with the digital printout of program $CLASS. In the first display example, a separate density symbol (selected from those available on a standard computer printer) was assigned to each category in the study, with category SOIL printed blank. A very "light" threshold level was given to this display result. It should be noted that thresholded signals are also printed blank by LARSYSAA and therefore not all blanks printed in this first display indicate SOIL. Most of the thresholded signals turned out to be those present in the category SNOW, since this category was such a difficult one to define. Table 5-3 lists the classification results as they pertain to the training samples only, and it can be seen specifically where the classification errors occurred within the training samples. These errors correspond closely with those expected from the divergency data previously obtained from program $SELECT.

The second display result was modified somewhat in that different density symbols were used to improve the visual interpretability of the printed output. Also, all categories were symbol-printed so that blanks in the display would indicate thresholded
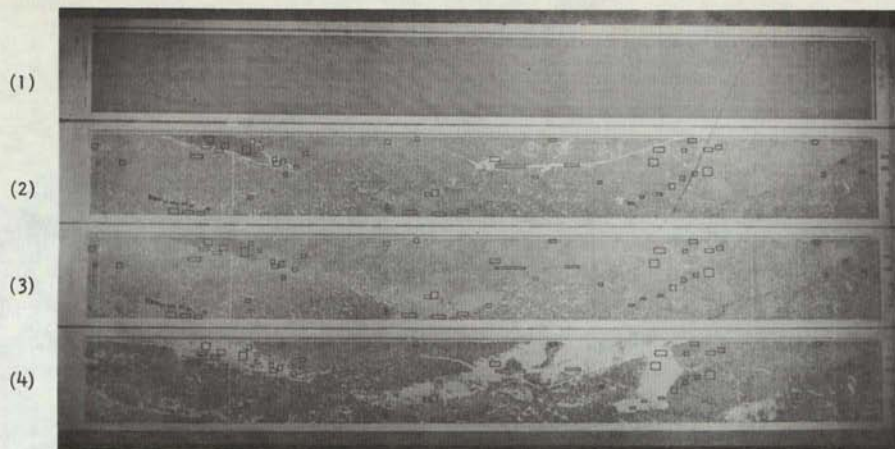
Figure 5.7(a) $CLASS and $DISPLAY output is illustrated above. The entire flight line analyzed in this study is shown. The top strip of printer output (1) is produced from program $CLASS while the remaining three strips (2), (3) and (4) are produced with different character manipulations using the information derived from the classification scheme. Figure 5.7(6) shows close-up portions of these displays more clearly.

Figure 5.7(b)   Three examples of DISPLAY
are illustrated at the right. Each re-
veals a different visual effect as a
function of character manipulation and
various threshold levels. The regions
outlined by black lines denote training
samples.

In the top view, all categories have
been assigned a character symbol, blank
spaces are points which were thresholded
from the display because they were cal-
culated to not adequately align with any
of the possible feature categories. In
the center view of the same portion of
data, different symbols have been used
and the ROAD and CLRD areas have been
printed blank. In the bottom view, only
vegetative categories have been assigned
symbols while all other categories have
been printed blank.
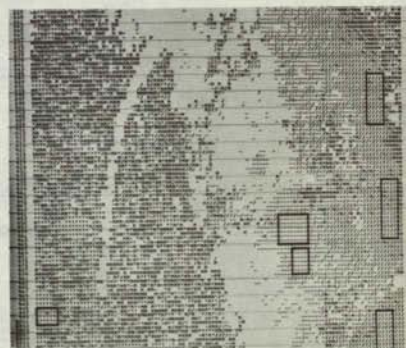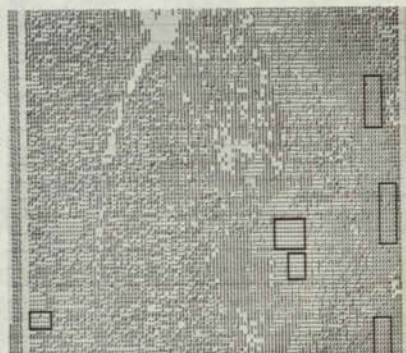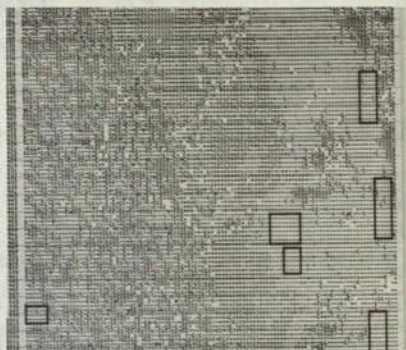
signals only. A medium threshold level was used in this display. Note that the road and lakeshore features were no longer as readily seen as they were in the first display. The blank line which appears near the left end of the flight line data is the result of an optical-mechanical scanner malfunction and subsequent faulty analog tape record. This malfunction only occurred during one scan line. The third and final display shows only vegetation categories printed out, with the remaining four categories left blank.

The critical concern with regard to these displays (and the classification scheme which enabled their output) is how "accurate" they are. The reason for any hesitancy in resolving this concern is caused by the tremendous diversity of features and conditions encountered in the wildland study area. For agricultural data, the categories fall into neat cultivated crops of geometric proportions. Thus, while some stray signals may appear in a field that is otherwise predominantly printed as wheat, say, the investigator can feel fairly confident that the entire field is wheat and disregard the scattered errors. Note, however, that in the wildland condition, random patterns of signals may not be errors at all and that an accurate appraisal of how well the classification scheme discriminates between the various categories being studied would require 100% ground reconnaissance in order to check out each corresponding signal element. On a point-by-point basis, this is an impractical and unwarranted approach to resolving accuracy. "Test fields" are used by the staff at LARS to determine accuracy levels in agricultural data. If a certain field was found to contain at least 70% of a particular correctly identified and classified signal,

then the _entire_ field was considered accurately identified and classified. It is felt that this approach would not apply to wild-land terrain features. Edge effects and type boundary delineations especially were difficult to assess and consequently the "field" concept for accuracy determination is inappropriate. By carefully reviewing the ground truth data and the photo reproductions of the M-5 imagery presented in Figure 5.3, one can readily see that, qualitatively speaking at least, the classification scheme for four channels of data was quite successful. Each category has been identified and classified in broad terms in its respective location along the flight line. It is fairly certain that most of the in-correct signals appearing in category WATER are simply classification errors; there is little doubt that the area itself is a large body of water and that indicated vegetation signals are errors. Also, the "errors" in classifying shadows as WATER are accountable as previously discussed. The major problems encountered in the clas-sification were (1) the difficulty in defining category SNOW; and (2) the similarity of signal responses for bare areas and ROAD and BANK categories.

The concern about topographic relief possibly influencing signal responses enough to cause classification errors only occurred in one area of the flight line. This region (near the right hand edge of the flight line) shows considerably more coniferous forest signal responses than actually existed in the area. It is now believed that topographic relief, coupled with the easterly aspect of this portion of data, contributed to a change in radiant response

such that many of the altered BRSHA signals more closely resembled CMIX signals. It is also felt that imagery obtained at a better sun angle inclination (i.e., around noontime) would have minimized many of these classification errors. In fact, topographic relief and aspect are not now suspected to significantly contribute to the alteration of a cateogry's signal responses obtained during optimum recording times in wildland terrain except for the very steep slopes that are infrequently encountered.

d) <u>Summary of study</u>. The ability to successfully discriminate agricultural resources through the use of statistically designed automatic pattern recognition techniques has been well demonstrated in results obtained by personnel at LARS. The adaptability of these digital computer oriented techniques to a specific wildland terrain environment and its resources has been presented in the present F.R.S.L. study together with some discussions of related digital techniques which will follow. The successful classification of most of the wildland features that were examined points to the potential extension of similar studies designed to rapidly inventory vast regions of wildland terrain. The justification for such an extension, however, rests not only on the successful demonstration of its <u>feasibility</u>, but also on an assessment of the costs to be incurred and the benefits to be derived. The estimated cost/benefit ratios would have to be more favorable than those derived from conventional techniques. In this discussion, conventional techniques for wildland resource inventory consist of the procurement and interpretation of aerial photography. This method of resource survey

is compared, as much as possible, with the optical-mechanical scanner imagery procurement and subsequent automatic "interpretation".

1. Aerial Photography Acquisition and Interpretation. In 1936, the U. S. Dept. of Agriculture began its still existing program of monitoring crop yields and determining price support levels. Since there are 478 million acres of croplands in the U. S., of which 350 million acres are considered significantly "active" (Belcher, 1967), the implementation of this program is no simple task. At the standard photo scale of 1:20,000, the USDA now spends more than $500,000 annually for the procurement of specified aerial photo coverage. If the entire 350 million acres were to be flown annually, it is estimated that the cost would exceed 1.3 billion dollars. There are insufficient available aircraft, equipment, and personnel to handle this volume of data, according to Belcher. Estimates for forest and rangeland coverage are about the same (because of the use of higher altitude aircraft), namely 1.3 billion dollars for annual U. S. coverage, even though a larger land area is involved. A United Nations survey estimates there are over 640 million acres of forested land in the U. S. (FAO, 1961). It would not be necessary to acquire aerial photo coverage of forested regions as often as agricultural regions because the features undergo changes at a slower rate. The benefits from this coverage would consist of a permanent reservoir of information about the terrain from which land managers could hopefully extract wise land-use allocations. The cost of extracting the information from aerial photos is difficult to determine because of the varied

applications for its use. Some of these applications, noted in the

Cornell University study previously cited (see Belcher, 1967), include:

forest land-use surveys, forest soil surveys, forest inventories,

site classification, scenic area evaluation, inventorying fire-

damaged areas, and insect and disease damage surveys. Benefits to

be derived from these applications are listed in Table 5-4:

Table 5-4   Applications and Benefits Derived from Remote Sensing of
U. S. Forested Lands (extracted from Cornell U. Study - see Belcher, 1967)

Application	*Source of Estimates	Annual U.S. Benefits (Millions of Dollars)
Forest land-use survey	P	7
Forest soil survey	H	98
Forest inventory	H	9
Forest site classification	H	10
Scenic area evaluation	N	*
Inventorying fire damaged areas	H	39
Assessing insect damage	H	60
Disease detection, salvage and control	H	50

* Legend: N = no source of estimate available
          P = based on project staff judgment
          H = supported by published information or from experts in
              the field
          * = no estimate of savings or improvements attempted

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2.   Optical-Mechanical Scanner Imagery Acquisition and Analysis

Cost figures for operational surveys using the optical-mechanical

scanner data and digital pattern recognition technique (such as the

one developed at LARS) are to date impossible to document because

no such extensive surveys have been conducted. Scanner security

restrictions and a lack of effective methods for analyzing the re-

sultant data have been the main deterrents. It is possible to extrap-

olate costs somewhat from those which were involved in acquiring the 1966 Michigan M-5 data and, to a limited extent, those involved in the analysis presented in this study. The total cost of remote sensing data during the entire 1966 mission (which also included some conventional photography) for all the areas sensed (which included sites in Oregon and Nevada as well as some other in California) was approximately $18,000. This figure would not be too different from the cost of conventional aerial color photography of the same regions at the same approximate photo scale (i.e., 1:25,000). Following acquisition of the scanner data, some pre-processing of it is required (analogous to that required for developing the film emulsion to proper specifications). At this stage, the comparisons of methods become more abstract. Human photo interpretation is a specialized skill and art that is not readily duplicated by automatic techniques. But, as this study revealed, there is considerable potential gain in efficiency and consistency of interpretation using pattern recognition methods that will automatically classify broad wildland resource types which may actually alleviate some of the interpretative tasks placed upon the human image analyst.

Computer processing of the data used in this study, including the A/D conversion, was performed at the LARS facility and consumed several hundred man-hours. The cost and time intervals that were involved were approximately:

1. Analog tape duplication at the University of Michigan and their delivery to LARS . . . . $500 - 2 man-hours

2. A/D formating and greyscale printouts of selected data channels for training sample selection . . . . $800 - $2000 - 5 manhours

167

3. One week's time spent at LARS processing the results presented in this study; includes over 7 hours of on-line computer time and one man-week of effort . . . . . no estimate attempted

An administrator of NASA recently commented, "...In the areas of agriculture, forestry and geology the principal need now is for improved identification of the signature of various species...." (Newell, 1968). While this statement can be generally acceptable to most individuals, it should be emphasized that the identification of signatures is currently feasible and in fact quite common in many scientific disciplines by automatic routines. The principal need, it would seem, is for a reliable, efficient technique for accurately defining the species or feature signatures. There is a sizable effort here at the Forestry Remote Sensing Laboratory as well as at other facilities to help solve this definition and re-cording problem.

On July 16, 1969, the University of Michigan aircraft flew the optical mechanical scanner and recorded wildland data shown in Figure 5.8 to provide new information that would complement the 1966 data. While these new data have not been processed and received from NASA-Houston at the time of this writing, the plans are to proceed with their interpretation as much as possible with the cooperation of the LARS facility and staff. Such interpreta-tion could be greatly facilitated through the use of a remote terminal which would be located at the FRSL and available for other interested parties to use for their own particular applications.

Figure 5.8 Flight lines flown by the Michigan Scanner in July, 1969, which are providing new, complementary data for subsequent analysis.

TABLE 5.1 WILDLAND TERRAIN FEATURE STATISTICS

The following nine pages contain tables of statistics
generated by LARSYSAA for each of the categories that
are included in this classification study. Means,
standard deviations, the covariance matrix, and the
correlation matrix are tabulated - by channels - for
the radiance level exhibited by all elements of a par-
ticular category's set of training samples.

Table 5.1: Terrain Feature Statistics

Category 1: CMIX
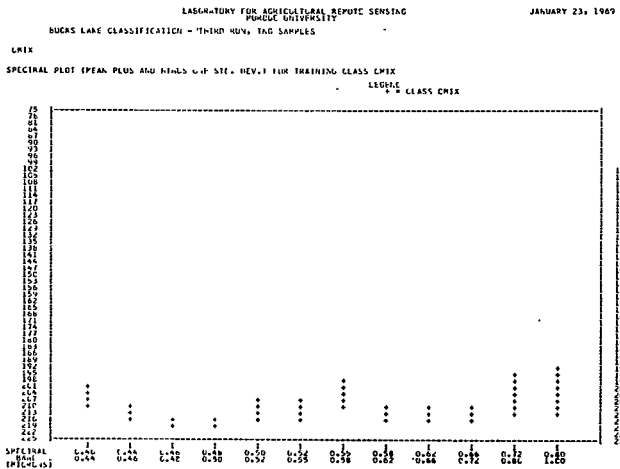
THE COVARIANCE AND MEAN FOR TRAINING CLASS CMIX

0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
MEAN	205.24	212.46	217.13	217.30	211.54	211.87	204.17	213.08	213.36	213.37	203.37	202.97
ST DEV	3.33	2.36	1.67	2.07	3.42	3.48	6.03	3.51	3.52	3.91	9.81	9.84

COVARIANCE MATRIX

0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
11.11											
5.26	5.58										
4.30	2.55	2.78									
4.04	3.46	2.32	4.29								
8.66	5.10	4.75	4.53	11.66							
1.50	2.48	0.85	1.39	1.55	12.12						
11.35	6.70	6.73	6.57	16.26	4.16	36.37					
7.66	4.29	4.57	4.39	10.90	1.18	16.76	12.29				
6.31	3.96	3.74	4.45	8.44	1.63	17.91	9.27	12.42			
6.96	3.71	4.36	4.02	10.85	1.94	17.45	12.08	9.11	15.26		
9.73	7.26	6.66	8.06	18.95	6.11	44.78	19.39	19.40	26.17	96.20	
11.25	6.79	7.41	6.90	22.06	5.97	36.81	22.91	15.07	30.12	78.32	96.77

CORRELATION MATRIX

0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
1.00											
0.67	1.00										
0.77	0.64	1.00									
0.56	0.71	0.67	1.00								
0.76	0.63	0.63	0.64	1.00							
0.13	0.30	0.15	0.19	0.13	1.00						
0.56	0.61	0.67	0.69	0.79	0.20	1.00					
0.67	0.52	0.76	0.60	0.91	0.10	0.79	1.00				
0.54	0.48	0.64	0.61	0.76	0.13	0.64	0.75	1.00			
0.53	0.40	0.67	0.50	0.81	0.14	0.74	0.68	0.66	1.00		
0.30	0.31	0.41	0.40	0.57	0.18	0.76	0.56	0.56	0.68	1.00	
0.34	0.29	0.46	0.34	0.66	0.17	0.62	0.66	0.43	0.78	0.81	1.00

171

Table 5.1: Terrain Feature Statistics, continued

Category 2: BRSHA

BUCKS LAKE CLASSIFICATION - THIRD RUN, TNG SAMPLES

BRSHA

SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS BRSHA

LEGEND
+ = CLASS BRSHA
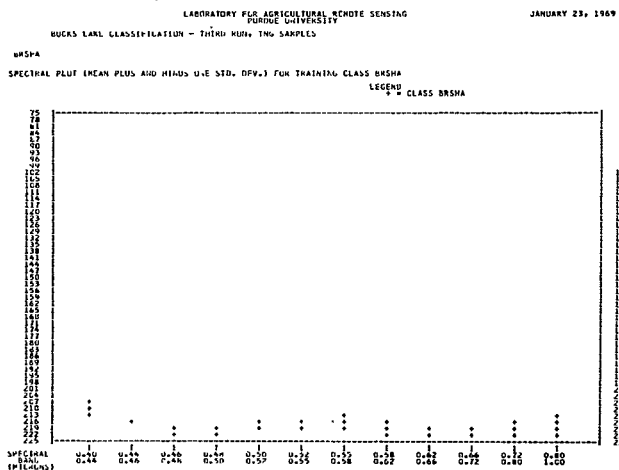
THE COVARIANCE AND MEAN FOR TRAINING CLASS BRSHA

	0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
MEAN	203.43	215.90	217.75	220.20	217.55	218.12	215.49	219.31	219.77	220.60	218.42	214.50
ST DEV	2.02	1.41	1.05	1.51	1.66	1.96	3.05	1.84	1.84	2.05	3.70	4.08

COVARIANCE MATRIX

0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
4.08											
1.66	2.00										
1.24	0.74	1.10									
1.36	0.86	0.73	2.27								
1.91	1.40	1.12	1.17	2.75							
1.03	0.91	0.40	0.58	0.91	3.85						
2.91	2.28	1.81	2.25	3.91	1.63	9.29					
1.78	1.27	1.11	1.36	2.41	0.87	4.54	3.18				
1.61	1.03	0.94	1.03	1.94	1.01	4.18	2.42	3.39			
1.74	1.17	1.09	1.34	2.36	1.03	4.72	2.90	2.61	4.21		
2.33	1.68	1.79	1.59	4.07	1.56	9.04	5.04	4.71	5.49	13.71	
2.65	1.94	2.03	1.83	4.58	1.43	8.59	5.41	4.57	5.74	11.31	16.67

CORRELATION MATRIX

0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
1.00											
0.58	1.00										
0.58	0.53	1.00									
0.45	0.40	0.46	1.00								
0.57	0.60	0.64	0.47	1.00							
0.26	0.33	0.19	0.20	0.28	1.00						
0.47	0.53	0.57	0.49	0.77	0.27	1.00					
0.48	0.49	0.57	0.49	0.79	0.24	0.81	1.00				
0.43	0.40	0.51	0.37	0.64	0.26	0.74	0.71	1.00			
0.42	0.39	0.50	0.43	0.67	0.25	0.76	0.77	0.69	1.00		
0.31	0.36	0.46	0.28	0.66	0.21	0.80	0.74	0.69	0.72	1.00	
0.32	0.34	0.47	0.30	0.68	0.18	0.69	0.72	0.61	0.69	0.75	1.00

Table 5.1: Terrain Feature Statistics, continued

Category 3: BRSHB

HUCKS LAKE CLASSIFICATION - THIRD RUN, TWO SAMPLES

BRSHB

SPECTRAL PLOT (PLAN PLUS / ID MINUS ONE STD. DEV.) FOR TRAINING CLASS BRSHB

LEGEND
* * CLASS BRSHB


```
SPECTRAL     0.40   0.44   2.46   0.48   0.50   0.54   0.55   0.58   0.62   0.66   0.72   0.80
BAND         0.44   0.46   2.48   0.50   0.52   0.55   0.58   0.62   0.66   0.72   0.80   1.00
(MICRONS)
```

THE COVARIANCE AND MEAN FOR TRAINING CLASS BRSHB

	0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
MEAN	193.23	202.96	210.65	210.71	200.20	203.02	188.45	202.53	200.69	204.11	199.37	197.76
ST DEV	3.15	2.03	1.55	1.90	2.46	2.21	3.62	2.33	3.06	2.33	3.45	3.75

COVARIANCE MATRIX

0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
9.95											
4.12	4.10										
3.77	1.74	2.41									
3.00	2.48	1.90	3.60								
5.62	3.54	2.53	2.77	6.05							
2.84	2.33	1.36	1.52	2.54	4.87						
7.56	5.12	3.59	4.05	7.02	4.54	13.13					
5.21	3.09	2.50	2.77	4.91	2.57	6.45	5.43				
6.51	4.20	3.17	1.66	5.77	3.31	8.97	5.76	9.39			
4.33	2.50	2.29	2.37	4.00	2.55	6.02	4.17	4.83	5.41		
2.06	1.40	1.32	1.09	3.04	2.29	5.77	3.24	3.53	4.31	11.92	
2.07	1.47	1.52	1.08	3.05	2.59	5.61	3.11	2.75	4.61	6.75	14.05

CORRELATION MATRIX

0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
1.00											
0.64	1.00										
0.77	0.57	1.00									
0.60	0.65	0.64	1.00								
0.72	0.71	0.66	0.59	1.00							
0.41	0.52	0.40	0.36	0.47	1.00						
0.66	0.70	0.64	0.59	0.79	0.57	1.00					
0.71	0.65	0.69	0.63	0.86	0.50	0.81	1.00				
0.67	0.68	0.67	0.69	0.77	0.49	0.81	0.81	1.00			
0.59	0.53	0.63	0.54	0.70	0.50	0.71	0.71	0.68	1.00		
0.23	0.20	0.25	0.17	0.36	0.30	0.46	0.40	0.33	0.54	1.00	
0.17	0.19	0.26	0.15	0.33	0.31	0.41	0.16	0.24	0.51	0.52	1.00

173

Table 5.1: Terrain Feature Statistics, continued

Category 4: BRSHC

BUCKS LAKE CLASSIFICATION - THIRD RUN, 1% SAMPLES

BRSHC

SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS BRSHC

LEGEND
* * * CLASS BRSHC

	0.40	0.44	0.46	0.48	0.50	0.52	0.55	0.58	0.62	0.66	0.72	0.80
SPECTRAL MEAN (MICRONS)	5.44	5.46	5.47	5.49	5.53	5.54	5.58	5.62	5.66	5.77	5.80	1.00

THE CIVARIANCE AND MEAN FOR TRAINING CLASS BRSHC

	0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
MEAN	197.26	206.80	212.63	212.39	202.74	203.02	189.52	204.26	203.91	203.19	189.17	186.55
ST DEV	3.12	2.45	1.89	2.03	3.22	2.96	5.12	3.12	3.30	3.11	5.40	5.80

COVARIANCE MATRIX

	0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
	9.44	5.99	0.48	0.50	0.52	0.45	0.58	0.62	0.66	0.72	0.80	1.00
	4.76											
	5.63	5.89										
	4.42	3.25	3.57									
	4.15	3.70	2.41	4.13								
	8.16	6.37	4.34	4.72	10.38							
	4.61	4.73	2.98	3.09	5.40	8.76						
	11.79	10.04	6.74	7.44	14.08	9.33	26.22					
	7.62	5.81	4.63	4.46	9.09	5.16	14.04	9.76				
	7.47	5.32	4.12	4.62	8.59	5.49	14.78	6.55	10.88			
	6.33	4.72	4.19	3.67	7.89	4.28	12.08	8.06	7.37	9.68		
	7.40	6.30	4.22	4.69	9.51	6.27	18.55	9.47	10.61	11.24	29.20	
	9.03	7.01	5.33	4.84	11.44	6.43	18.52	11.45	10.11	12.87	23.05	33.61

CORRELATION MATRIX

	0.40 0.44	0.44 0.46	0.46 0.48	0.48 0.50	0.50 0.52	0.52 0.55	0.55 0.58	0.58 0.62	0.62 0.66	0.66 0.72	0.72 0.80	0.80 1.00
	1.00											
	0.74	1.00										
	0.75	0.71	1.00									
	0.65	0.75	0.63	1.00								
	0.41	0.62	0.74	0.72	1.00							
	0.50	0.66	0.73	0.51	0.57	1.00						
	0.74	0.61	0.70	0.74	0.65	0.62	1.00					
	0.78	0.77	0.78	0.70	0.90	0.56	0.88	1.00				
	0.72	0.74	0.66	0.69	0.81	0.56	0.88	0.83	1.00			
	0.65	0.63	0.71	0.58	0.74	0.46	0.76	0.83	0.72	1.00		
	0.47	0.46	0.41	0.43	0.55	0.39	0.67	0.54	0.60	0.67	1.00	
	0.50	0.50	0.49	0.41	0.61	0.37	0.62	0.63	0.53	0.71	0.74	1.00

174

Table 5.1: Terrain Feature Statistics, continued

Category 5: CLRD

BUCKS LAKE CLASSIFICATION - THIRD RUN, TNG SAMPLES

CLRD

SPECIAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS CLRD

LEGEND
* = CLASS CLRD

THE COVARIANCE AND MEAN FOR TRAINING CLASS CLRD

	0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
MEAN	176.51	191.67	202.71	201.51	163.31	149.90	163.80	182.42	174.24	192.49	199.89	199.56
ST DEV	7.12	5.42	4.04	4.68	8.67	8.01	16.69	14.06	18.39	10.70	6.48	6.37

COVARIANCE MATRIX

0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
50.64											
27.71	29.33										
25.03	15.61	16.14									
25.96	23.17	14.74	21.37								
54.04	32.15	33.17	30.70	75.15							
25.96	31.38	16.69	24.47	35.79	64.18						
66.70	67.53	54.35	64.03	122.04	83.50	258.92					
71.72	47.78	47.68	45.16	109.97	68.55	201.74	197.73				
92.24	67.11	50.48	64.46	136.12	96.64	201.94	243.54	336.14			
49.68	34.70	34.14	32.96	80.21	52.89	149.86	147.65	183.02	114.40		
23.47	15.12	16.45	15.72	39.10	21.96	76.99	62.27	81.68	49.73	42.06	
19.03	13.30	15.08	13.01	36.90	21.10	64.50	62.16	71.88	51.09	33.12	40.52

CORRELATION MATRIX

0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
1.00											
0.72	1.00										
0.90	0.71	1.00									
0.76	0.92	0.74	1.00								
0.69	0.68	0.95	0.76	1.00							
0.46	0.72	0.52	0.65	0.52	1.00						
0.77	0.78	0.84	0.85	0.88	0.65	1.00					
0.72	0.63	0.84	0.69	0.90	0.61	0.89	1.00				
0.73	0.67	0.79	0.75	0.84	0.66	0.95	0.94	1.00			
0.65	0.60	0.79	0.66	0.87	0.62	0.87	0.98	0.93	1.00		
0.51	0.43	0.63	0.52	0.70	0.62	0.74	0.68	0.66	0.72	1.00	
0.42	0.39	0.59	0.44	0.67	0.41	0.63	0.69	0.61	0.75	0.80	1.00

Table 5.1: Terrain Feature Statistics, continued

Category 6: ROAD

```
                    LABORATORY FOR AGRICULTURAL REMOTE SENSING          JANUARY 23, 1969
                              PURDUE UNIVERSITY

        BUCKS LAKE CLASSIFICATION = TRAIN (01, 136 SAMPLES

ROAD

SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS ROAD
                                              LEGEND
                                              + + CLASS ROAD
```
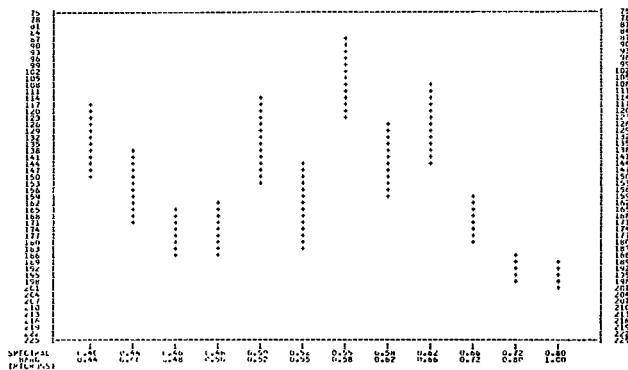


```
THE COVARIANCE AND MEAN FOR TRAINING CLASS ROAD
           0.42-   0.44-   0.46-   0.48-   0.50-   0.52-   0.55-   0.58-   0.62-   0.66-   0.72-   0.80-
            0.44    0.46    0.48    0.50    0.52    0.55    0.58    0.62    0.66    0.72    0.80    1.00
MEAN     133.14  134.03  176.70  173.61  131.44  164.55  105.71  141.74  125.91  169.03  192.85  195.24
ST DEV    15.16   15.60   10.40   11.12   20.00   19.02   18.64   16.74   18.86   11.47    6.03    5.21
```

```
COVARIANCE MATRIX
           0.40-   0.44-   0.46-   0.48-   0.50-   0.52-   0.55-   0.58-   0.62-   0.66-   0.72-   0.80-
            0.44    0.46    0.48    0.50    0.52    0.55    0.58    0.62    0.66    0.72    0.80    1.00
224.94
211.96  243.22
149.54  148.37  108.12
152.29  168.44  107.63  123.56
285.16  282.20  203.24  207.16  400.09
121.67  172.65   92.88  109.20  178.23  392.74
244.05  250.54  164.92  169.67  338.23  155.55  347.51
206.64  203.80  152.94  156.48  312.60  146.55  282.91  280.26
203.93  218.27  134.08  172.41  317.14  162.14  326.61  293.03  353.53
117.96  120.65   91.95   95.23  193.11   96.56  176.18  163.79  199.34  131.64
 45.25   51.60   36.07   42.31   77.26   44.00   82.37   77.35   96.68   56.00   36.41
 39.45   46.05   32.32   36.15   69.87   44.96   65.95   68.63   78.53   50.99   23.70   27.16
```

```
CORRELATION MATRIX
           0.40-   0.44-   0.46-   0.48-   0.50-   0.52-   0.55-   0.58-   0.62-   0.66-   0.72-   0.80-
            0.44    0.46    0.48    0.50    0.52    0.55    0.58    0.62    0.66    0.72    0.80    1.00
1.00
0.90  1.00
0.95  0.91  1.00
0.90  0.97  0.93  1.00
0.94  0.90  0.76  0.93  1.00
0.41  0.56  0.45  0.50  0.45  1.00
0.86  0.86  0.88  0.92  0.81  0.42  1.00
0.82  0.78  0.88  0.84  0.93  0.44  0.91  1.00
0.71  0.74  0.79  0.82  0.84  0.43  0.94  0.93  1.00
0.66  0.67  0.77  0.75  0.84  0.42  0.96  0.92  1.00
0.47  0.55  0.57  0.63  0.64  0.37  0.63  0.77  0.65  0.81  1.00
0.51  0.57  0.60  0.67  0.67  0.44  0.68  0.79  0.78  0.85  0.75  1.00
```

Table 5.1: Terrain Feature Statistics, continued

Category 7: BANK

BUCKS LAKE CLASSIFICATION - THIRD RUN, TNU SAMPLES

BANK

SPECTRAL PLOT (PLAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS BANK

LEGEND
* = CLASS BANK

SPECTRAL	0.44	1.44	1.46	6.41	0.24	0.56	0.55	6.58	6.62	0.66	0.72	0.80
BAND	0.44	0.44	1.44	0.50	0.24	0.55	0.56	0.62	0.66	0.72	0.80	1.00
(MICRONS)											

THE COVARIANCE AND MEAN FOR TRAINING CLASS BANK

	0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
MEAN	138.33	102.02	102.32	180.25	143.61	166.73	116.03	151.08	139.83	176.83	196.35	198.49
ST DEV	14.40	11.72	6.24	10.04	17.66	14.17	19.53	15.15	16.92	8.38	4.54	4.40

COVARIANCE MATRIX

0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.66–0.72	0.72–0.80	0.80–1.00
222.62											
172.13	166.16										
131.70	106.45	65.30									
170.63	133.30	81.50	100.78								
252.36	199.16	159.21	153.68	311.70							
93.51	120.46	59.52	77.48	104.64	200.69						
247.63	223.22	154.57	178.72	302.22	119.63	381.36					
201.37	145.32	120.26	116.55	252.17	71.58	256.12	229.44				
210.33	180.54	131.64	145.91	258.21	97.44	321.38	226.10	286.17			
104.44	75.55	67.15	60.84	134.46	38.10	135.05	122.40	120.54	70.28		
16.15	16.73	13.51	15.66	26.88	13.66	33.61	20.87	27.82	15.98	20.65	
10.76	9.72	5.63	7.52	20.69	9.38	13.85	15.65	11.04	13.78	12.47	19.39

CORRELATION MATRIX

0.40–0.44	0.44–0.46	0.46–0.48	0.48–0.50	0.50–0.52	0.52–0.55	0.55–0.58	0.58–0.62	0.62–0.66	0.72–0.80	0.80–1.00
1.00										
0.64	1.00									
0.90	0.84	1.00								
0.87	0.97	0.88	1.00							
0.96	0.82	0.90	0.87	1.00						
0.44	0.62	0.45	0.54	0.42	1.00					
0.86	0.84	0.66	0.91	0.88	0.43	1.00				
0.69	0.70	0.90	0.77	0.94	0.33	0.87	1.00			
0.83	0.78	0.64	0.86	0.66	0.41	0.97	0.88	1.00		
0.84	0.66	0.87	0.72	0.91	0.32	0.82	0.96	0.85	1.00	
0.25	0.30	0.32	0.34	0.34	0.21	0.38	0.36	0.36	0.42	1.00
0.16	0.16	0.24	0.17	0.27	0.15	0.16	0.23	0.15	0.37	0.62	1.00

Category 8: SNOW

LABORATORY FOR AGRICULTURAL REMOTE SENSING   JANUARY 23, 1969
PURDUE UNIVERSITY

BUCKS LAKE CLASSIFICATION - THEMF NU4, T IG SAMPLES

SNOW

SPECTRAL PLOT (MEAN PLUS AND PLUS ONE STD. DEV.) FOR TRAINING CLASS SNOW

Table 5.1: Terrain Feature Statistics, continued

Category 9: WATER

RUCKS LAKE CLASSIFICATION - THIRD RUN, 1% SAMPLES

WATER

SPECTRAL PLOT (MEAN PLUS AND MINUS ONE STD. DEV.) FOR TRAINING CLASS WATER

LEGEND
* = CLASS WATER

THE COVARIANCE AND MEAN FOR TRAINING CLASS WATER

CORRELATION MATRIX
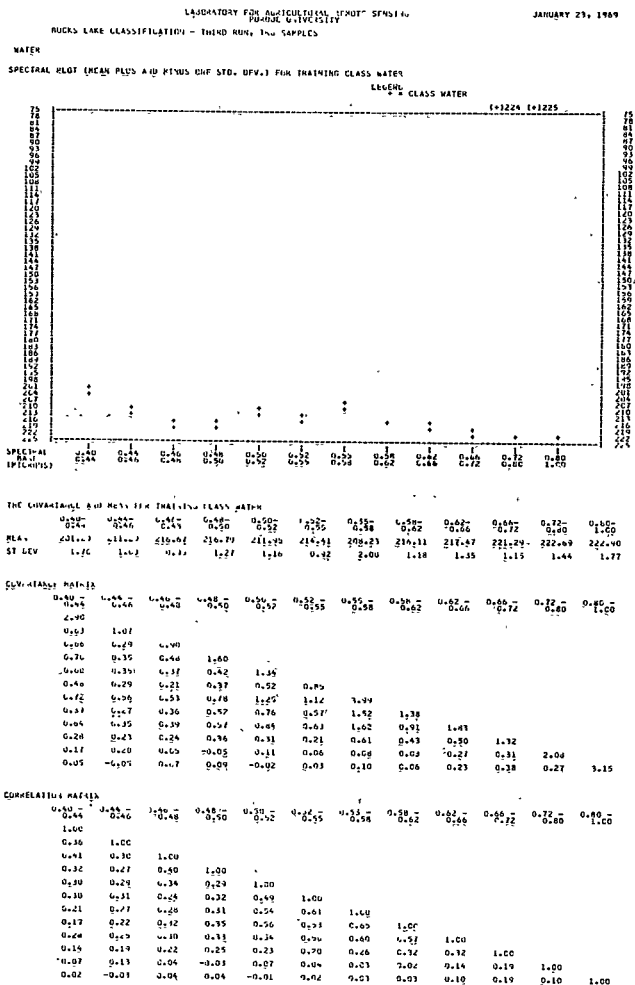
TABLE 5.2   CATEGORY HISTOGRAMS

On the following pages are listed the category "histograms", channel
by channel, computed for all training samples within each category
included in the classification study. It is the study of these histo-
grams which reveals the potential separability of features. Narrow,
peaked histograms indicate a well-defined radiance level for any par-
ticular feature; broad, poorly peaked histograms suggest a feature
signature which will be confused with others, causing errors in the
classification scheme in certain cases. Category SNOW, for instance,
is seen to have a poorly defined radiance level, but in this case, its
overall intensity is so much different from any of the other categories
included in this study that it is readily discriminated from them. The
histograms presented are computer printed in fourteen intervals such
that the vertical scale of each must be noted carefully since computer
control determines how to allocate the total radiance signals for the
category to these fourteen intervals <u>for each channel</u>.

CATEGORY 1 : CMIX

CHANNEL 1
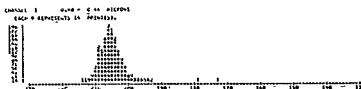
CHANNEL 2
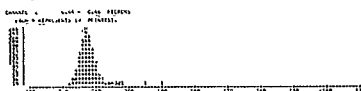
CHANNEL 3

CHANNEL 4

CHANNEL 5

CHANNEL 6

CHANNEL 7

CHANNEL 8

CHANNEL 9

CHANNEL 10

CHANNEL 11

CHANNEL 12

181
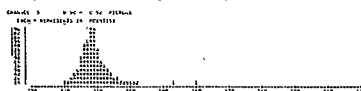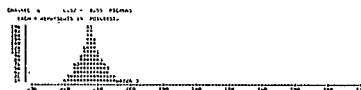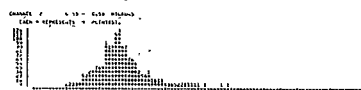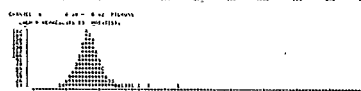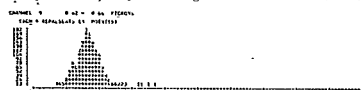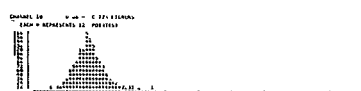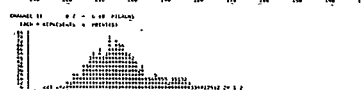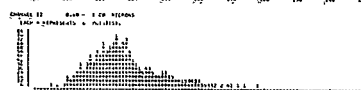
CATEGORY 2 : BRSHA

CHANNEL   1
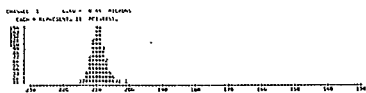
CHANNEL   2
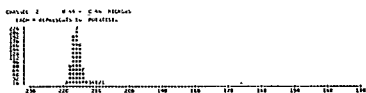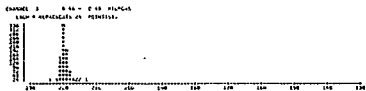
CHANNEL   3

CHANNEL   4

CHANNEL   5

CHANNEL   6

CHANNEL   7

CHANNEL   8

CHANNEL   9

CHANNEL   10
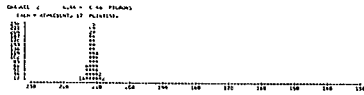
CHANNEL   11

CHANNEL   12

182

CATEGORY 3: BRSHB

CHANNEL 1

CHANNEL 2
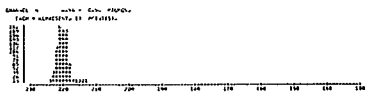
CHANNEL 3
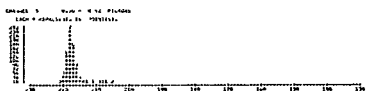
CHANNEL 4

CHANNEL 5
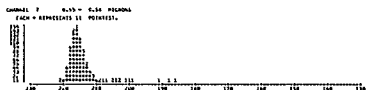
CHANNEL 6

CHANNEL 7

CHANNEL 8

CHANNEL 9
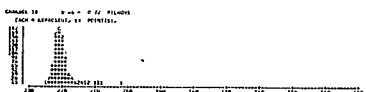
CHANNEL 10
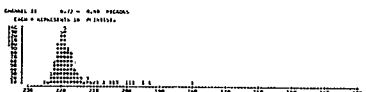
CHANNEL 11
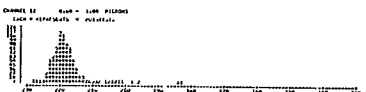
CHANNEL 12

CATEGORY 4: <u>BRSHC</u>

CHANNEL 1
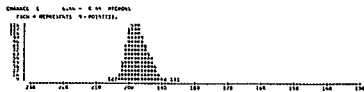
CHANNEL 2
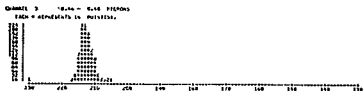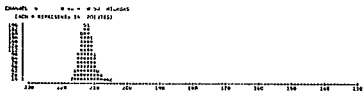
CHANNEL 3

CHANNEL 4

CHANNEL 5

CHANNEL 6

CHANNEL 7

CHANNEL 8

CHANNEL 9

CHANNEL 10
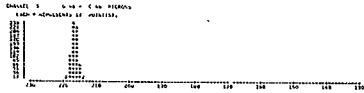
CHANNEL 11

CHANNEL 12

184
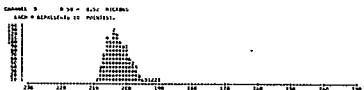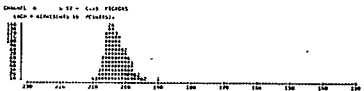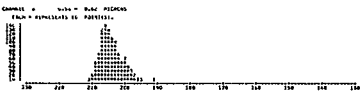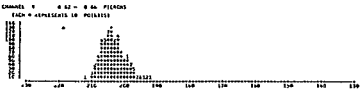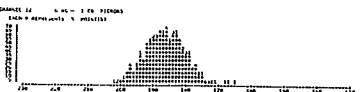
CATEGORY 5: <u>CLRD</u>

CHANNEL 1
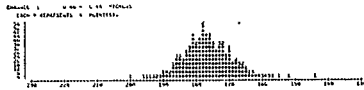
CHANNEL 2
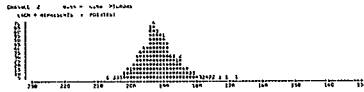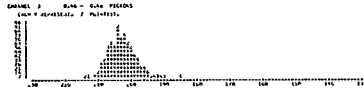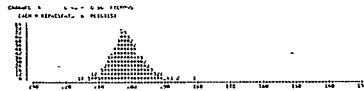
CHANNEL 3

CHANNEL 4

CHANNEL 5

CHANNEL 6

CHANNEL 7

CHANNEL 8

CHANNEL 9

CHANNEL 10

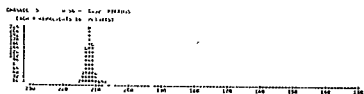·CHANNEL ·11

CHANNEL 12

185
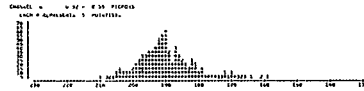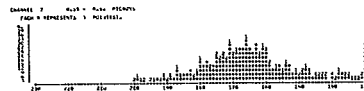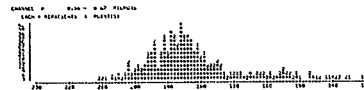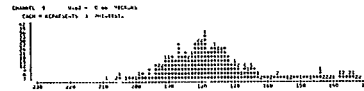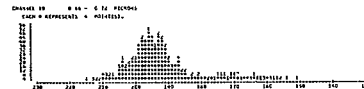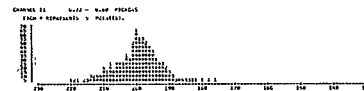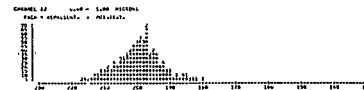
CATEGORY 6 : ROAD

CHANNEL 1
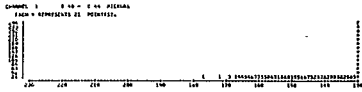
CHANNEL 2
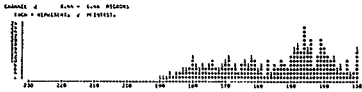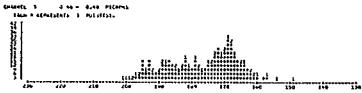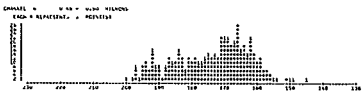
CHANNEL 3
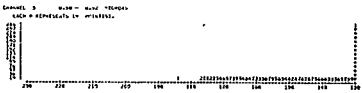
CHANNEL 4
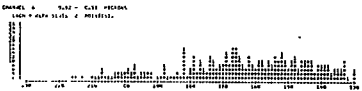
CHANNEL 5
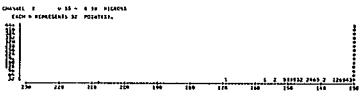
CHANNEL 6
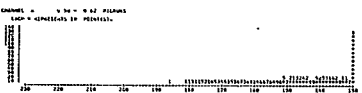
CHANNEL 7
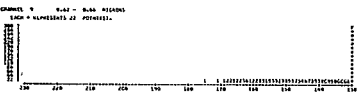
CHANNEL 8

CHANNEL 9
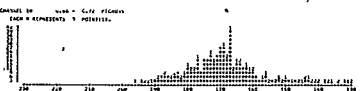
CHANNEL 10
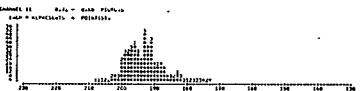
CHANNEL 11
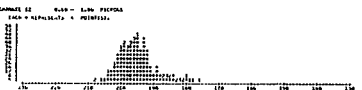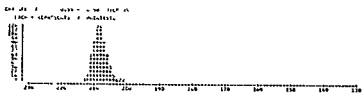
CHANNEL 12

CATEGORY 7 : <u>BANK</u>

CHANNEL 1
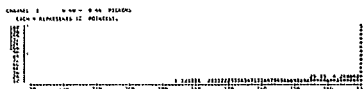
CHANNEL 2
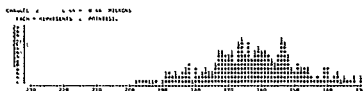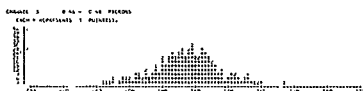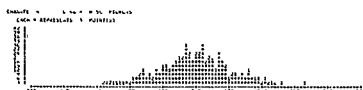
CHANNEL 3

CHANNEL 4

CHANNEL 5

CHANNEL 6

CHANNEL 7

CHANNEL 8

CHANNEL 9

CHANNEL 10

CHANNEL 11

CHANNEL 12

187
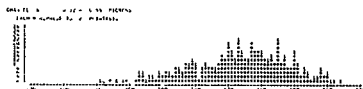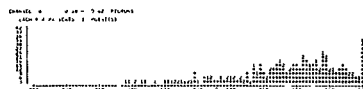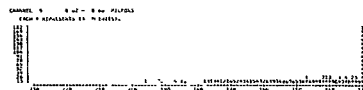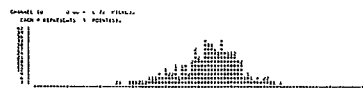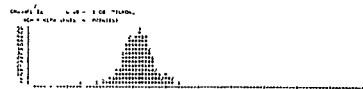
CATEGORY 8: <u>SNOW</u>

CHANNEL 1

CHANNEL 2

CHANNEL 3

CHANNEL 4

CHANNEL 5

CHANNEL 6

CHANNEL 7

CHANNEL 8

CHANNEL 9

CHANNEL 10

CHANNEL 11

CHANNEL 12

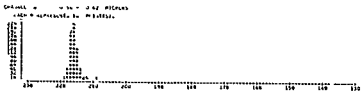CATEGORY 9: <u>WATER</u>

CHANNEL 1
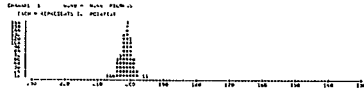
CHANNEL 2

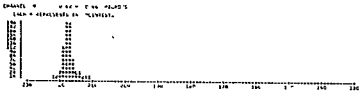CHANNEL 3

CHANNEL 4

CHANNEL 5

CHANNEL 6

CHANNEL 7

CHANNEL 8

CHANNEL 9
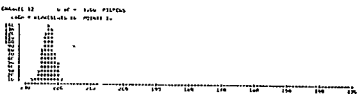
CHANNEL 10

CHANNEL 11

CHANNEL 12

189
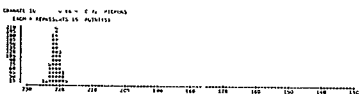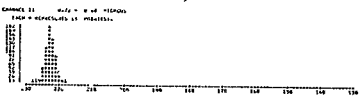
Table 5.3 Training Sample Classification Summary

BUCKS LAKE CLASSIFICATION - THIRD RUN, TNG SAMPLES

CLASSIFICATION STUDY :: SERIAL NO. 123906200
CLASSIFICATION DATE :: JANUARY 23, 1969

```
                    RUN NUMBER-----26602690        DATE------ 5/19/66
                    FLIGHT LINE----BL03            TIME------1702
                    TAPE NUMBER---- 118            ALTITUDE-- 2000 FEET

            CLASSES CONSIDERED                              FEATURES CONSIDERED

        SYMBOL    CLASS       THRESHOLDS             CHANNEL NO.           SPECTRAL BAND
          -       BRSHA        11.100                                       0.46    0.48
          /       BRSHB        11.100                     1                 0.46    0.48
          f       BRSHC        11.100                     3                 0.48    0.52
          f       CMIX         11.100                    11                 0.52    0.55
          I       CLRD         11.100                                       0.72    0.80
                  SOIL         11.100
          W       WATER        11.100
          S       SNOW         11.100
```

CLASSIFICATION SUMMARY BY TRAINING CLASSES

NO OF SAMPLES CLASSIFIED INTO

	CLASS	NO OF SAMPS	PCT CORCT	BRSH	BRSH	BRSH	CMIX	LLRD	SCIL	WATE	SNOW	THRS
1	BRSH	215	98.1	211	0	0	4	0	0	0	0	0
2	BRSH	96	59.0	0	95	0	1	0	0	0	0	0
3	BRSH	299	93.3	0	7	279	12	0	0	0	0	1
4	CMIX	401	93.3	21	0	4	374	1	0	0	0	1
5	CLRD	218	97.2	0	3	0	0	212	3	0	0	0
6	SOIL	346	91.6	0	0	0	0	28	317	0	0	1
7	WATE	176	99.4	0	0	0	1	0	0	175	0	0
8	SNOW	78	88.5	0	0	1	6	1	2	0	69	5
	TOTAL	1829		232	105	284	392	242	322	175	69	8

OVERALL PERFORMANCE = 94.7
AVERAGE PERFORMANCE BY CLASS = 95.1

Four channel classification results for the sixty-four training
samples are listed in the above table. It reveals that classification
of training samples within a category averaged 95% accurate and that
the overall performance for training samples was slightly less than
95%. In which categories the errors occurred is also shown. Note,
for example, in category one (containing a total of 215 sampling
elements) that 4 elements which were supposed to be classified as
BRSHA were classified in category CMIX. Note also that most of the
signals that could not be classified (using the "light" threshold
level indicated) occurred in category SNOW, as the statistics indicated.

B. A View on the Desirability of Setting up the LARSYSAA
Programs at Distant Computing Facilities.

Anyone who has worked with the LARSYSAA programs for any length
of time soon develops an interest in setting up these programs at
his own computing facility. This is generally caused by an aware-
ness on the part of the user that the LARS staff is far too busy
with their own research program and development to provide assistance
to all potential users with varied applications who might desire
access. Also, the user might well perform a more thorough study if
only he had more time available for complete computer/user "inter-
facing" and option selection. These problems might be resolved if
the LARSYSAA programs were readily adaptable to each user's com-
puting facility. Unfortunately, considerable work is involved in
adapting a program of LARSYSAA's complexity. Too, most computing
facilities operate on a "closed-shop" time-sharing basis which
makes user interaction and option selection a slow and inefficient
process. There is also some question about the adaptability of the
digitized tape records which LARS produces for their analysis from
the original analog record; it is quite likely, they report, that
the required format instructions are incompatible with the I/O
devices that are likely to be employed at various distant computing
facilities.

What may be required is some extensive software to enable
LARS produced digital tapes to be compatible with each particular
facility's capability and user requirements. Further modifications
to the LARSYSAA programs will be required where closed-shop operations

prevail. These should be relatively minor changes, compared to the

tape reading format changes mentioned earlier. Another possible

solution to the problem of enabling a larger number of experimenters

to use LARSYSAA is to set up remote terminals to the LARS computer

facility directly. While this at first might seem overly adventure-

some, it should be pointed out that a number of worthwhile objectives

could be accomplished. First, it would reduce the strain on the

LARS facility in meeting outside user requests. And second, it

could provide a separate facility with complementary training

capability by providing "on-line' instruction in the techniques of

automatic image classification. Such a training capability is

currently being organized at the Forestry Remote Sensing Laboratory.

<div align="center">Future Research Activities</div>

A. The Development of a Scanning Densitometer for Aerial
Photo Research Applications.

A scanning and analysis system is being developed at the FRSL

to provide increased data recording and quantitative analysis capa-

bilities. The tentative formulation of this system appears in

Figure 5.9. Current plans are to set up a remote terminal linked to

the SDS910 computer for magnetic tape drive control, but this would

be modified if tape recording were made available. Present funding

levels preclude any purchase of such hardware. The scanner itself

is designed to overcome some of the limitations noted in commercial-

ly available equipment, and to provide the FRSL with an "in-house"

capability to do research directly rather than solicit data to be

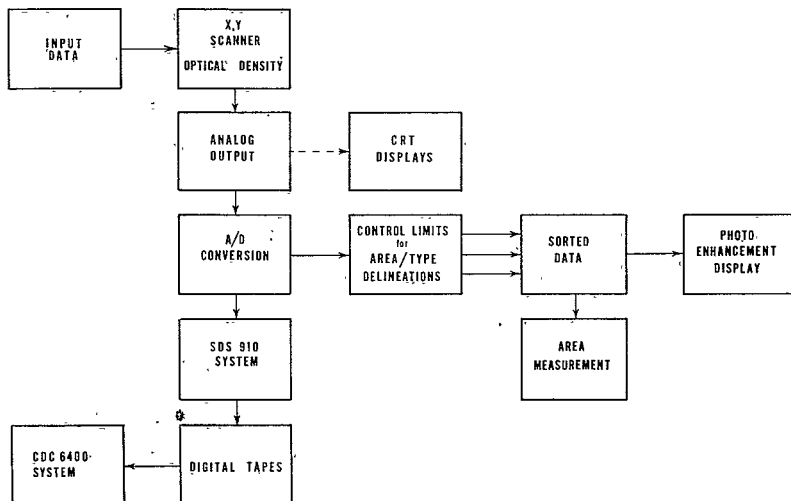recorded by any number of private operations in a multitude of

<div align="center">192</div>

INPUT DATA → X,Y SCANNER OPTICAL DENSITY

ANALOG OUTPUT - - - → C R T DISPLAYS

A/D CONVERSION → CONTROL LIMITS for AREA/TYPE DELINEATIONS → SORTED DATA → PHOTO ENHANCEMENT DISPLAY

SDS 910 SYSTEM

AREA MEASUREMENT

CDC 6400 SYSTEM ← DIGITAL TAPES

Figure 5.9 Diagram of photo scan and analysis sequence. This flow chart starts with "input data" which initially will be in the form of black-and-white film emulsion, but eventually can be any color transparency. Once scanned, the optical densities can be either displayed on CRT equipment (either as a single trace or eventually as an entire scan "playback") or converted to digital records. The SDS910 computer indicated would provide a certain amount of pre-processing capability but is not essential if tape recording hardware were otherwise available. The digital tapes could then be analyzed on a large high speed computer such as the University of California CDC 6400 system. Non-computer analysis and display are also readily possible for certain applications, such as area or type delineations and measurement.

formats and data handling limitations. The scanning device will have
an x-y dimension capability of 4" x 5". It is anticipated that 70mm
film will be the most common film type subjected to extensive quantita-
tive analysis. But 9" wide film can be scanned if it is properly
arranged. Scanning will be completely automatic, with the limits of
the scan manually programmed by switching controls. Other artificial
limits can be implemented when area or type delineations are required
by properly orienting an opaque border around the area of interest.
Too, the scanning device ultimately will record the optical density of
each of three layers of a color film emulsion in a single pass, rather
than by alternately changing filters for each of three passes (which
trebles the recording time). Initial recording will be done with black-
and-white negative or positive transparencies without filters. It is
anticipated that spatial resolution of approximately 20 μ can be
attained with the scanning device.

The reasons behind an emphasis upon developing such a scan-
ning device are to be found in our belief that multiband reconnais-
sance by means of cameras, films and filters rather than by optical
mechanical scanners or other sensing devices will continue, for
some time, to dominate the earth resource inventory field. The
advantages which photography offers over other remote sensing systems
at high altitude and spacecraft altitudes are very significant, par-
ticularly with reference to spatial resolution. It is felt that the
techniques being developed for automatic discrimination of terrain

features from multichannel optical mechanical scanner data can be made to accommodate photographic data also, thereby facilitating rapid analysis of terrain features from high resolution multiband photography. This capability should prove applicable even to high altitude and spacecraft photography of the quality found in other chapters of this annual report. Currently, with but few exceptions, photography appears to be the only sensing medium which will yield a resolution sufficient to warrant such research from these altitudes. The overall application potential (in the near future at least) of photographic systems is suggested in Figure 5.10 where sensor capabilities are related to real and potential applications in the earth resources field.

B.   The "Data Bank" Concept for Earth Resource Surveys.   A considerable increase in efficiency of performing earth resource surveys could be obtained if it were possible to minimize (or even eliminate) the collection of ground truth for the purpose of providing "training sample" material to be used for classifying terrain features.   Instead, a "data bank" of resource signatures might be developed and updated periodically to serve this function.   This would involve an extensive program of documentation and storage for signatures of all possible terrain conditions, densities, slopes, etc., but once established would provide rapid access for analytical purposes.   For programs relating to a specific region (and presumably, a known complex of resources and conditions which must be managed) such a procedure could greatly speed up surveys.   For very large land regions or global efforts, this procedure would be much more difficult.   The data bank concept is particularly appealing

195

Figure 5.10 Sensor Capabilities vs Real and
Potential Applications in the Inventory of
Earth Resources

+ greatest current application
- some application, still being researched
0 no current application

	Microwave Radiometry	Photography (Multiband)	Thermal Mapping (Imaging)	Multichannel Scanner (Recording)	Magnetometer Surveys	Infrared Radiometry (Non-Imaging)
WILDLAND MANAGEMENT (FORESTRY AND RANGE)						
Resource mapping	-	+	+	+	0	-
Fire detection and damage assessment	0	+	+	+	0	-
Insect and disease damage assessment	-	+	-	-	0	-
Forest management	-	+	+	+	0	+
Land-use surveys	0	+	+	+	0	-
Recreation site evaluation	0	+	-	-	0	-
Livestock and wildlife counts	0	+	+	+	0	+
Range management	0	+	+	+	0	-
Watershed evaluation	-	+	+	+	0	-
AGRICULTURE						
Land-use surveys	0	+	+	+	0	-
Soil surveys	-	+	+	+	0	-
Crop yield	0	+	+	+	0	0
Crop distribution	0	+	+	+	0	0
Insect and disease damage assessment	0	+	+	+	0	-
Site evaluation or conversion	0	+	-	-	0	0
GEOGRAPHY						
Land-use management	0	+	-	+	0	0
Transportation planning	0	+	+	-	0	0
Urban analysis	0	+	+	+	0	0
Site evaluation	0	+	-	-	0	0
Land classification mapping	0	+	-	+	0	0
Pollution control	-	+	+	+	0	+
GEOLOGY						
Mineral potential	0	+	+	-	+	0
Petroleum potential	0	+	0	0	+	0
Geothermal activity	-	-	+	+	0	+
Structural mapping	0	+	+	+	+	0
Geo-type mapping	-	+	+	+	+	-
HYDROLOGY/OCEANOGRAPHY						
Flood control	0	+	0	0	0	0
Pollution control	-	+	+	+	0	+
Fishery yield	0	+	0	0	0	·0
Kelp surveys	0	+	+	+	0	
Erosion potential	0	+	-	-	0	0
Hydro-electric development	0	+	+	+	0	-

from the standpoint of point location or reference capability. Not only can coordinate points be stored in magnetic memory files, but also any amount of coded information about that point can also be stored, such as types, slope, longitude, latitude, remote sensing records collected over that point, by whom, with what, on what date, etc.

In order to demonstrate the overall gain in using such a technique for ground truth reference, we will develop on a small scale a "data bank" of earth resources information in the Bucks Lake Test Site or some other suitable site, using the scanning microdensitometer and analytical programs developed for it. These exploratory efforts will be reported upon in future progress reports.

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CHAPTER 6

TRAINING PROGRAM FOR THE INVENTORY OF WILDLAND RESOURCES

Robert N. Colwell
Gene A. Thorley

Introduction

There is a definite trend today toward greater complexity in data
collecting systems and data analysis procedures. Already, large well-
staffed data analysis centers are necessary to analyze the data from
existing remote sensing systems. Acquisition of data from space and
subsequent analysis involves even more complex techniques of data storage
and handling. There is a great danger that the user--the individual most
knowledgeable as to whether the end product of this sophistication is
meaningful--may be forced out of the data acquisition and analysis loop
as the systems and procedures become more complex. It is our feeling
that a strong training program, based on access to scientists active in
all phases of remote sensing data acquisition and analysis, offers the
best means of bridging this gap in communication and background between
potential users and remote sensing scientists. The Training Unit of our
Forestry Remote Sensing Laboratory was organized to pursue an aggressive
program designed to bring the results of research to the user through
the offering of various kinds of training programs and workshops, through
the dealing with our research results, and through personal contact,
especially with scientists who, from time-to-time, visit our laboratory.

Specific objectives of the unit are:

(a) To train personnel to inventory earth resources by various means
which will make maximum use of present day remote sensing capabilities
from aircraft and spacecraft, including those soon to be tested in ERTS-A.

(b) To provide an effective program to visiting scientists which

198

will utilize the expertise of the scientists of the FRSL, other institutions, and government agencies, in such a way as to minimize the competition between training and research.

(c) To develop a series of training seminars, involving FRSL scientists and, where appropriate, scientists from other institutions and government agencies. A primary objective of these seminars is to provide a means of increasing the general understanding of remote sensing by scientists who by necessity must specialize in rather narrow applications (e.g., spectral measurements, automatic data analysis, etc.).

(d) To provide training-related materials and other support to the technical units of the FRSL (e.g., slides, displays, public relations and library), to disseminate publications (e.g., reports, syllabi and brochures) and to give various training-oriented presentations (e.g., lectures, conferences, seminars, short courses, field trips and workshops).

(e) To provide a means whereby requests by NASA for briefing aids and the training of personnel can be rapidly and efficiently completed.

(f) To contact many practicing wildland resource managers and make them aware of the current state-of-the-art of remote sensing from spacecraft and high altitude aircraft.

It is apparent that the unit relies heavily on a total integrated effort by the staff of the Forestry Remote Sensing Laboratory

Current and Future Activities

Because of the great advances that recently have been made in the ability to acquire remote sensing data from aircraft and spacecraft, a commensurately great demand has arisen for people who are adequately trained to extract from such data useful information about the earth's resources. At the Forestry Remote Sensing Laboratory we are attempting

to help satisfy this demand by sponsoring training sessions and by giving
on-the-spot training to individuals from other institutions and, in some
cases, other countries. We also are responding, as fully as possible, to
the tremendous number of requests which we continue to receive for copies
of our reports and syllabi which might be used as training aids for courses
taught elsewhere.

It is apparent that the problem of producing well-trained remote
sensing specialists in adequate numbers for staffing various earth
resources survey programs will only intensify in the future. At the time
of this writing, President Nixon is reportedly planning to express, in an
address to the United Nations, the willingness of the United States to
provide remote sensing assistance for the solution of earth resource
problems in foreign countries. Such pronouncements will serve to increase
the demand for remote sensing training, not only in this country but in
many foreign countries as well.

Virtually all of the remote sensing courses currently being offered
to other than regular university students at the present time are merely
"appreciation courses", i.e., those designed to convey to the attendee
that remote sensing techniques offer a powerful means of making accurate,
timely, economical inventories of earth resources. While there may be
a continuing need for these courses to be presented to various top-level
"decision-makers", the major need will soon be to train the actual "doers".
Mere appreciation courses definitely will not prepare them to accomplish
the all-important task of making operationally useable inventories.
Instead, they need to receive rigorous training in how to produce, through
an analysis of remote-sensing data, a survey of earth resources of the
type that will meet the specific informational needs of the resource
manager. To gain confidence in their ability to produce such a product,

and to become aware in highly specific terms of the limitations in their ability to produce that product merely from an office examination of remote sensing data, these trainees must also be taken into the field. Ideally, they will be given the opportunity, even before beginning their analysis of remote sensing data for a particular geographic area, to visit a representative portion of that area in company with the individuals who are charged with managing the earth resources of the area. By so doing, they will better gain an appreciation of the kinds of information which these managers will find most useful, the forms in which they wish to have the information presented to them, and the time constraints governing the usefulness of that information to them. Ideally, these remote sensing trainees also will be given the opportunity of visiting representative portions of the area once they have completed their remote sensing exercise, at which time they can field check the accuracy of their resource maps and interpretations and further determine from the resource managers whether the products, as produced by the trainees, are of optimum usefulness to such managers.

It is with these considerations in mind that personnel of our Training Unit currently are in the process of preparing training materials that will incorporate the following elements, and with specific orientation toward the various NASA Test Sites in which we have been conducting our research of the past six years under the NASA-USDA Remote Sensing Research Program. (Several of these sites are near enough to our Forestry Remote Sensing Laboratory to permit us to transport trainees to them): (1) specific user requirements at these sites for earth resource information; (2) remote sensing capabilities in various parts of the electromagnetic spectrum; (3) basic matter and energy relationships; (4) multistage sampling techniques including techniques for the acquisition of ground truth;

(5) photo interpretation equipment and techniques; (6) image enhancement techniques; (7) automatic data processing techniques; (8) techniques for optimizing the interaction between humans and machines during the analysis of earth resource data; (9) uses and limitations of both multiband and sequentially acquired remote sensing data; and (10) techniques for optimizing the interaction between those who provide earth resource inventories and those who use them in the management of earth resources.

In all of our future training programs, as in the ones which we have conducted thus far, maximum use will be made of the concept of "learning by doing". Consistent with this concept, actual rather than hypothetical problems will be emphasized. These problems will be centered around the inventory of earth resources at the aforementioned NASA test sites, one of which (the San Pablo Reservoir Test Site) is only eight miles from our classroom facilities at the University of California where our Forestry Remote Sensing Laboratory is located. Several training films, based on this and other NASA test sites which our group has studied during the past five years, have been prepared. These illustrate various data acquisition and analysis techniques with emphasis on both the gathering of "ground truth" data and the extraction of information from remote sensing imagery. Our extensively illustrated reports of research conducted at these test sites are proving useful as syllabi for undergraduate, graduate and University Extension courses currently being taught by personnel of our laboratory. Under NASA auspices a "Manual of Multiband Photography", in which much of this work is summarized, and a 150-page report entitled, "Analysis of Earth Resources on Apollo 9 Photography" are both nearing the publication stage, as is a special report entitled "Analysis of Earth Resources on Sequential, High Altitude, Multiband Photography." All of these materials should prove very valuable

in operational type instructional programs which we plan to offer, as previously described.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Robert N. Colwell

In the introductory chapter of this annual report, the rationale
is given for a systematic forestry remote sensing research program of
the type in which our Laboratory is engaged. The unit organization of
our Laboratory that has been developed in order to conduct a comprehen-
sive program also is described and a statement is given of the types of
programs that are investigated by the Laboratory's five major units, viz.,
(1) Operational Feasibility; (2) Spectral Characteristics; (3) Image
Enhancement and Interpretation; (4) Automatic Image Classification and
Data Processing, and (5) Training.

Chapters 2, 3, 4, 5 and 6 deal, respectively, with the activities
and accomplishments of these five units during the past year. Most of
these activities have been oriented toward a single objective: develop-
ing a capability for extracting useful, timely earth resources informa-
tion from data of the type that soon will be provided by ERTS-A and sup-
porting data-collection vehicles. Care has been exercised, in conducting
these research activities, to make the efforts of our Forestry Remote
Sensing Laboratory complementary to, rather than competitive with, the
efforts of other investigators who are funded under the NASA-USDA Earth
Resources Survey Program or through other sources. Also, care has been
taken to obtain quantitative measures of feasibility wherever possible,
since most of the investigations previously conducted have been merely
qualitative in nature.

Most of our research this past year has been conducted on (1) multi-
band space photography obtained in March, 1969 by the Apollo 9 astronauts

204

of selected NASA test sites in California, Arizona, New Mexico and Mississippi; (2) multiband sequential "high-flight" photography obtained of these and the Bucks Lake test site from an altitude of approximately 70,000 feet at intervals of roughly one month throughout the 1969 growing season and (3) multiband photography and related remote sensing data obtained periodically from conventional altitudes (e.g. 10,000 to 30,000 feet) by various NASA Houston-based aircraft and private contractors, not only of these test sites, but also of certain NASA test sites in northern California and Oregon, viz. the Harvey Valley, San Pablo Reservoir and Klamath Falls test sites.

In all of these studies a maximum effort has been made to relate remote sensing capabilities to user requirements, based on the presumption that the primary user will be the actual manager of earth resources. Chapter 2 of this report gives a great deal of practical and philosophical consideration to this aspect of the problem. When this rigorous criterion is applied it serves to reinforce our earlier conclusion that the obtaining of useful earth resource information by means of remote sensing from aircraft and spacecraft is, at best, a difficult task. When an attempt is made to extract such information from only one photograph, the results can be quite discouraging. However, our results show that the amount of useful information derivable by means of remote sensing is greatly increased when we employ multiband, and/or multidate, photography, and when we employ multi-enhancement techniques through the use of various optical and electronic image combiners. Furthermore, our studies on automatic data processing techniques demonstrate that the extraction of useful earth resource information is facilitated when the human exercises the opportunity that can be his to interact with the machine at each of

205

several stages in the information-extraction process.

While a significant amount of evidence in support of the following conclusions will be found in chapters 2 through 6 of this report, some valuable and more highly detailed supporting information will be found in two other publications of our Forestry Remote Sensing Laboratory: (1) "An Evaluation of Earth Resources Using Apollo 9 Photography", dated 30 September 1969, and (2) "Analysis of Earth Resources on Sequential High Altitude Multiband Photography", which is being completed and will be dated 31 December 1969.. Among the specific conclusions indicated by our studies this year are the following:

1. In spite of the difficulties in applying photo interpretation to existing multiple use zoning procedures, much could be gained by attempting to develop a multiple-use zoning process particularly amenable to the use of aerial photography.

2. The spectral reflectance characteristics of certain brush species when gathered in situ with a field portable spectroradiometer agree in ranking with the optical density of the image as measured on multiband negatives.

3. The accurate discrimination of some important earth resource features (e.g., timbered vs. agricultural lands, vegetated vs. fallow fields) is possible even on individual black-and-white space photos.

4. A great many more earth resource features are identifiable on Infrared Ektachrome space photos (e.g., bottomland and hardwood stands, pine-hardwood stands, and certain individual crop types).

5. When the matching frames of black-and-white photography are combined and enhanced either optically or electronically, interpretability is improved to where the information derivable is equivalent to (and sometimes better than) that obtained from the Infrared Ektachrome

photography.

6. While, on the one hand, there are strong proponents for using aircraft rather than spacecraft for the making of earth resource surveys and, on the other hand, those who advocate using spacecraft rather than aircraft, our findings are for the most part in support of a third view, viz., that operational earth resource surveys of the future might best be made by means of a multistage sampling technique which employs space-craft, aircraft and ground observations.

7. The use of the L.A.R.S. automatic classification techniques in a wildland environment was not as successful as has been demonstrated for agricultural resources. The results suggest that classification schemes which do not rely on the Gaussian assumption should be tested on the data.