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CHANGE VECTOR ANALYSIS: AN APPROACH FOR DETECTING FOREST CHANGES WITH LANDSAT

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I. ABSTRACT

Periodic multiresource surveys and effective management of forest resources would be facilitated by capabilities for accurate detection of disturbances and other changes in land cover. Current techniques are not as effective and efficient as desired. This paper describes a recently developed digital method for change detection using multidate Landsat data. The method employs calculation of spectral change vectors from two different dates, prompting its name -- Change Vector Analysis. The concept and a stratification procedure are described and their features are compared to other approaches. An implementation was tested that utilizes a linear transformation of Landsat data channels and spatial-spectral clustering of multidate data for the definition of spectrally homogeneous stand-like "blobs". Maps of two types of change, harvesting and regrowth, were produced and analyzed for a test site in Northern Idaho.

II. GENERAL

A. INTRODUCTION

The U.S. Forest Service has a requirement to acquire and aggregate periodic multiresource survey and inventory information into regional and national assessments of the status of renewable resources within the country. In addition, detailed information is required on the local level for effective management of resources within the National Forest System. Similar problems face resource analysts and managers in other countries. The problem is that current techniques for detection and inventory of disturbances and other changes in land cover are not as effective or efficient as desired.

Data from the Landsat multispectral scanner, with its synoptic and regular (18-day and year-to-year) coverage, offer potential for application to these inventory and assessment problems. In particular, analysis of Landsat data from different years should provide information on changes that occur in land use, cover type, and cover condition in areas of interest. If one were able to stratify a scene into two parts -- areas that are likely to have changed and areas likely to be unchanged -- using Landsat, one might more efficiently and cost-effectively allocate limited ground observation resources. Manual image interpretation methods have been applied to Landsat data analysis[1], as well as digital methods[2,3]. This paper describes a recently developed digital method which is described more fully elsewhere.[4]

Three aspects of change information are important in updating resource inventories and surveys. The first is detecting that changes have occurred. The other two are identifying the nature of these changes and measuring or estimating their areal extent. Landsat potentially can contribute to all three, but the complexity of analysis required and the accuracy of performance are different for each aspect. The major emphasis of this paper is on the first aspect, i.e., change detection, although the other aspects are addressed to a limited extent.

B. APPROACH

A new digital processing concept for change detection and stratification was formulated. It is called Change Vector Analysis (CVA), for reasons discussed in

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the next sections which describe the concept in detail and compare it to other methods. An initial procedure for applying this concept to multidate Landsat data was developed and tested for feasibility, using data from a site located within the Clearwater National Forest in the state of Idaho.

III. THE CHANGE VECTOR ANALYSIS CONCEPT AND PROCEDURE

When a forest stand undergoes a change or disturbance, for example is clear cut, its spectral appearance in Landsat multispectral scanner data changes accordingly. If two spectral variables were measured for a stand both before and after some change occurred and then were plotted on the same graph, a diagram such as Figure 1 might result. The vector describing the direction and magnitude of change from Date 1 to Date 2 is a spectral change vector.

A. CONCEPT

The underlying concept of the Change Vector Analysis procedure is simple. Given multi-date pairs of spectral measurements, one computes spectral change vectors and compares their magnitudes to a specified threshold criterion. The decision that a change has occurred is made if that threshold is exceeded. Figure 2(a) illustrates a case where no change would be detected, while Figures 2(b) and 2(c) illustrate cases where definite changes would be detected. Parts (b) and (c) also illustrate the other half of the information contained in the change vector, namely its direction. Having detected changes of sufficient magnitude, one might then differentiate between their directions, which should contain information about the type of change. For example, the direction of change due to harvesting should be different than that due to regrowth.

B. PROCEDURE

Next consider the requirements and practical details that a procedure must address in implementing and applying this Change Vector Analysis concept. They involve all three of the basic characteristics of Landsat data -- spatial as well as spectral and temporal -- and can be grouped into five categories:

(1) Spatial registration of multidate data,
(2) Spectral transformation and normalization,
(3) Spatial entity selection (individual vs. clusters of pixels)
(4) Change vector analysis logic,
(5) Level of application (stratification, classification, measurement).

Precise spatial registration of Landsat data from at least two dates is an essential requirement. Spatial misregistration can introduce false indications of change. Geometric correction, resampling, and registration to a map base are desirable from the application point of view.

Preprocessing transformations can improve or stabilize performance by adjusting for differences in atmospheric haze effects and sun angles, as well as providing new spectral variables with dimensionality reduction, physical interpretability, and little or no loss of information. Normalization functions would gain importance as the scale or area of interest increased and the application became operational. Other useful functions would be screening for bad data and for the presence of clouds and cloud shadows.

In many current forest inventories, areas less than ten acres in size are not of interest, whereas the standard Landsat pixel (picture element) represents an area of approximately 1.1 acres. Decisions made individually for each pixel tend to result in "salt and pepper" effects. For these reasons, change vector analysis on spectral averages of computer-defined clusters of spectrally homogeneous and contiguous pixels is an attractive option. The CVA logic, however, can be applied just as easily to individual pixels.

The change vector analysis logic must be adaptable to the type of preprocessing that is or is not performed, to the spectral composition and acquisition dates and Landsat calibration of the scenes being analyzed, and to the intended application. Ideally, one would like acquisitions by the same scanner, acquired at the same stages of phenological development on the ground, and made under identical viewing conditions. To the extent that these conditions are not met, the processing and logic should try to adjust or compensate. The CVA approach can be applied to individual Landsat bands as well as to transformed variables. The complexity of the decision logic, particularly the extent to which type of change is determined depends on the type of application intended. For advanced applications, the magnitude threshold could be made a function of the direction of change and the starting point.

The simplest stratification approach would just identify two categories, one where some change is likely to have occurred and the other where it is unlikely. Greater levels of detail can be envisioned, culminating in the identification or classification of the before and after classes and conditions. Measurement can be done on a "wall to wall", i.e., complete-enumeration, basis or by sampling.

C. IMPLEMENTATION

The initial implementation of the CVA stratification procedure made use of a digital image processing software system and concept, called QLINE, which was developed at ERIM for agricultural investigations conducted under NASA sponsorship.[5] A specific stratified area estimation procedure, called Procedure M, embodies modules to preprocess the data (screening for clouds, etc., atmospheric haze and sun angle corrections, creating linear transformations of Landsat data) and perform other functions.[5] One of the modules implements the BLOB spatial-spectral clustering algorithm which defines spectrally homogeneous groups of neighboring pixels called "blobs".[6] Originally intended for defining agricultural fields, its usefulness for forestry purposes was established in a prior investigation sponsored by the Nationwide Forestry Applications Program.[7] In using the BLOB algorithm, one chooses values for spectral and spatial parameters which affect the size and homogeneity of the blobs defined. The advantage of blobbing multitemporal Landsat data is that it automatically matches spatial patterns on the two dates. If half a stand of trees that would irdinarily be contained in a single blob were clear cut, two blobs would be formed--one with the uncut trees and one with the harvested area.

The Change Vector Analysis logic was implemented for this investigation through a module that operates on the spectral means of blobs produced by the BLOB algorithm and generates decisions based on the measured magnitudes and angles of change. The decision for each blob mean is extended to all pixels within that blob. Then these decisions can be mapped pixel-by-pixel by other portions of the processing system, displayed on CRT devices, and/or converted to photographic form for analysis and documentation.

While the CVA principle can be applied using original Landsat bands, it was decided to first transform the data from each date to the Brightness and Greenness variables of the Tasseled-Cap Transformation of Landsat data.[8] The major features of that transformation are summarized in Table 1: in essence, it produces two linear combinations of the four Landsat bands which capture 95% or more of the variability present and contain the information of interest in a physically interpretable form. Other preprocessing operations of the Procedure M software were not employed for this initial developmental test and evaluation effort.

D. COMPARISON WITH OTHER METHODS

A variety of change detection approaches would be possible to implement digitally, as indicated in Figure 3. A comparative study of alternative approaches was beyond the scope of this investigation, so the choice of a procedure was based on several reasons which are summarized in Table 2 and elaborated in the next three paragraphs.

The CVA stratification procedure described herein was selected and developed for three major reasons. First, it operates on spatially contiguous groups of pixels rather than on individual pixels in isolation. Second, it does not require classification with attendant training and ground truth requirements. Finally, it maximizes the interpretability and use of available information and has the potential to simplify the subsequent identification and mensuration phases of change inventory which may be required at a later time. In addition, the preprocessing transformations which precede the analysis can improve the overall effectiveness of the procedure.

Computer definition and analysis of spectrally homogeneous blobs or groups of pixels, instead of individual pixels in isolation, has several advantages. First, it reduces the number of entities being analyzed for change (e.g., data reduction factors on the order of 20 to 100), allows one to consider only areas above a given size, and substantially reduces "salt and pepper" appearances in the results. Also, it automatically matches data groups between the two dates and produces standlike analysis units that should be correlatable to stand examination data. Finally, it reduces noise effects by data averaging and reduces effects of spatial misregistration.

Most prior studies of digital change detection techniques[2,3] have involved classification operations which actually combine (perhaps unnecessarily) the change detection and change identification aspects of using change information to update resource surveys. Classification of forest cover types in Landsat data is an imperfect process, especially at the pixel level. Pixel-by-pixel comparison of two separate classification results can produce a large number of erroneous change indications since an error on either date gives a false indication of change. For example, two maps produced by a 90% correct classifier might have only a 0.90 x 0.90 x 100= 81% correct joint classification rate. With an 80% correct classifier, the joint rate could reduce to as low as 64%. While the presence of systematic errors could raise the joint performance figure, it nevertheless is clear that problems do exist with such an approach.

Other aspects of classification are the requirements for training and supportive ground "truth" data -- major problems identified in Reference 2. The training problem is compounded in mountainous regions where slope and aspect have large effects on signal values. The clustering approach of the CVA stratification procedure is much less affected by topographic effects since, as long as data acquired on comparable calendar dates are analyzed, different blobs are defined when substantial differences in slope and aspect (solar insolation) are encountered. In addition, one could use preprocessing based on registered topographic data to adjust for these effects.[9]

The final reason for developing the Change Vector Analysis approach was its retention of information and enhanced interpretability of changes compared to simple and less costly differencing of data channels or non-linear classification decisions. This advantage is promoted by use of a linear data preprocessing transformation which captures most of the information content of Landsat data in a reduced number of dimensions having direct physical interpretation. The basic data quantities produced by the procedure also have substantial potential for later use in change identification and mensuration.

IV. DEVELOPMENT AND TESTING OF THE CVA PROCEDURE

Feasibility tests of the implemented Change Vector Analysis procedure for detection and stratification of change were conducted on Landsat data from a test site in the State of Idaho.

A. TEST SITE AND DATA SET

The test site was located in the Palouse District of the Clearwater National Forest in Northern Idaho. The District contains some of the most productive and intensively managed commercial forest land in the Intermountain Region. The terrain is mountainous with elevations ranging from approximately 2,500 ft to 5,000 ft.

The data base analyzed in most detail covered an area of approximately 200 km^2 (77 mi^2) that comprised three timber compartments (55, 56, and 59) at the northern boundary of the Palouse District. Digital Landsat data of 30 August 1972 and 13 August 1977 were geometrically corrected, registered to a UTM map projection, restored, and resampled to a 50 meter cell size (see Table 3).

B. APPROACH

The multidate Landsat data from the test site were processed using previously described procedures. Two variables (Brightness and Greenness) were used for each date, spatial-spectral clustering of the multidate data produced spectrally homogeneous blobs averaging 70 to 80 pixels in size, and a spectral change vector was then computed for each blob. Maps of the magnitude and direction of spectral change were produced for the three-compartment area using threshold criteria established during analysis of data from another (initial) study area on the District. Limited comparisons of the maps were made with stand examination records obtained from the District and with aerial photography.

C. RESULTS

An examination of the computed spectral change vectors showed that, while a majority of them had low magnitudes, a number of them had substantial change magnitudes. Figure 4 presents a map of change magnitude for the three-compartment area, the darker the tone the greater the magnitude of change.

Next, only magnitudes in given directions were mapped. First, change angles were limited to ±60°, directions that had been associated with recent harvesting activities in the initial study area. The resulting map is shown in Figure 5. A good correspondence was found between this map and District Office stand maps of Compartment 56 areas that had been clear cut and one or two selection cuts. In one instance the CVA change map showed a larger area than the District Office map, indicating logging beyond the stand boundary; aerial photography confirmed the CVA result. In other stands where overstory removal, shelterwood, and selection cuts had been made, changes were usually detected but not as fully or as spatially true as clear-cut stands. A few apparent false detections are present in bright areas, but most should be amenable to correction by relatively minor changes in the decision logic.

Next, magnitude was mapped only for change angles between 60° and 100°, directions that had been associated with regrowth in previously harvested stands in the initial study area. The resulting CVA map in Figure 6 also appeared to be a reasonable representation of the site, to the limited extent that checks were possible.

In the three versions of the CVA maps and especially in developmental analyses, it was clear that the performance of the CVA procedure is sensitive to its parameter settings and that additional studies to optimize their selection and to normalize differences in scene conditions are desirable.

The final analysis result was a tabulation of two different estimates of change related to harvesting activities. Both a wall-to-wall pixel count and a sample count on a systematic grid of pixels were made. The results were in close agreement, 7.7% and 7.1% of the area, respectively. The stand examination records show 4% of the area had been harvested, but they are incomplete since a fair portion of the area in these compartment boundaries is privately owned and logging activities there are not included in Forest Service records. Alternatively, the procedure could be applied only at and around sample plot locations to reduce data processing loads.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The Change Vector Analysis (CVA) stratification procedure was implemented and initial developmental tests were performed using Landsat data from the Palouse District of the Clearwater National Forest in Idaho. These initial results support the CVA approach to change detection. The spatial/spectral clustering of multi-date data appeared to be effective in delineating spectrally homogeneous areas where change had occurred. The calculated date-to-date change vectors contained useful information, both in their magnitude and their direction. Use of the Tasseled-Cap linear transformation on the Landsat data and the availability of forest stand examination information both were helpful in interpreting these changes. The direction of change enabled differentiation between changes due to harvesting and those due to regrowth. Some sensitivity to selection and shelter-wood cuts was found in addition to detection of clear cuts. Refinements of parameter selections should improve the delineation of these areas. Cartographically accurate stand maps are needed to get full benefit from stand examination records for development use and potentially for updating those records based on change information gained through analysis of remotely sensed data.

For the short term, additional testing and development work are needed to gain more understanding of the algorithm's parameter settings and to better understand forest spectral signatures and incorporate that knowledge in more sophisticated decision logic. It is believed that working-level interaction with field personnel in such efforts would be desirable and of substantial benefit to both researcher and field manager. Other needs relate to quantitative comparison with other procedures, user interfaces (e.g., with resource analysts and managers), developing subsequent identification and mensuration procedures, and incorporating and/or developing procedures to support large area applications.

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Table 1. Description of Landsat Data Transformation

1. Landsat is a four-channel system (two visible and two infrared)

2. Data from the four bands are correlated, i.e., are not independent of each other, especially:
    - the two visible bands, and
    - the two infrared bands

3. Most of the variability in Landsat data can be described by two linear combinations of the four bands

4. The "Tasseled Cap" transformation provides such linear combinations, in a way that gives them physical meaning:
    - Brightness (an indicator of overall reflectance)
    - Greenness (an indicator of vegetation)

5. In Landsat false-color images
    - healthy dense vegetation appears in bright red tones; these have high greenness values
    - exposed soil and rock and dead vegetation appear with varied lightness in other tones; these have varied Brightness and low Greenness values

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Table 2. Factors in Choice of the CVA Change Detection Approach

Factor	Advantages of CVA	Advantages of Individual Pixels
Choice of Blobs or pixel groups as analysis units rather than individual pixels	Reduced number of units to analyze (e.g., 1/50th) Choice of minimum size Stand-like units defined in common Large reduction of "salt and pepper" effects in map products Reduced effects of noise due to averaging Reduced sensitivity to spatial misregistration	One pass through data instead of two, except additional pass required for spatial processing Finer spatial detail
	Advantages of CVA	Advantage of Classification
Omission of classification	Elimination of errors due to misclassification Much reduced training and ground truth requirements Reduced sensitivity to topographic effects	Classification step may be required later
	Advantages of CVA	Advantages of Data Differencing
Analysis of change vectors rather than data differences	More complete use of information Interpretability and quantification of change direction and magnitude Availability of information for later identification and mensuration	Faster Lower cost

Table 3. Description of Landsat Data Set

		Sun Position		Time of Acquisition	
Date	Frame No.	Azimuth	Elevation	GMT (hours)	MDT
30 August 1972	1038-18084	143°	46°	1808	12:08 PM
13 August 1977	2934-17335	127°	46°	1733	11:33 AM

OPERATIONS PERFORMED

- Geometric correction
- Restoration and resampling at 50 meter intervals
- Registration to map (UTM coordinates)

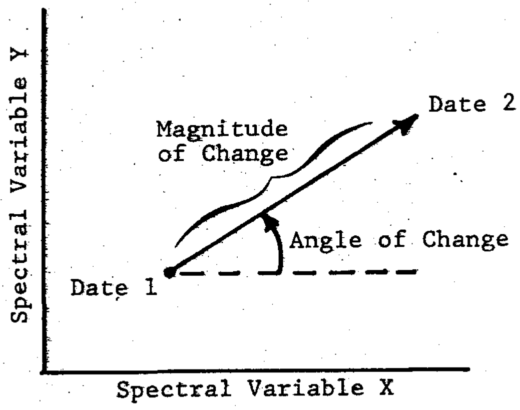

Figure 1. Illustration of a Spectral Change Vector

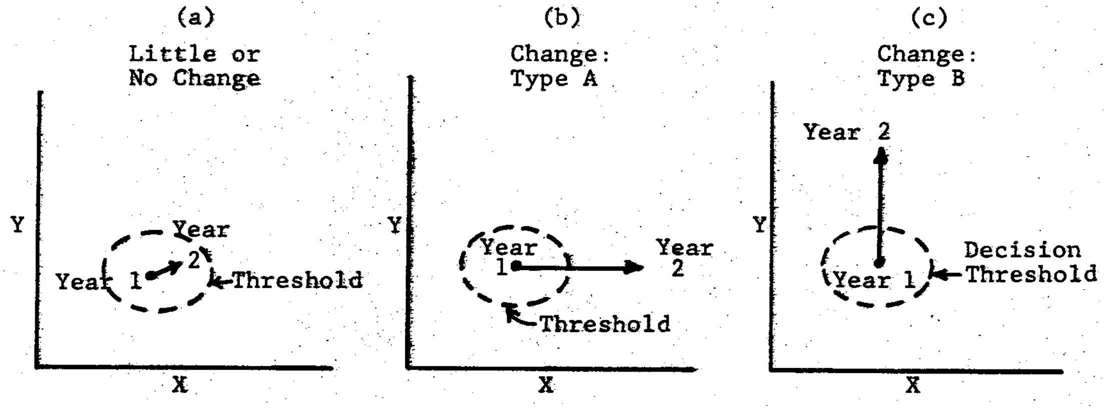

Figure 2. Illustration of Spectral Change Vectors for Different Types of Change

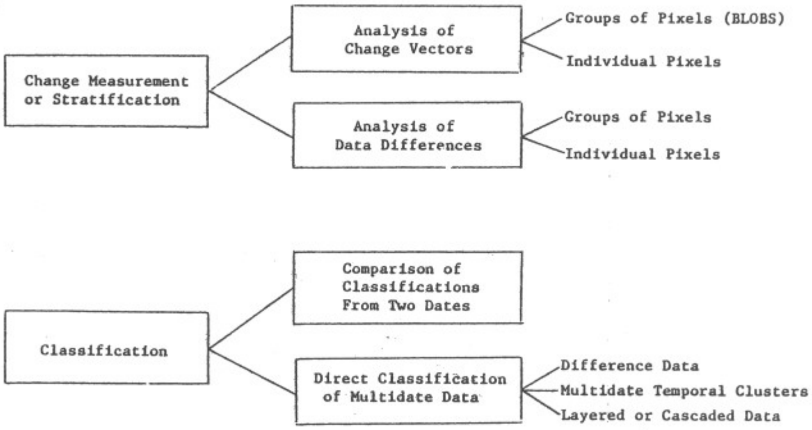

Figure 3. Some Digital Change Detection Approaches Using Landsat

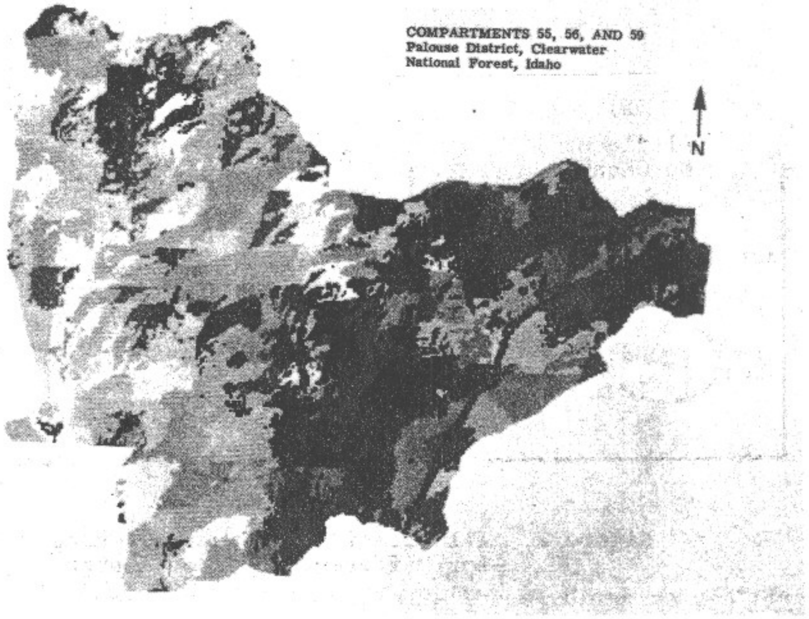

Figure 4. Map of Change Magnitude

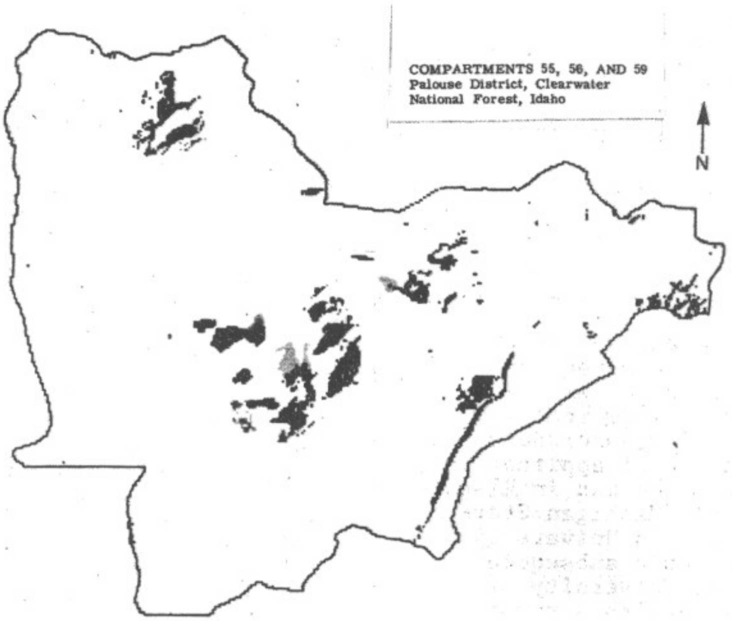

Figure 5. Map of Change Magnitude for Change Angles Indicating Likely Disturbances ($-60^\circ < \theta \leq 60^\circ$)

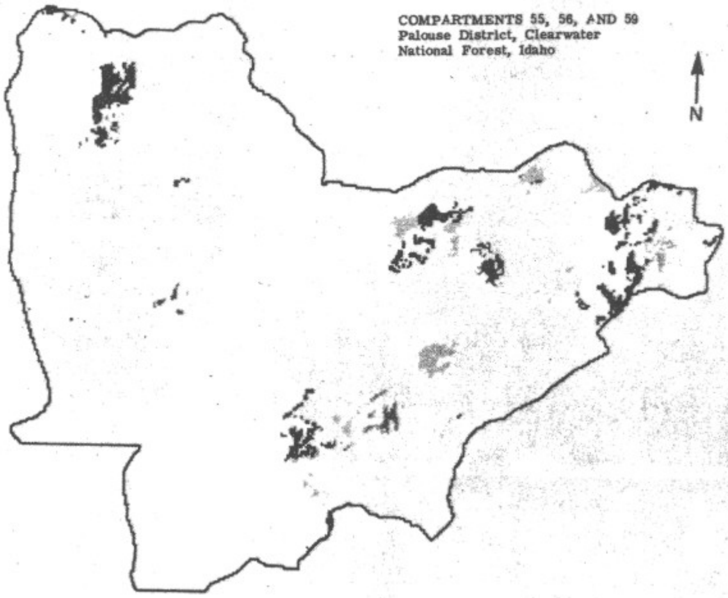

Figure 6. Map of Change Magnitude for Change Angles Indicating Likely Regrowth ($60^\circ < \theta \leq 100^\circ$)

Dr. Malila has been active since the mid 1960's in the development and testing of techniques for extracting resource information from remotely sensed multispectral scanner data, with emphasis on agricultural applications. His BS and MS education was in Electrical Engineering from Michigan State University and Stanford University, respectively, while his subsequent degree was from the University of Michigan in Forestry with a remote sensing emphasis.