A review and comparison of vegetation indices: An application of landsat spectral reflectance digital data to the northern range, Yellowstone National Park.

Brian Lee Soliday
A REVIEW AND COMPARISON OF VEGETATION INDICES: AN APPLICATION OF LANDSAT SPECTRAL REFLECTANCE DIGITAL DATA TO THE NORTHERN RANGE, YELLOWSTONE NATIONAL PARK

A Thesis
Presented to the

Faculty of the Graduate College
and the
Department of Geography-Geology
University of Nebraska

In Partial Fulfillment
Of the Requirements For the Degree

Master of Arts

University of Nebraska at Omaha

by
Brian Lee Soliday

June 1988
THESIS ACCEPTANCE

Accepted for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Arts, University of Nebraska at Omaha.

COMMITTEE

<table>
<thead>
<tr>
<th>NAME</th>
<th>DEPARTMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael P. Peterson</td>
<td>Geography/Geology</td>
</tr>
<tr>
<td>Jeff Verduzco</td>
<td>Geography/Geology</td>
</tr>
<tr>
<td>Thomas J. Bregh</td>
<td>Biology</td>
</tr>
</tbody>
</table>

CHAIRMAN

Michael P. Peterson

DATE

6/27/88
To Mom and Dad; thanks for your love and support.
ABSTRACT

The last two decades have seen vast progress in the utilization of spectral reflectance digital data for vegetation assessment purposes. The development of over fifty vegetation indices have been documented in the literature. Although the amount of variability between these indices has been studied, no comprehensive review of indice development efforts and theories exists. Therefore, the primary objectives of this study were to; 1) review the history and theories behind the development of the vegetation indices that have been applied in previous research, with particular emphasis on their spectral characteristics and use in grassland environments, and; 2) compare and evaluate the vegetation indices through correlation techniques.

Through these correlation techniques, it was determined that a number of the proposed indices provide transformed digital data that are highly redundant. This study identified three separate groups, with three indices each in two groups and two indices in the other, and two groups, each with only a single index. The indices within each group were equivalent in terms of the image data and the statistical analysis.

The use of spectral reflectance digital data provides a unique opportunity for resource managers and other interested parties. The use of remotely acquired digital information in rangeland management applications will surely increase as its benefits and capabilities are further uncovered and incorporated into various natural resource management plans.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER I : INTRODUCTION</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Purpose</td>
<td>3</td>
</tr>
<tr>
<td>1.2 Site/Situation</td>
<td>4</td>
</tr>
<tr>
<td>1.3 Thesis Organization</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHAPTER II : VEGETATION INDICES DEVELOPMENT</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Introduction</td>
<td>7</td>
</tr>
<tr>
<td>2.2 Data Acquisition Characteristics</td>
<td>7</td>
</tr>
<tr>
<td>2.3 Multispectral Scanner Characteristics</td>
<td>10</td>
</tr>
<tr>
<td>2.3.1 Band 4</td>
<td>10</td>
</tr>
<tr>
<td>2.3.2 Band 5</td>
<td>11</td>
</tr>
<tr>
<td>2.3.3 Band 6</td>
<td>11</td>
</tr>
<tr>
<td>2.3.4 Band 7</td>
<td>12</td>
</tr>
<tr>
<td>2.4 Bidirectional Spectral Reflectance</td>
<td>12</td>
</tr>
<tr>
<td>2.4.1 Background Soil Reflectance</td>
<td>12</td>
</tr>
<tr>
<td>2.4.2 Vegetation Canopy Conditions</td>
<td>13</td>
</tr>
<tr>
<td>2.4.3 Vegetation Amount (Standing Crop)</td>
<td>14</td>
</tr>
<tr>
<td>2.4.4 Vegetation Productivity (Rate of</td>
<td>15</td>
</tr>
<tr>
<td>Production)</td>
<td></td>
</tr>
<tr>
<td>2.4.5 Vegetation Senescence</td>
<td>15</td>
</tr>
<tr>
<td>2.4.6 Other Biophysical Parameters</td>
<td>16</td>
</tr>
<tr>
<td>2.5 Other Considerations</td>
<td>16</td>
</tr>
<tr>
<td>2.5.1 Preprocessing</td>
<td>17</td>
</tr>
<tr>
<td>2.6 Index Development</td>
<td>19</td>
</tr>
<tr>
<td>2.7 Ratio Based Indices</td>
<td>20</td>
</tr>
<tr>
<td>2.7.1 Ratio Vegetation Index</td>
<td>22</td>
</tr>
<tr>
<td>2.7.2 Difference Vegetation Index</td>
<td>23</td>
</tr>
<tr>
<td>2.7.3 Ashburn Vegetation Index</td>
<td>23</td>
</tr>
<tr>
<td>2.7.4 Normalized Difference Index</td>
<td>24</td>
</tr>
<tr>
<td>2.7.5 Transformed Vegetation Index</td>
<td>24</td>
</tr>
<tr>
<td>2.8 Orthogonal (N - Space) Indices</td>
<td>25</td>
</tr>
<tr>
<td>2.8.1 Tassled Cap Transformation</td>
<td>26</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The Northern Range Spatial Distribution in Yellowstone National Park</td>
<td>5</td>
</tr>
<tr>
<td>2.1</td>
<td>Idealized Reflectance Patterns of Herbaceous Vegetation and Soil</td>
<td>8</td>
</tr>
<tr>
<td>2.2</td>
<td>Moving Average Filter</td>
<td>18</td>
</tr>
<tr>
<td>2.3</td>
<td>Red and Infrared Radiance Values Plotted Against Dry Green Biomass</td>
<td>21</td>
</tr>
<tr>
<td>2.4</td>
<td>Locations of Various Types of Land Cover When Plotted in the</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Brightness-Greenness Spectral Space</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>A Graphical View of the Orthogonal Relationship Between the SBI and</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>the GVI</td>
<td></td>
</tr>
<tr>
<td>2.6</td>
<td>Diagram Illustrating the Principle of the Perpendicular Vegetation</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Index (PVI) Model</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Conceptual Data Flow Model</td>
<td>38</td>
</tr>
<tr>
<td>3.2</td>
<td>Locations of Study Sites</td>
<td>41</td>
</tr>
<tr>
<td>3.3</td>
<td>SAS Plot of the Correlation of the RV75 and MSBI</td>
<td>49</td>
</tr>
<tr>
<td>3.4</td>
<td>SAS Plot of the Correlation of the DVI and PVI7</td>
<td>49</td>
</tr>
<tr>
<td>3.5</td>
<td>SAS Plot of the Correlation of the AVI and PVI6</td>
<td>50</td>
</tr>
<tr>
<td>Table</td>
<td>Name</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3.1</td>
<td>Spearman Data Corelation Matrix for All Sites</td>
<td>43</td>
</tr>
<tr>
<td>3.2</td>
<td>Pearson Data Corelation Matrix for All Sites</td>
<td>44</td>
</tr>
<tr>
<td>3.3</td>
<td>Indices Equivalency</td>
<td>46</td>
</tr>
<tr>
<td>A.1</td>
<td>Primary Vegetation Types and Associated Species</td>
<td>57</td>
</tr>
<tr>
<td>D.1</td>
<td>Spearman Corelation Matrix for Study Site A</td>
<td>82</td>
</tr>
<tr>
<td>D.2</td>
<td>Spearman Corelation Matrix for Study Site B</td>
<td>83</td>
</tr>
<tr>
<td>D.3</td>
<td>Spearman Corelation Matrix for Study Site C</td>
<td>84</td>
</tr>
<tr>
<td>D.4</td>
<td>Univariate Analysis of Study Site A</td>
<td>85</td>
</tr>
<tr>
<td>D.5</td>
<td>Univariate Analysis of Study Site B</td>
<td>86</td>
</tr>
<tr>
<td>D.6</td>
<td>Univariate Analysis of Study Site C</td>
<td>87</td>
</tr>
<tr>
<td>D.7</td>
<td>Composite Univariate Analysis of For All Study Sites</td>
<td>88</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

Numerous individuals helped in the development and completion of this research. I would like to offer my appreciation to the members of my committee: Dr. Michael Peterson and Dr. Jeffrey Peake of the Geography Department, and Dr. Thomas Bragg from the Biology Department. Their help in accomplishing this goal will always be remembered. Also, I would like to thank Mr. Mark Laustrup, Manager of UNO's Remote Sensing Application Laboratory, for his help with the programming and image processing this project required.

I would like to thank Dr. Charles Gildersleeve, Chairman of the Geography Department, for allowing me the opportunity to be a part of the graduate program, but more importantly, for providing a lasting friendship that is all too often missing from student-professor relationships. Additionally, I would like to thank Don Despain of the National Park Service in Yellowstone National Park. My initial contact with him in August, 1986, lead to the ideas behind the development of this thesis.

This thesis would not have become a reality without the love and guidance of my parents. Their interest and desire to see this goal achieved was the driving force in its success, and the reason that this thesis is dedicated to them. Finally, I would like to thank my future wife, Lanette Dau, whose understanding and deep concern provided the support that enabled me to overcome the inherent difficulties of this research.
CHAPTER I INTRODUCTION

The value of remote sensing has been recognized in a wide variety of environmental disciplines, particularly those involving the planning, development and management of natural resources. The task of establishing and monitoring on-going inventories of vegetation conditions, by means of traditional techniques, is extremely difficult. Assessments of vegetative cover and crop conditions are generally based upon field observations or manual sampling techniques. This process is time-consuming, labor-intensive, expensive and may destroy the natural vegetative cover for any subsequent temporal-based measurements within the same plot. Furthermore, obtaining these data can be difficult in many regions, especially in terms of securing vegetation samples in areas which are physically remote and/or legally isolated.

As a result of these data acquisition difficulties, several indirect methods of monitoring plant community biomass and vegetation characteristics have been developed. One of the most promising methods is in the utilization of Landsat Multispectral Scanner (MSS) data, and analysis by means of digital image processing techniques (Boutton and Thieszen, 1983; Hardisky et al., 1984; Asrar et al., 1985; and Weiser et al., 1986). Landsat digital data provide the opportunity for extracting unique vegetation characteristics on a spectral, spatial and temporal basis. The quick and accurate assessment of the condition of a vegetative canopy is necessary to ascertain rangeland conditions, percentage of cover, and the carrying capacity of a given region. The repetitive availability, relatively low cost per unit area and digital format of the Landsat data make such information of potential interest to resource managers (McGraw and Tueller, 1983), although resolution limitations of the MSS digital data (.42
hectares or approximately 1.12 acres per pixel) along with the complexity, diversity and heterogeneity of grassland vegetation have tended to discourage its use for some applications.

Since the inception of the Landsat data acquisition program in 1967 and the first orbiting satellite in 1972, there has been substantial research in developing techniques for the quantitative and qualitative assessment of vegetative cover from the spectral reflectance values of Landsat MSS digital data. This research has primarily concentrated on reducing the four channels of MSS data to a single number, or value, per pixel that predicts or assesses the biophysical characteristics of the vegetation canopy. These data transformations are known as vegetation indices. Numerous indices, consisting of formulae for both linear and non-linear transformations of spectral digital data, have been developed.

Vegetation indices are simply functions that associate a real value to the four-dimensional (4 band) Landsat reflectance measurement vector. They have been utilized to identify, quantify, assess and predict vegetative resource phenomena such as biomass, productivity, classification type, leaf area index, percentage of ground cover, soil moisture status and the effect of background soil radiance and reflectance (Colwell, 1973; Kauth and Thomas, 1976; Richardson and Wiegand, 1977; Tucker, 1977c, 1979; Waller et al., 1981; Richardson et al., 1983; Krausmann, 1984; Weiser et al., 1986). Remote measurements of a vegetative canopy's bidirectional spectral reflectance provides researchers and other interested parties with a rapid and nondestructive method for assessing plant canopy biophysical parameters (McCloy 1980, Waller et al., 1981, and Weiser et al., 1986). These bidirectional digital data can be defined as measurements of the energy reflectance of a scene. The use of information derived from the transformation of the raw bidirectional data can yield accurate vegetation assessments without the need for in situ measurements.
A review of the literature has revealed the use of approximately fifty different vegetation indices. For current researchers, the question then arises as to which vegetation indices will provide transformed data values that are not redundant or equivalent to each other, and are therefore contributing unique and relevant information with which to support resource management decisions.

It is the belief of many researchers that for every vegetation assessment application, an optimum index exists. However, without an extensive literature review to delineate the appropriate indices that have been used in similar studies, future researchers may rely more heavily upon subjective factors, and therefore reduce the chance of accurately assessing the vegetative biophysical parameters from the raw digital data. This is apparent in that the literature contains references to anomalous results and some apparently contradictory findings.

1.1 Purpose

The purpose of this thesis is to; 1) review the history and theories behind the development of the vegetation indices that have been applied in previous research, with particular emphasis on their spectral characteristics and use in grassland environments, and 2) compare and evaluate the vegetation indices through correlation techniques. This study could prove to be beneficial to other researchers interested in determining the equivalence of assorted indices, as well as providing a historical review of index development. The MSS digital data for the selected grassland study sites will be transformed utilizing a selection of the various indices that were identified through literature review. Selected portions of the resultant data files will then be correlated in an attempt to determine the data equivalence and variability that occur between the
1.2 Site/Situation

A comparison and evaluation of the indices will be accomplished with a Landsat 2 scene of the Greater Yellowstone Ecosystem. To explain the need for research concerning vegetation indices, the general setting of this region will be briefly reviewed.

The Northern Range of Yellowstone National Park is a region that is relatively isolated, both physically and politically, and poses numerous problems for park research personnel involved with regional resource assessment and management. The area contains a large percentage of Yellowstone Park's 2.2 million acres and extends from the northern boundary of the park, the Yellowstone River, to as far south as the Southeast Arm of Yellowstone Lake and the Two Ocean Plateau (Figure 1.1). Additional information regarding Yellowstone's vegetation and climate, and their effects on vegetation distribution throughout the Northern Range, is presented in Appendix A.

Various herbivores, including the world's largest population of elk (*Cervus elaphus*), rely heavily upon the vegetative cover produced within this area's grasslands to develop winter fat reserves, as well as using the lower elevations of the area as winter range. The amount of biomass available for forage is a limiting factor in the carrying capacity and animal distribution within the Northern Range (Cole, 1972). The effective management of the ungulate population in relation to their resource requirements necessitates an assessment of vegetative availability on a spatial and temporal basis. This is particularly important with the increased number of elk creating a significant
spatial impact upon the park's vegetation because of their numbers and migratory behavior. Grassland biomass production, as well as the relationship of biomass production variability to fluctuations in the ungulate population in the Northern Range, needs to be achieved.

![Figure 1.1](image)

**Figure 1.1**
The Northern Range spatial distribution in Yellowstone National Park

Vegetation canopy conditions are dynamic. The correct and timely
appraisal of vegetation conditions are essential for forecasting trends and estimating the carrying capacity of a given region (Myers, 1983). This is a major concern for resource managers in the Yellowstone region, especially since the adequacy of the vegetative resources within the Northern Range to sustain the numbers of elk has become a matter of heated debate among various interested parties. Some groups have called for herd reductions because of possible overgrazing of the range, although National Park Service (NPS) research has failed to document retrogressive plant succession caused by ungulate grazing (U.S. NPS, 1986).

Before the consideration of any possible herd management alternatives for the region, a more complete understanding of the biological productivity of the Northern Range is needed, specifically the biomass available for grazing during the growing season. It is therefore imperative for park officials to implement a program to capture the required biophysical data. If incorporated into some sort of continuing management scheme, the procurement of vegetation samples by the traditional method would involve a continuing effort each year at considerable cost. Hence a more cost-effective management tool has been sought to provide resource specialists the ability to monitor the temporal and spatial changes in vegetation patterns on a regional scale (Milner and Hughes 1968, Hardisky et al., 1984). Remote sensing and the use of vegetation indices, may provide such an alternative, although the application of this technique can only be possible through a thorough understanding of the vegetation indices that have been proposed.

1.3 Thesis Organization

An explanation of the data acquisition characteristics of the Landsat multispectral scanner, as well as a review of the development of the
CHAPTER II VEGETATION INDICES DEVELOPMENT

2.1 Introduction

This chapter will review the data acquisition characteristics of the Landsat multispectral scanner and vegetation index development, with particular emphasis on the history and philosophy behind individual indices. A survey of relevant research associated with vegetation indices will also be presented.

2.2 Data Acquisition Characteristics

Landsat satellite vehicles incorporate a multispectral scanner (MSS) as one of their main sensor systems. Each natural entity is thought to have an identifiable spectral signature, which can be regarded as its fingerprint. The strategy behind the development of the Landsat multispectral scanner is that, by separating the electromagnetic spectrum into a number of narrow bands, the unique spectral signature can be obtained for a given object or phenomena, and therefore isolate the objects of greatest interest. These spectral data can best be described as comprising the brightness values for each of the four multispectral channels (McGraw and Tueller, 1983). These four MSS channels are located in the visible and near infrared (NIR) portions of the electromagnetic spectrum (Figure 2.1).

The Landsat multispectral scanner utilizes electronic detectors to afford a view of the reflectance properties of terrain surfaces and are designed to sense energy in a number of narrow spectral bands simultaneously. These bands can range from the ultraviolet wavelengths through the visible, reflected IR and
thermal portions of the spectrum. The Landsat MSS operates on the principle of selective sensing in multiple spectral bands and provides inherent advantages over photographic sensors as follows:

- Increased sensing range from 0.5 \( \mu \text{m} \) to 1.1 \( \mu \text{m} \).
- Use of the same optical system to collect data in all spectral bands simultaneously.
- MSS data can be electronically transmitted to ground receiving stations.
- Because of its electronic format, MSS data can be dealt with in a numerical format.

*Figure 2.1*

*Idealized reflectance patterns of herbaceous vegetation and soil (after Deering et al., 1985).*

Every part of the earth receives solar radiation. This radiation is either reflected, transmitted, or absorbed in specific wavelengths within the electromagnetic spectrum. The characteristic 'spectral signature' of a surface is
the value captured within these specific wavelengths and recorded in digital format by the sensor systems on board various satellites. There are two main data sensors which can be used for obtaining data for analyses such as those being undertaken in this research. These are photographic sensors, such as those carried on board aircraft at a variety of altitudes, and multispectral scanner and thematic mapper systems, such as on Landsat or other satellite vehicles. Photographic sensors primarily provide qualitative spectral data, whereas multispectral scanners provide quantitative digital data (Claire, 1982). In terms of products, photographic sensors yield photographic images, whereas the multispectral scanner allows researchers the option of both quantitative digital spectral data and qualitative image products. The MSS image products are viewed as the optimum formats for evaluating spatial and textural characteristics. However, quantitative data are better for the analysis of spatial and temporal characteristics.

A possible disadvantage in using MSS data is its spatial resolution. Each pixel in a MSS scene relates to a corresponding 79 m² (1.12 acres/pixel) ground area. Many small or linear features are therefore not accurately captured and recorded by the scanner. The recent addition of the Thematic Mapper (TM) to the Landsat platforms has increased the spatial resolution to 30 m². This resolution can be a great advantage, especially in urban applications, although increased data costs and processing time make MSS data the most cost-effective for large-scale regional environmental assessments.

Because of the fact that bidirectional spectral reflectance data are a measure of the energy reflectance of a scene, raw data values are modified by factors such as atmospheric transmission, noise from a variety of biotic and abiotic sources, and measurement errors (McCloy 1980, Weiser et al. 1986). Attempts at using remote sensing data for biomass estimations and other forms of vegetation assessment have produced some disappointing results due to
data variability. Maxwell (1976) proposed that low correlation coefficients between ratioed digital values and the channels that they were formed from is indicative of high noise levels. The literature, however, does not provide any further answers based on this hypothesis.

The bidirectional spectral reflectance digital values captured and recorded by the MSS have been utilized to estimate attributes such as percent ground cover, Leaf Area Index (LAI) and vegetative biomass (Wiegand et al., 1979; Pearson et al., 1976; Tucker, 1977b). Upon computing correlation coefficients, it was found that the coefficients ranged from 0.30 for band 7 with actual crop cover, to 0.88 for band 6 with a Leaf Area Index (LAI). Tucker (1979) supported these findings by the computation of similar correlations.

2.3 Multispectral Scanner Characteristics

To effectively review the development of vegetation indices, it is critical to inspect the agents which affect the bidirectional spectral reflectance of each specific MSS channel. Within the visible region of the electromagnetic spectrum (0.4-0.7 micrometers(μm)), typical chlorophyll concentrations result in the absorption of eighty to ninety percent of the total incoming radiation (Tucker and Miller, 1977). The reduction in the amount of chlorophyll present in dead or dormant vegetation causes a markedly higher reflectance throughout the visible wavelengths of the spectrum. This is an important factor in assessing spectral reflectance in both the green (MSS Band 4) and red (MSS Band 5) wavelengths.

2.3.1 Band 4 (Green wavelength, 0.5 - 0.6 μm)

MSS Band 4 is situated in a spectral region where reduced chlorophyll absorption occurs. This is advantageous for green vegetation assessment
applications because of the fact that the same relationship exists across the entire channel width (Tucker, 1978). Because of the slight peak in spectral reflectance in MSS4, the green portion of the spectrum dominates the spectral response of living vegetation in the visible region (see Figure 2.1). Band 4 is also characterized by a reduced level of pigment absorption. This results in a higher reflectance value than the adjacent blue or red wavelengths.

2.3.2 Band 5 (Red wavelength, 0.6 - 0.7 μm)

Band 5 of the multispectral scanner is located in a region of strong chlorophyll absorption. The more green biomass present in an image, the more functioning chlorophyll there is present in the leaf tissue, and the more absorption or less reflectance of measurable energy (Pearson, 1973). This chlorophyll absorption has been thoroughly researched and has been found to peak in the 0.67 - 0.68 μm range (Salisbury and Ross, 1969). Therefore, a solid relationship exists between the spectral reflectance in this region and the amount of green biomass present.

2.3.3 Band 6 (Near Infrared, 0.7 - 0.8 μm)

Channel 6 provides a strong association to green leaf biomass as well as the associated high soil-green vegetation reflectance contrast which peaks in the 0.75 - 0.8 μm region (Tucker and Miller, 1977). The rise in the spectral reflectance curve from 0.7 - 0.8 μm (Figure 2.1) is caused by the reflection of energy from the spongy mesophyll cells within the leaves of healthy plants (Pearson, 1973). These wavelengths are subsequently sensitive to the green or photosynthetically active vegetation, and to a lesser extent, the senescent, dead or nonphotosynthetically active vegetation (Colwell, 1974; Tucker, 1977b, 1978). Therefore, the more healthy foliage present, the higher the reflectance values. MSS6 contributes spectral reflectance information that is much the same as band 7, and can be considered redundant, although it also includes
the 0.70 - 0.74 μm wavelengths which are characteristically very noisy.

2.3.4 Band 7 (Near Infrared, 0.8-1.1 μm)

Spectral radiances which are highly correlated and directly related to green leaf density are recorded by MSS band 7. Within this near IR region, the internal leaf structure of most vegetation is the source of high reflectivity and low absorption. Tucker (1978) concluded that MSS7 is superior to MSS6 for high green biomass situations, while MSS6 has been shown to be superior to MSS7 for lower green biomass environments. The near IR spectral reflectance varies the least with maturity and is perhaps the best all season spectral region for biomass estimations (Colwell, 1974; Tucker, 1977a; Waller, et al, 1981).

2.4 Bidirectional Spectral Reflectance Characteristics

The idealized reflectance patterns of live vegetation, dormant or dead vegetation, and soil produce different patterns. Most vegetation indices are based on the fact that there are significant differences in the spectral curves of these three entities (Figure 2.1). The assumption that these three materials have relatively unique spectral curves, although, is an oversimplification as green and dried vegetation grade spectrally one into another, depending on productivity. The bidirectional spectral reflectance measurements for each channel recorded by the MSS are therefore influenced by such factors as vegetation characteristics, soil background and atmospheric conditions (Perry and Lautenschlager, 1984).

2.4.1 Background Soil Reflectance

The reflectance of soils varies over a wide range, depending on
parameters such as moisture content, mineral content, structure and surface texture (Huete et al., 1984, 1985; Elvidge and Lyon, 1985;). The reflectance pattern of soil is somewhat lower than dead or dormant vegetation in the visible region, but higher than live vegetation. The literature provides numerous studies on the background reflectance of soils (Richardson and Wiegand, 1977; Tucker and Miller, 1977; Elvidge and Lyon, 1984; Huete et al., 1984, 1985). Soil brightness effects from the ratio-based indices have been shown to be opposite from the orthogonal indices. Indices are considered orthogonal if a statistical independence is imposed on all four MSS bands. In the ratio indices, greenness values decrease with increasing soil brightness, whereas in the orthogonal indices, greenness values increase under a constant vegetation canopy with increases in soil brightness (Huete et al., 1984). This reflectance is quite important in affecting canopy reflectance in certain ecosystems, especially those with a low percentage of vegetative cover.

The amount of soil moisture also has a distinct affect on the bidirectional reflectance. In the longer wavelengths, such as is MSS band 7, the moisture acts as an energy absorber. The higher the concentration of water in the surface soil, the greater the absorption, and hence less energy is sensed for the vegetation canopy. In the shorter wavelengths, soil moisture increases the amount of reflectance and can have varied effects upon the accuracy of vegetation assessments, depending on the amount of moisture and the actual wavelength being sensed.

2.4.2 Vegetation Canopy Conditions

One of the most frequently used parameters in analyzing vegetation from MSS digital data is the image tone of the vegetation. Within the short wave (0.3 - 3.0 μm) part of the spectrum, the bidirectional spectral reflectance of the vegetation canopy is the primary determinant for the relative image tone (Colwell, 1974). Several different kinds of vegetation information can be
obtained by the analysis of this image tone (signature). One of these is pigmentation. Variations in vegetation pigmentation are detectable in the visible region of the spectrum (MSS bands 4 & 5). A significant advantage that MSS-derived digital data has over conventional color aerial photography lies in the scanner's capability for detecting subtle tonal variations. Recording these variations and converting them to categories can be difficult if performed over large areas (Morain, 1974). This difficulty can be attributed to the fact that species and community reflectance patterns are variable both directionally (spatially) and temporally.

2.4.3 Vegetation Amount (Standing Crop)

The amount of vegetation has a direct relationship to infrared reflectance and an inverse relationship to reflectance in the strong vegetation absorption wavelengths (MSS channels 4 & 5) (Tucker, 1977b). This previously identified relationship results from the strong spectral absorption of incident radiation by plant chlorophyll. The 0.63-0.69 µm radiance is inversely proportional to the amount of chlorophyll present in the plant canopy and thus is sensitive to the amount of green or photosynthetically active vegetation that is present (Myers, 1983). These reflectance characteristics are maintained until the ground surface is covered with vegetation. After this threshold is reached, any further increase in vegetation amount will result in proportionally smaller reflectance changes (Curran, 1980).

The difference between reflectance in the wavelengths of vegetation absorption and infrared reflectance is at a minimum when vegetation amount is low, and at a maximum when vegetation amounts are high, although the effects of productivity (addressed below) should also be considered. This difference can be expressed by the proposed vegetation indices.
2.4.4 Vegetation Productivity (Rate of Production)

The important role that productivity or active growth plays in assessing vegetation with MSS digital data was first inferred by Carnegie et al., (1974), who recorded that Landsat MSS7 / MSS5 ratios peaked during the period, not of greatest biomass (standing crop), but of greatest vegetation productivity. Biomass predictions by the use of MSS digital data have therefore been found to be accurate during the summer, but have not received favorable results during the spring (high productivity) months (Curran, 1980). This can be attributed to the fact that the relationship between a multispectral reflectance ratio and vegetation amount is temporally dynamic, as the multispectral reflectance ratio is really a measure of vegetation amount and productivity. Curran (1980) concluded that while low multispectral ratios usually indicate low amounts of vegetation, a high multispectral ratio cannot differentiate between a high vegetation amount with low productivity and low vegetation amounts with high productivity. For example, a low biomass grassland region undergoing a period of active growth (high productivity) would strongly absorb blue and red light for photosynthesis. The grassland would have a greater infrared to red difference and a higher reflectance ratio than a high biomass area with low productivity.

Studies by Tucker (1977b) and Colwell (1974) indicate that near infrared spectral reflectance data varied the least with maturity and is perhaps the best all-season spectral region for vegetation assessment. These findings were supported by the results of Waller et al., (1981).

2.4.5 Vegetation Senescence

The onset of leaf senescence generally causes light reflectance to increase markedly in the green wavelength region (0.5-0.6 μm), peaking at 0.55 μm. This deterioration in leaves, as they near the end of their functional life,
also causes a decrease in the amount of near IR reflectance in the 0.75-1.35 μm regions (Myers, 1983). However, this decrease in infrared light reflectance is not nearly as great as the increase in visible light reflectance.

Excessively large or very small accumulations of dead biomass compared to average accumulations can yield underestimations and overestimations of live biomass from canopy spectral radiance (Hardisky, et al., 1984). Investigators have suggested that the amount of dead or senescent biomass in the vegetation canopy can be a significant modulator of the canopy radiance digital values (Colwell, 1974; Tucker, 1978).

2.4.6 Other Biophysical Parameters

The majority of vegetation assessment targets are composites of various natural components, such as leaves or other plant structures, as well as background reflectance and shadow effects. These individual components are also oriented at different angles with respect to the source of incident radiation, solar zenith angle, azimuth, slope, aspect and the satellite view angle. The bidirectional spectral reflectance data therefore represents a composite value of all biophysical attributes present (Colwell, 1973; Maxwell, 1976).

2.5 Other Considerations

The significant amount of information available from the four bands of MSS data causes a substantial increase in data volume and complexity over more traditional methods of obtaining biophysical characteristics. Each 185 kilometer x 185 kilometer, four channel Landsat image contains over 7.5 million digital data values. This volume of data as well as the multispectral complexity of the images, offer obstacles to efficiently extracting the required information.
Numerous methods have, therefore, been developed for transforming this data, deriving features which are easier to handle (lower volume) and/or easier to interpret (less complex) (Crist and Kauth, 1986).

Because remote sensing data is a measure of the energy reflectance and transmittance of energy in a scene, it can be modified by factors such as atmospheric transmission, noise from a variety of sources, and measurement errors (McCloy, 1980, Weiser et al., 1986). Attempts at using remote sensing data for biomass estimations have produced some disappointing results due to data variability. Maxwell (1976) proposed that low correlation coefficients between ratioed digital values and the channels that they were formed from is indicative of high noise levels. The literature however does not provide any further research based on this premise.

2.5.1 Preprocessing

Several preprocessing (cleaning) techniques have been pursued in attempts to improve data processing, reduce noise, and more accurately interpret data in terms of scene characteristics. Maxwell (1976) utilized numerous preprocessing techniques in a multivariate system analysis. By using a two-dimensional moving average filter (Figure 2.2), classification errors were reduced from approximately 19% to less than 4%. This spatial filter incorporates a local operator to determine the average value of a user-specified matrix. This average value is then given to the center pixel of the local operator. Virtually all sources of noise and transmittance fluctuations can be reduced to some degree by filtering the data.

Linear transformations have also be used in preprocessing attempts of raw bidirectional spectral reflectance data. A principal component analysis (described in Section 2.8.2) of the data can aid in maximizing the separation of classes along new axes, although McCloy (1980) found that a canonical
transformation could provide better results in certain ecosystems. The use of contrast stretching of raw data in vegetation assessment studies has found some success. Lo et al., (1986) and Klemas et al., (1987) found that by performing a contrast stretch of the original image values, it is possible to create a spectral variance similar to that found in some linear transformations. Contrast stretching involves replacing the raw digital values with values derived from the following equation, where INTGR is equal to the new value: \[ \text{INTGR} = \text{INT} \left( \frac{\text{Raw Digital Number}(n) - \text{Minimum Digital Value of the Image}}{\text{Range of Raw Data Values}} \right) + 0.5 \]. The variance of digital values is therefore stretched to provide greater contrast between spectral classes.

![Data Matrix Diagram](image)

**Figure 2.2**
Moving average filter (3x3 local operator)
(After Maxwell, 1976)
An important advantage to using vegetation indices is that, in many cases, the indices reduce the amount of noise in the original Landsat digital data. Factors such as atmospheric conditions (clouds, haze), sun angle, topography, shadow, soil and dead or senescent vegetation may affect all four bands in similar or dissimilar ways. In many cases it has been shown that band ratioing or transformations can result in partially reducing the noise, or possibly a complete noise reduction (Maxwell, 1976).

2.6 Index Development

Assorted algorithms have been developed to assess the biophysical parameters of vegetation canopies. Perry and Lautenschlager (1984) studied the history and formulae of some four dozen vegetation indices that utilized MSS data to assess vegetation characteristics such as species, leaf area, stress, and biomass. Vegetation indices are based on ratios or linear combinations of the four MSS channels. The development and usefulness of vegetation indices is dependent upon the degree to which the spectral contribution of non-vegetative components can be isolated from the measured response digital data (Huete et al., 1985). These MSS based indices therefore exploit differences in the reflectance patterns of vegetation and soil.

Vegetation indices, or greenness measures, can be classified into two categories; ratio-based and n-space(orthogonal) indices. Tucker (1979) stated that without exception, linear combinations are much more significant in assessing plant canopy biophysical parameters. Although individual MSS channels sometimes correlate better with vegetation yield than vegetation indices, indices provide better capabilities for temporal comparisons of vegetation amounts and conditions (Richardson and Wiegand, 1977).
2.7 Ratio Based Indices

A majority of vegetation index formulae are based on between band ratios or linear combinations which exploit differences in the reflectance patterns of green vegetation and other objects. The ratioed digital values from the individual MSS channels have been utilized by researchers to make qualitative and quantitative estimates of biomass, vegetative cover types, leaf area and various other biophysical parameters (Pearson and Miller, 1972; Wiegland et. al., 1974; Curran, 1982; Boutton and Tieszen, 1983; Asrar et al., 1985; Hardisky et al., 1984; Krausmann, 1984).

Ratio-based indices employ raw or atmospherically corrected digital data to measure the vegetative canopy's bidirectional spectral reflectance. Two wavelength bands have been widely used for estimating and assessing the herbaceous vegetation of grasslands. MSS Band 5 (red) and band 7 (infrared) provide most of the needed data variance for such a biomass estimate (Perry and Lautenschlager 1984, Weiser et al., 1986). These indices couple the high near infrared (NIR) reflectivity of green leaf materials in the 0.9-1.1μm region with the intense chlorophyll absorption and low reflectance in the red wavelengths (0.6-0.7 μm) (Figure 2.3). There is usually a positive relationship between the red and infrared reflectance ratio and the standing crop biomass of green vegetation. However, this bidirectional reflectance is known to vary independently of green biomass due to the effect of soil background, presence of senescent vegetation, angles of sun and sensor, and the canopy geometry (Curran, 1982).

The earliest experiments involving the transformation of bidirectional spectral reflectance digital data used the infrared/red ratio (Jordan, 1969, Pearson and Miller, 1972; Rouse et al., 1973; Colwell, 1974; Carnegie et al.,
The IR/red ratio and related linear combinations were found to be superior to green/red ratios and associated transformations (Tucker, 1979). Bands 5 and 7 have been chosen for other studies not only because of their recurrent use by previous researchers interested in vegetation canopy assessment, but also because of the reduced atmospheric scattering in these longer wavelengths.

![Graph showing red and infrared radiance values plotted against dry green biomass](image)

**Figure 2.3 (After Tucker, 1979)**
Red and Infrared radiance values when plotted against dry green biomass

Although twelve pairwise ratios (six of which are the inverse of the other six) have been used, only the ratio of channels 5 and 6 (RV65 = Ch6/Ch5) and channels 5 and 7 (RV75 = Ch7/Ch5) have become standard formulae for the ratio vegetation index approach to assessing vegetation bidirectional reflectance patterns. Rouse et al., (1973), Tucker, (1978) and Weiser et al.,
determined that ratio coefficients were slightly higher than those coefficients for the corresponding channel differences.

2.7.1 Ratio Vegetation Index (RVI)

The use of a NIR/red ratio method for the estimation of biomass or leaf area index (LAI) was first recorded by Jordan (1969), who derived the LAI for a forest canopy in a tropical rain forest. The most commonly used ratio vegetation index employs the red (band 5) and the near infrared (band 7) wavelengths, and is expressed as:

$$RV75 = \frac{\text{MSS Band 7}}{\text{MSS Band 5}}.$$ 

It is important to note that the ratio of channel 7 to channel 5 is sensitive to the photosynthetically active or green biomass, and may be considered as an indicator of living standing crop biomass and, therefore related to rate of the so-called "primary production" (discussed in Section 2.4.4) within a given species type or the chlorophyll content per unit area (Clough and Morley, 1977). Although this simple RV75 may be used to measure greenness, and has been shown to have some utility for biomass estimations (Carneggie et al., 1975), spatial differences and deviations of the Landsat-derived spectral data could induce considerable errors (Rouse et al., 1973).

Colwell (1973) concluded that the IR/red ratio was somewhat effective in normalizing the effect of soil background reflectance variations, although darker soil backgrounds in an image scene resulted in higher digital values for the ratioed image. Maxwell (1976) also analyzed bidirectional reflectance data using ratio methods. He determined that the ratio; $RV65 = \frac{\text{MSS Band 6}}{\text{MSS Band 5}}$ was slightly more statistically significant than RV75, despite the fact that both are valuable in monitoring green biomass. An explanation of the greater utility of band 6 versus band 7 for use in rangelands, is based upon the soil-green vegetation spectral contrasts proposed by Rouse et al., (1974) and
2.7.2 Difference Vegetation Index (DVI)

All of the proposed ratio-based indices are calculated without defining a soil-rock baseline, the Difference Vegetation Index; DVI=(2.4 * MSS7 - MSS5), suggested by Richardson and Wiegand (1977), also does not define this line, but since it does not involve the traditional ratio-based operation, it yields values comparable to a Perpendicular Vegetation Index (described in Section 2.8.3) when the soil-rock baseline has a slope close to zero. This index was also found to be computationally easier than PVI7 and produced values which essentially represented a rescaling of the PVI7 (Perry and Lautenschlager 1984). Lougey et al., (1987) found that the DVI is most appropriate in the assessment of canopy conditions in low biomass environments. Tucker (1979), in his research of red and photographic infrared linear combinations, suggested another DVI, where DVI = (MSS7 - MSS5), although this index does not compensate for different irradiational conditions and subsequently should be excluded from use for future research (Tucker, 1979).

2.7.3 Ashburn Vegetation Index (AVI)

Another vegetation index based upon the same theory of image differencing as the DVI, is the Ashburn Vegetation Index (AVI). This index was suggested as a measure of green growing vegetation (Ashburn, 1978) and is represented as: AVI = (2.0 * MSS7 - MSS5).

The concept behind this theory was first developed by Pearson and Miller (1972) who found that the 0.78 μm - 0.68 μm contrast provides a better greenness measure than the single MSS channels. The doubling of channel 7 is designed to normalize the scaling between channel 7 and 5. Band 7 is 6-bit data (possible digital data values from 0 - 63 ) and therefore has only one-half
the range of bands 4, 5 and 6 which are 8-bit data (possible digital data values from 0 - 127). The simplicity of the AVI make its use very desirable in large-scale computer applications (Miller, 1981). It can also be used in data masking applications because of the fact that a positive AVI transformation value indicates at least some growing vegetation in a Landsat scene while a zero signifies no growing vegetation.

2.7.4 Normalized Difference Index (NDI)

Because of the problems incurred in using the RVI's, Rouse et al., (1973), developed one of the first successful linear transformation indices based on band ratioing. He computed the normalized difference of digital data values from bands 5 and 7 and referred to it as the Normalized Difference Index (NDI) or just simply the Vegetation Index (VI). The most widely used formula for this index is: \( \text{NDI}_7 = \frac{(\text{MSS Band 7} - \text{MSS Band 5})}{(\text{MSS Band 7} + \text{MSS Band 5})} \), although the application of MSS6 has also been used to form the equation: \( \text{NDI}_6 = \frac{(\text{MSS Band 6} - \text{MSS Band 5})}{(\text{MSS Band 6} + \text{MSS Band 5})} \).

2.7.5 Transformed Vegetation Index (TVI)

To avoid working with negative values that sometimes resulted from the use of the NDI, Deering et al., (1975) proposed adding 0.5 to the values, and then utilizing the square root of the result. This formula was designed to stabilize the variance within the data and is called the Transformed Vegetation Index (TVI) or the Transformed Normalized Difference Index. The most commonly used formula for this index was: \( \text{TVI}_7 = \sqrt{\left(\frac{(\text{MSS Band 7} - \text{MSS Band 5})}{(\text{MSS Band 7} + \text{MSS Band 5})}\right) + 0.5} \) (Deering et al., 1975; Tucker, 1979; ). It was later determined that the addition of 0.5 did not totally eliminate all negative values, so Perry and Lautenschlager (1984) suggested a computationally correct formula for the TVI where: \( \text{TVI}_7 = \frac{\left(\left(\frac{(\text{MSS Band 7} - \text{MSS Band 5})}{(\text{MSS Band 7} + \text{MSS Band 5})}\right) + 0.5\right)}{|\left(\frac{(\text{MSS Band 7} - \text{MSS Band 5})}{(\text{MSS Band 7} + \text{MSS Band 5})}\right)|} \).
MSS Band 5) / (MSS Band 7 + MSS Band 5)) + 0.5) * SQRT (ABS(((MSS Band 7 - MSS Band 5) / (MSS Band 7 + MSS Band 5)) + 0.5))), where ABS indicates the absolute value and SQRT represents the square root.

The TVI band selections have been modified by several researchers since the index was first used. Tucker (1977b) utilized MSS band 6 instead of band 7 and called the index the TVI6 where: TVI6 = [(((MSS Band 6 - MSS Band 5) / (MSS Band 6 + MSS Band 5)) + 0.5) / ABS(((MSS Band 6 - MSS Band 5) / (MSS Band 6 + MSS Band 5)) + 0.5) * SQRT (ABS(((MSS Band 6 - MSS Band 5) / (MSS Band 6 + MSS Band 5)) +0.5))).

Tucker stated that band 6 was primarily beneficial because of the apparently greater soil-green vegetation contrast obtainable in this spectral region. Other researchers have also substituted band 6 (Krausmann, 1984), although band 7 is still used more often, primarily because of the reduced noise effects previously mentioned. Lautenschlager and Perry (1981) concluded that the digital values of TVI7 and TVI6 are essentially equivalent to the less computationally intensive RV75 and RV65.

2.8 Orthogonal (N - Space) Indices

The evolution of n-space indices began with the development of techniques that transformed the Landsat bidirectional spectral reflectance data in four-dimensional space by employing combinations of the four MSS bands. These indices measure departures from the bare rock-soil baseline established by the use of two or more bands (Curran, 1982, Elvidge and Lyon, 1985). The orthogonal indices are distinct from the ratio-based indices in that lines of equal greenness do not converge at the origin, but instead remain parallel to a predefined, principal axis of soil spectral variation known as the "soil line" (Huete et al., 1985). Jackson (1983) concluded that these n-space indices
succeed in their primary purpose, that being to discriminate vegetation signatures from soil background reflectance.

2.8.1 Tasseled Cap Transformation

Kauth and Thomas (1976) developed a very important set of indices derived from the "tasseled cap transformation". These transformations are based on the Gram-Schmidt orthogonalization technique which produces an orthogonal transformation of the original four band MSS data to a new four dimensional data space. This technique allows the researcher to freely establish a physical interpretation by choosing the order in which the calculations are performed (Perry and Lautenschlager, 1984). For the transformation, a feature named brightness was defined in the direction of soil reflectance variation, and greenness was defined in a perpendicular direction associated with the reflectance characteristics of green vegetation (Crist and Kauth, 1986). The name "tasseled cap" was assigned because of the cap shape of the data when plotted on these greenness and brightness axes (Figure 2.4).

This orthogonal transformation has been thoroughly tested and has been used primarily for monocultural crop studies. The four new axes identified by the tasseled cap transformation are named to indicate the characteristics the indices are intended to measure (Lautenschlager and Perry, 1981). These are the Soil Brightness Index (SBI), Green Vegetation Index (GVI), Yellow Stuff Index (YVI) and the Non-Such Index (NSI), which is associated with atmospheric effects. These indices are obtained by multiplying each of the four original Landsat MSS digital numbers for each pixel by the corresponding tasseled cap coefficient. The formulae, with the respective tasseled cap coefficients, for the SBI, GVI, YVI and the NSI, were taken from Kauth et al., (1978):
The Green Vegetation Index (GVI) was developed from the same concepts as the SBI, although geometrically it behaves in a similar manner as the Perpendicular Vegetation Index (Huete et al., 1985). A graphical representation of the orthogonal relationship between the GVI and the SBI is presented in Figure 2.5. The GVI, which is sensitive to the vigor of vegetation, is defined as the orthogonal distance in three or more bands, away from the soil line, towards
some "point of vegetation" (Kauth and Thomas, 1986). Therefore in theory, the GVI contains more information and gives a better representation of the actual vegetation than transformations which utilize only two channels (Lo et al., 1986).

![Figure 2.5](image)

**Figure 2.5**
A graphical view of the orthogonal relationship between the SBI and the GVI (After Miller, 1979)

It is interesting to note that all the SBI variable coefficients are positive, while the GVI variables for MSS4 and MSS5 are negative. The data space of soils is therefore established by the SBI while the GVI departs from it. This stems from the fact that the GVI is sensitive to soil type as well as soil moisture
conditions (Huete et al., 1984). By using variable coefficients of this nature, the GVI delineates areas of high biomass concentrations while reducing the effect of soil reflectance. Because of the variance of vegetation reflectance, Ezra et al., (1984) and Huete et al., (1984) suggested the calculation of coefficients for use in the GVI on a site specific basis, rather than utilizing the global coefficients. Formulae to determine these coefficients can be found in Jackson (1983).

Kauth and Thomas (1976) discovered that 98% of the variance in bare soil spectral signatures from various soil types could be explained by the SBI, while 95% of all scene information could be extracted from the GVI. Because of this factor, the YVI and the NSI are rarely utilized and will not be reviewed in greater depth.

2.8.2 Principal Components Analysis (PCA)

The majority of digital remote sensing data require a variety of data dependent preprocessing procedures before any analytical techniques can be applied. Several of these procedures were described in Section 2.5. A preprocessing technique that has been utilized in previous research to remove geometric and radiometric distortions is principle components analysis (PCA) (Campbell et al., 1983). PCA can be used in the preprocessing of digital images to remove noise and to reduce the dimensionality of the data, therefore providing a clearer image.

Campbell et al., (1983) stated that with PCA techniques, the image data are transformed from the existing vector (variable) space coordinate system to a new coordinate system where: 1) the original is the grand mean of the data; 2) the axes are mutually perpendicular and fitted to the data; and 3) the PCA values mapped to each axis are uncorrelated. The primary axis of this new coordinate system is the first principal component, where deviations are
minimized because the axis has been fit to the data.

PCA techniques have also been successfully employed for data reduction, with results being obtained without a significant loss in data information content (Campbell et al., 1983). This technique can aid in maximizing the separation of classes along new axes, although McClow (1980) found that a canonical transformation could provide better results in certain ecosystems. Wheeler et al., (1976) and Misra et al., (1977) applied principal components analysis to raw MSS digital data and produced results very similar to those of the Kauth-Thomas tasseled cap transformation. The formulae for these indices are:

\[
\text{MSBI} = [(0.406 \times \text{MSS4}) + (0.6 \times \text{MSS5}) + (0.645 \times \text{MSS6}) + (0.243 \times \text{MSS7})];
\]

\[
\text{MGVI} = [(-0.386 \times \text{MSS4}) - (0.530 \times \text{MSS5}) + (0.535 \times \text{MSS6}) + (0.532 \times \text{MSS7})];
\]

\[
\text{MYVI} = [(0.723 \times \text{MSS4}) - (0.597 \times \text{MSS5}) + (0.206 \times \text{MSS6}) - (0.278 \times \text{MSS7})];
\]

\[
\text{MNSI} = [(0.404 \times \text{MSS4}) - (0.309 \times \text{MSS5}) - (0.505 \times \text{MSS6}) + (0.762 \times \text{MSS7})].
\]

Perry and Lautenschlager (1984) view the similarity of the Kauth-Thomas (tasseled cap) and Wheeler-Misra (PCA) results as remarkable in light of the fact that the concepts and techniques underlying the two transformation are very different.

2.8.3 Perpendicular Vegetation Index (PVI)

At approximately the same time that Kauth and Thomas (1976) were proposing the tasseled cap transformations using the four MSS bands in linear combinations, Richardson and Wiegand (1977) were developing the two dimensional Perpendicular Vegetation Index (PVI). They found that plots of digital values for MSS7 and MSS5 were found to fall on a straight line (the 'soil line'). As vegetation grows on the soil, the red radiance decreases and the NIR radiance increases. The perpendicular or orthogonal distance of a vegetated
spectral point to the "soil line" is therefore the measure of greenness. The soil line, a two dimensional analogue of the Kauth-Thomas SBI, is estimated by linear regression techniques. The originally proposed index incorporated the red and near IR bands to form the equation; \( PVI = \sqrt{(R_{gg5} - R_{p5})^2 + (R_{gg7} - R_{p7})^2} \); where \( R_{p} \) is the reflectance of a vegetation point for MSS bands 5 and 7, and \( R_{gg} \) is the reflectance of soil background corresponding to the vegetation point. A graphical representation of the principle of the PVI model is presented in Figure 2.6.

Figure 2.6 (After Richardson and Wiegand, 1977)
Diagram illustrating the principle of the perpendicular vegetation index (PVI) model

Transformations of the PVI using channel 6 in place of channel 7 have also
been proposed. The formulae for these two PVI's yield coefficients that can be represented as:

\[ PVI_7 = \sqrt{[(0.355 \cdot MSS_5 - 0.149 \cdot MSS_6)^2 + (0.355 \cdot MSS_5 - 0.852 \cdot MSS_6)^2]} \]

\[ PVI_6 = \sqrt{[(-0.498 - 0.457 \cdot MSS_5 + 0.498 \cdot MSS_6)^2 + (2.734 + 0.498 \cdot MSS_5 - 0.543 \cdot MSS_6)^2]} \]

It was later found that a minor error was made in deriving the PVI_6 and the correct formula was defined as: \[ PVI_6 = \sqrt{[(-2.507 - 0.457 \cdot MSS_5 + 0.498 \cdot MSS_6)^2 + (2.734 + 0.498 \cdot MSS_5 - 0.543 \cdot MSS_6)^2]} \] (Perry and Lautenschlager, 1981). Using this formula, Richardson and Wiegand (1977) were able to conclude that a positive PVI indicates vegetation, a value of zero indicates bare soil and a negative value indicates water.

The initial equations for PVI_6 and PVI_7 have been shown to be computationally inefficient and do not distinguish right (water) from left (green vegetation) of the soil line (Perry and Lautenschlager, 1984). The proposed correct formulae are:

\[ PVI_6 = \frac{(1.091 \cdot MSS_6 - MSS_5 - 5.49)}{\sqrt{(1.091^2 + 1^2)}} \]
\[ PVI_7 = \frac{(2.4 \cdot MSS_7 - MSS_5 - 0.01)}{\sqrt{(2.4^2 + 1^2)}} \]

Huete et al., (1985) found that greenness values increased with increasing soil brightness under equivalent vegetation amounts, although the overall magnitude of soil background influence on greenness appears to be less with the PVI than in the ratio-based indices, especially in areas with darker soil substrates, where the PVI is relatively unaffected (Elvidge and Lyon, 1984). This index is considered by many to be the best equation for normalizing the amount of soil background variations and reflectance values of the digital data in the longer wavelengths, particularly at vegetation levels below 30% (Colwell, 1983; Perry and Lautenschlager, 1984). The multispectral scanner can distinguish differences in reflectance patterns for vegetation and soil in areas with vegetative cover as low as seven percent. Krausmann (1984) used the
PVI7 formula to successfully discriminate vegetation from soil at this seven percent cover threshold in a desert shrubland environment.

2.9 Other Indices

Another set of indices, based on the concept of spectral brightness and contrast, was proposed by Misra et al., (1977). They defined spectral brightness and contrast in spectral density space, and then transformed this information back to digital counts. The four resulting indices are expressed as:

\[
\begin{align*}
SSBI &= 0.437 \times MSS4 + 0.564 \times MSS5 + 0.661 \times MSS6 + 0.233 \times MSS7; \\
SGVI &= -0.437 \times MSS4 - 0.564 \times MSS5 + 0.661 \times MSS6 + 0.233 \times MSS7; \\
SYVI &= -0.437 \times MSS4 + 0.564 \times MSS5 - 0.661 \times MSS6 + 0.233 \times MSS7; \\
SNSI &= -0.437 \times MSS4 + 0.564 \times MSS5 + 0.661 \times MSS6 - 0.233 \times MSS7.
\end{align*}
\]

A vegetation indicator known as GRABS (Greenness Above Bare Soil) was developed by Colwell et al., (1979). The determination of variable coefficients for this index was made using the Kauth-Thomas tasseled cap transformation applied to sun-angle and haze corrected spectral reflectance data. GRABS is viewed as another attempt to develop an indicator for which a threshold value could be specified for detecting green vegetation (Lautenschlager and Perry, 1981). This index is somewhat similar to the GVI, since the SBI contributes less than ten percent of GVI, where:

\[
GRABS = (GVI - 0.09178 \times SBI) + 5.58959.
\]

A major drawback of using GRABS is easily identified in the fact that the user must first define two other indices for use in the equation. This would be very costly to process and time-consuming for assessing large tracts of land.

A linear transformation of the GVI, known as the GIN (Green Number) was
proposed by Thompson and Wehmanen (1978). This transformation used spectral reflectance digital data to indicate when agricultural vegetation is undergoing moisture stress. The GIN is used to estimate the percentage of land in an area with canopy cover that is determined to be 'healthy'. The 'soil line' used in this formula is defined by inspecting the digital data and removing spectral responses which are not considered reasonable for agricultural data. The minimum value remaining in band 5 is then incorporated in formula as the soil line. The formula for the GIN is:

\[ \text{GIN} = \text{GVI} - \text{soil line}. \]

This index is designed to be used primarily in monocultural environments and is somewhat subjective, and hence will not be analyzed in this research.

A ratio of the GVI to the SBI was suggested by Badwar (1981) as a crop discrimination indicator. The proposed formula for this index is;

\[ \text{GVBS} = \text{GVI} / \text{SBI}. \]

This index has not been readily used because it is basically a generalization of a normalized difference and is computationally more CPU intensive (Lautenschlager and Perry, 1981).

2.10 Conclusions From Previous Research

Richardson and Wiegand (1977), in their research on distinguishing vegetation from soil background reflectance, correlated eight separate vegetation indices (R75, DVI, TVI6, TVI7, PVI6, PVI7, GVI and SBI) with four plant biophysical parameters (shadow cover, crop cover, plant height and leaf area index (LAI)). The derived coefficients obtained in correlation by plant cover component were very similar, except for the SBI.

Tucker (1977b) concluded that the infrared/red ratio and the various channel transformations were found to be useful in estimating canopy variable
total dry biomass. He also found that the regression significance was extremely similar for the different infrared bandwidths of 0.75 - 0.80 μm, 0.80 - 0.90 μm, and 0.75 - 0.90 μm when ratioed with the red reflectance digital values or used in the assorted transformations. With resulting digital values being so similar, he sees no real reason to perform separate ratios with different Infrared bandwidths. In the same study, Tucker also determined that only slight differences were found between the RV75, DVI, ND7 and the TVI, and that there is no advantage to transforming the NDI into the TVI.

Vegetation indice similarities were first researched by Dixon and Brown (1979). They used the Biomedical Computer Program P1M and the cluster analysis of variables to determine the absolute value of the bivariate correlations. This value was subsequently used to measure the distance between the indices. This study separated the indices into two distinct groups with a number of smaller clusters. One of the large groups contained VI's based on MSS5 and MSS7, which included R75, ND7, TVI7, AVI and the PVI7. The other large group contained VI's based on MSS5 and MSS6, and several indices that incorporated all four channels. This group included R65, ND6, TVI6, PVI6, GVI, MGVI, SGVI and GRABS. These indices all had simple linear correlations greater than .90, with a greater percentage above .95.

Wiegand et al., (1979) also correlated VI's with LAI's for fields of winter wheat (PVI6, PVI7, TVI6, TVI7, and the GVI). The correlation coefficients for both within and among the fields were very similar.

Lautenschlager and Perry (1981) studied the empirical relationships among the various vegetation indices by the use of cluster analysis. This research separated the indices into two large groups, plus a number of smaller groups. One of the larger groups contained indices that were based on channels 5 and 7. This group included the AVI, PVI7, R75, TVI7 and ND7 (much like Dixon and Brown). The other group, based on channels 5 and 6 and
several four band transformations included the R65, TVI6, ND6, GVI, MGVI, SGVI, GRABS and PVI6. The correlation coefficients within these two groups were greater than 0.90. A correlation of greater than 0.80 for the elements of each group supported their theory of redundancies among the indices. They also identified three smaller groups of indices: (SBI, MSBI, SNSI), (R76, NSI) and (R64, R74). Therefore, these index groups were not correlated with the others, and were somewhat off by themselves. It was suggested that they contain unique information not contributed by the other indices (Lautenschlager and Perry, 1981).

Perry and Lautenschlager (1984) further evaluated the functional equivalence of indices by incorporating graphic display techniques and alarm models into their research. The results from this study demonstrated that the majority of the most widely used vegetation indices are equivalent. Two indices were determined to be equivalent if the decision based on the information of one index could have equally been made on the basis of the other index. The redundancies of indice information was highlighted by the findings that all transformed indices are equivalent to their corresponding band ratios.

2.11 Summary

The history of vegetation indice development spans nearly two decades. This chapter described the data acquisition characteristics of the Landsat multispectral scanners and their effect upon index development throughout this period. The most widely used indices and the theories behind their evolution were also described in detail. A review of the conclusions obtained from previous research regarding vegetation index data variability was provided. A summary of the formulas for the indices that were discussed in this chapter are presented in Appendix C.
Although the aforementioned vegetation indices are available for the estimation of assorted biophysical parameters, the problem of determining temporal and spatial variations of vegetation conditions still exist. The determination of which indices provide the greatest variety of digital information for assessing vegetation conditions in mountainous grassland environments still needs to be achieved. The information described in this chapter will contribute greatly to the development of the methodology proposed in the following chapter which addresses this problem.
CHAPTER III METHODOLOGY & ANALYSIS

The determination of variability among the proposed vegetation indices involved several major steps. This chapter will discuss the process of creating the correlation matrix that was required for a comprehensive analysis of the indices.

Various studies have been performed that utilize vegetation index models for biomass estimations. These were discussed in detail in Chapter 2 and will not be reviewed here. This study attempts to define data redundancies and variability that are achieved when applying data transformation techniques to raw bidirectional reflectance digital data from mountainous grassland environments. In particular, the primary objective was to determine which indices provide the greatest variability of digital information when applied to this environment.

A conceptualization of the data flow required to obtain the vegetation indice correlation matrix is presented in Figure 3.1. This figure portrays the major processes undertaken in this research, from initial data acquisition, to final analysis and documentation.

3.1 Data Acquisition

To develop the proposed methodology, a single date Landsat MSS Computer Compatible Tape (CCT) was required. The full-scene image that was used is indexed as Path 41, Row 29. This image, captured on July 25, 1978 by Landsat 2, includes a portion of northwest Wyoming, southwestern Montana and northeastern Idaho. The digital data in the image covered the area known
Initial Data Acquisition

Landsat → CCT → Tape Transferred To PDP - 11

Perform Calculations On Eye-Com → Literature Review

Vegetation Index Data Files → Select Study Areas From Each Index

Vax / SAS Create Composite Data File → Create Data Correlation Matrix

Analysis & Documentation

Figure 3.1
(Conceptual Data Flow Model)
as Yellowstone National Park, as well as the entire Greater Yellowstone Ecosystem. A 640 x 480 subscene image was then extracted from this full scene CCT to delimit the boundaries of the initial study region.

The initial step in this research was to review the literature to define the algorithms required for the construction of the vegetation index models. It was identified very early in the study that several authors had made reference to a specific index, with each author providing different variable coefficients (these were primarily orthogonal indices). The author of this research was therefore forced to search for the original author's documentation to determine the validity of each reference and ascertain which formula was correct. After this was accomplished, software programs which utilized these algorithms were written.

### 3.2 Computer Resources and Programming

Thirteen separate programs were written and coded in FORTRAN 77 to perform the required index calculations. The programs utilized in this research are provided for review in Appendix C.

Upon completion of the development of the software programs, the indices were then calculated. The data transformation and image processing of the original MSS bidirectional digital data was performed on the Remote Sensing Applications Laboratory's DEC PDP 11/73. This computer supports a Spatial Data Systems EYECOM II image processor that provides three 640 x 480 pixel by 256 grey-level image planes. The computer hardware configuration allowed direct output of the data transformations to the EYECOM image screen. After an index had been calculated, the program(s) would also output the minimum and maximum index values, the range of index values, and an option to contrast stretch the output of the index. The contrast stretch option was provided to allow
subtle differences in the image tone to be more apparent in the resultant image.

3.3 Study Site Identification

Various criteria were used to identify the selected study sites that would be analyzed in greater detail. In the development of the proposed methodology, an attempt was made to avoid sites with patchy or non-homogeneous vegetation. Also, ecotonal areas were avoided because of the fact that they constitute a source of noise-induced error, where boundary pixels include reflectance information from several vegetation communities (Daus, 1975). Because of an interest of the researcher in the use of satellite imagery for ungulate management, the study sites were also selected based on their relationship to known elk grazing areas (Houston, 1982), and because of a large concentration of grassland vegetation types known for being primary forage for these herbivores (Despain, 1986).

It was possible to identify large tracts of seemingly homogeneous grassland areas by the use of vegetative cover maps. A review of these manually produced vegetative cover type maps (Despain, 1983) identified three study sites which met this basic criteria. All three sites had similar vegetation, which included Big Sagebrush, Idaho Fescue and Bearded Wheatgrass habitat types (Despain, 1988). More information on the vegetation communities of the areas is provided in Appendix A. The geographic locations of the three study sites are represented in Figure 3.2.

3.4 Composite Data File Development

Each vegetation index model was performed on the raw bidirectional reflectance data. Upon completion of this task, a 10 x 10 matrix (approximately
112 acres), or window, of data was extracted for each study site by the use of
the WINDOW program (Appendix C). The three extracted data files for each
index, each of which contained 100 index values, were then merged to form a
single file of 300 digital values. The original data files were also saved for
correlation analysis between the study sites. At this point, each composite
index file contained data values for the same 300 pixels.

![Map of study sites](image)

Figure 3.2
Locations of Study Sites

Ten separate indice data files were used in the correlation process. These
were the RV65, RV75, AVI, DVI, PVI6, PVI7, SBI, GVI, MSBI, and the MGVI. Several index models were not employed or analyzed in this step because of their known relationship to other indices, including the ratio indices whose correlation had previously been reported. The Transformed Vegetation Indices (TVI6 & TVI7) were not analyzed because of their known equivalence to HV65 and RV75 (Lautenschlager and Perry, 1981). The indices incorporated into this research were selected on the basis of previously identified correlations. The idea behind these selections was to identify if data from a mountainous grassland ecosystem would affect the data equivalency that have been previously documented.

3.5 Indice Correlation Analysis

The University's DEC VAX 8650 super mini-computer was utilized to process the index data files and determine the correlation coefficients. The data files were manipulated by utilizing the CORR (Correlation) module of SAS (Statistical Analysis System). Data correlations can be defined as a measure of the closeness of a linear relationship between two variables (Allen, 1982). Therefore, if one variable (index) can be expressed exactly as a linear function of another variable (index), then the correlation is 1 or -1. This value depends on whether the two variables are directly related or inversely related. Conversely, a correlation of 0 between two variables means that each variable has no linear predictive ability for the other.

The initial correlations performed on the index data sets employed the Spearman's rank order correlation. Spearman correlation coefficients can be defined as a nonparametric measure that is calculated as the correlation of the ranks of the digital data (Allen, 1982). With this correlation technique, the digital data are first truncated and ranked, and then the correlation coefficients are computed on these ranked data.
The resultant composite Spearman and Pearson indice correlation matrices for all sites, are presented in Table 3.1 and Table 3.2. Pearson's correlation was performed to see if any of the correlation coefficients obtained from the two formulae were different. A review of Tables 3.1 and 3.2 identified only subtle differences between these formulae, although the correlations which
incorporated the two RVI's (RV65 and RV75) and the two soil brightness indices (SBI and MSBI) were distinctively different.

<table>
<thead>
<tr>
<th></th>
<th>RV65</th>
<th>RV75</th>
<th>AVI</th>
<th>DVI</th>
<th>PVI6</th>
<th>PVI7</th>
<th>SBI</th>
<th>GVI</th>
<th>MSBI</th>
<th>MGVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV65</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV75</td>
<td>0.890</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVI</td>
<td>0.873</td>
<td>0.883</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVI</td>
<td>0.866</td>
<td>0.876</td>
<td>0.999</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI6</td>
<td>0.876</td>
<td>0.866</td>
<td>0.988</td>
<td>0.988</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI7</td>
<td>0.864</td>
<td>0.876</td>
<td>0.999</td>
<td>0.999</td>
<td>0.987</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBI</td>
<td>0.752</td>
<td>0.749</td>
<td>0.953</td>
<td>0.958</td>
<td>0.963</td>
<td>0.958</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GVI</td>
<td>0.883</td>
<td>0.880</td>
<td>0.994</td>
<td>0.994</td>
<td>0.997</td>
<td>0.993</td>
<td>0.957</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSBI</td>
<td>0.749</td>
<td>0.747</td>
<td>0.952</td>
<td>0.957</td>
<td>0.962</td>
<td>0.957</td>
<td>0.999</td>
<td>0.955</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>MGVI</td>
<td>0.873</td>
<td>0.873</td>
<td>0.995</td>
<td>0.995</td>
<td>0.996</td>
<td>0.995</td>
<td>0.963</td>
<td>0.998</td>
<td>0.962</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 3.2
Pearson Data Correlation Matrix for All Sites

After an introductory analysis of the initial composite matrices, it was determined that the Spearman calculations would be used for the remainder of the analysis. Because of the relatively low range of the pre-contrast stretched
values of the RVI's (RV65=eight and RV75=seven), the resultant index was somewhat classified. The incorporation of the Spearman formula for the final analysis was based on this fact, in that some of these index values were already semi-classified, so the use of data ranking in Spearman's correlation would therefore tend to normalize the digital index values. The correlation matrices for the individual study sites and univariate analyses of the data are presented in Appendix D.

The remaining analyses were performed with the composite data files. The reasoning behind using the composite files of all three sites, was that the composite data files would normalize any index values that were not truly representative of the actual scene characteristics. These anomalous values could have been caused by a number of things, including erroneous scan lines in the raw data or scene noise.

Digital index value equivalency can be expressed by different means. To determine the equivalence or difference between indices, several criteria were introduced. Three possibilities were provided to determine the equivalency between the proposed indices; 1) each index was equivalent to itself (reflexive property), 2) If \(\text{index}(A)\) was equivalent to \(\text{index}(B)\), then \(\text{index}(B)\) was equivalent to \(\text{index}(A)\) (symmetric property), and 3) If \(\text{index}(A)\) was equivalent to \(\text{index}(B)\), and \(\text{index}(B)\) was equivalent to \(\text{index}(C)\) then \(\text{index}(A)\) was equivalent to \(\text{index}(C)\) (transitive property). These simple rules (Lautenschlager and Perry, 1981) permitted equivalency determinations without the need for a series of computer intensive computations.

This research attempted to define the data redundancy and/or variability of the proposed indices by utilizing correlation coefficients. The highest correlation occurred between the AVI, DVI and the PVII7. These three indices were grouped together (See Table 3.3) and had correlations within their group that exceeded .999. Not surprisingly, this group of indices are all defined by
employing MSS bands 7 and 5. It was expected that a very high correlation would be achieved between the AVI and the DVI because of the fact that they both are based on the theory of image differencing. The equivalency of PVI7 to these two indices is related to all three indices using the soil background line of bands 5 and 7. A correlation of .999 suggests that decisions based on information extracted from any one of these three indices could be achieved by a query of digital values from either of the other two. These indices can therefore be considered equivalent.

<table>
<thead>
<tr>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVI</td>
<td>SBI</td>
<td>PVI6</td>
</tr>
<tr>
<td>DVI</td>
<td>MSBI</td>
<td>GVI</td>
</tr>
<tr>
<td>PVI7</td>
<td></td>
<td>MGVI</td>
</tr>
</tbody>
</table>

* The RV65 and RV75 were determined as separate from any group

Table 3.3
Indices Equivalency

The SBI and the MSBI made up a small group that appeared to be relatively isolated from the other indices. The same relationship between these indices was also determined by Lautenschlager and Perry (1981). The grouping of these two indices may be attributed to the variable coefficients used in the transformation process. All four variable coefficients for the SBI and MSBI are positive. These indices therefore establish the data space of soils and provide unique digital values. With a correlation coefficient of .998, it appears that either index would provide efficient amounts of relevant data. However, in the use of these indices in this particular environment, it is suggested that the SBI be utilized. This is because of the MSBI's lower, albeit slight, correlation with the other proposed indices. Equivalent or redundant data could therefore
be avoided by its use.

The final group of indices was the PVI6, GVI and the MGVI. Although the GVI and MGVI are four channel transformations, and are based on the same concept as the SBI, their variable coefficients are such that they geometrically behave in a similar manner as the PVI6, which is calculated with MSS bands 5 and 6. This relationship was identified and reported by Huete et al., (1985). The correlation coefficient of greater than .995 in this study supports their findings and again suggests the data redundancies which frequently occur. The high correlation of these indices is not surprising. The PVI6 was developed to provide the orthogonal distance from a vegetation point to the so-called 'soil line', and therefore, the index value is essentially a measure of greenness. Because of their utilization of negative variable coefficients for bands 4 and 5, the GVI and MGVI delineate areas of high biomass concentrations and reduce the effects of soil brightness. Another possible reason for the high correlation is that the use of MSS band 6 in the PVI is superior in characterizing lower (rangeland) green biomass environments (Tucker and Miller, 1977), so an expected lower index value in the GVI and MGVI would provide a valid correlation.

It is interesting to note that the Ratio Vegetation Indices, RV65 and RV75 did not have a high correlation with any of the other indices. It appears that these two indices are providing digital information that is much different from the others. This could be attributed to the very low range of values achieved when calculating the original indices, before the contrast stretch was performed. The highest correlation within these indices was with the GVI (.908 and .902 respectively). This can be attributed to the fact that the GVI was developed as a greenness measure, and the ratio-based indices of R65 and R75 have been documented as being valuable indicators of vegetative cover.

The lowest coefficient was derived when correlating the RV65 with the
MSBI (.797). These two indices, if used in making a resource management decision, would each provide relevant data that is not redundant to one another. Although, the type of information that was being sought and the study area would determine if both indices would be required.

Although statistical data can provide a determination of the absolute data redundancies and equivalencies between indices, graphical representations can also prove beneficial in providing a visual comparison of indices equivalence. Figure 3.3 is a SAS plot of the correlation between the RV75 and the MSBI (.773). It is easy to interpret that the data values representing these two indices are only moderately correlated and are distributed unevenly. These indices are therefore providing information that is not redundant and may be considered unique. The correlation of the DVI and PVI7 (.999) is presented in Figure 3.4. The distribution of data in this figure identifies the visual similarity of these two indices and supports their statistical equivalence. Figure 3.5 represents the correlation between the AVI and the PVI6 (.984). This figure is provided to show that although the correlation coefficient is relatively high, each index provides digital values that would not be obtained by the use of the other.
Figure 3.3
SAS Plot of the Correlation of the RV75 and MSBI

Figure 3.4
SAS Plot of the Correlation of the DVI and PVI7
3.6 Summary

This study attempted to ascertain vegetation index variability when applied to Landsat MSS spectral reflectance digital data from a mountainous grassland environment. Three separate groups and two single indices were found to comprise the total variability of the indice values. The three groups were; 1) SBI and MSBI, 2) PVI6, GVI and MGVI, and 3) AVI, DVI and PVI7 (See Table 3.3). The two ratio vegetation indices (RV65 and R75) were not highly correlated with each other or with any other indices, and hence it was determined to view these indices as separate groups, with only one index in each. The majority of data variability within the study area can therefore be defined by the use of relatively few vegetation indices.
CHAPTER IV CONCLUSION

4.1 Results and Conclusions

The intent of this research was to; 1) provide a review of the history and theories behind vegetation indice development, and 2) compare and evaluate the proposed indices through correlation techniques.

Gray and McCray (1981) stated that the correlation between the proposed indices in the literature is so strong that any one index can be considered representative. They felt that generally, VI's provide a marginal improvement over the use of the original spectral data. This belief is quite a deviation from the findings of Pearson and Miller (1972) whose research findings indicated that the quantity of vegetation, in addition to its type and condition, may be determined with data transformation techniques. The present research supports the findings of Pearson and Miller in that separate groups of vegetation indices were identified. The use of any two indices within a group would only provide redundant data. Whereas, the use of a single index from each group would provide diverse, if not unique, information.

Although Morain (1974) stated that remote sensing, no matter how complete the program, will never substitute for field investigations, the application of data correlation techniques can provide a methodology in which to assess data variability and equivalence between vegetation indices, without the need for the accustomed method of obtaining ground truth.

Curran (1980) stated that there is no optimum data transformation technique, rather the choice is made on the basis of: (1) the relationship between the data recorded and scene reflectance (this relationship is
logarithmic for photographic optical density and linear for radiometric measurements); (2) the wavelengths sensed; (3) the amount of data reduction required; and (4) preference of the researcher. It is hoped that this study will provide future researchers a comprehensive analysis of vegetation index characteristics with which to determine the appropriate indices for the given environment, and therefore reduce the amount of redundant information that is inherently produced.

The application of this methodology to research in the grasslands of the Northern Range of Yellowstone National Park could also allow park research personnel to incorporate remote sensing techniques into a temporally-based management scheme to monitoring herbivore grazing effects on the ecosystem. Without the use of remote sensing data acquisition techniques, an accurate assessment of the grassland resources of this region would be relatively impossible, if not economically unfeasible, if not logistically impossible. The results from such a management plan could subsequently be used to monitor and/or estimate the relationship of biomass production variability and fluctuations in ungulate populations on the Northern Range. Linked with present ungulate surveys, quantitative and qualitative information on the spatial and temporal variability of green biomass within the summer ranges due to forage intensities could be determined. A reduction in the amount of image processing time and costs, inherent to most large-scale vegetation assessment programs, such as in the Northern Range, could also be supported by the use of the proposed methodology.

The use of spectral reflectance digital data provides a unique opportunity for resource managers and other interested parties to ascertain vegetation conditions without the need for in situ measurements. The twenty years of vegetation indice development has seen numerous changes. These changes will continue, as the spatial and spectral capabilities of the sensing systems on board new satellite vehicles increase, and researchers capitalize on these
technological advancements to formulate new indices. The value of '...remote sensing is a reality...it is too powerful a tool to be ignored...it could change our perceptions, our methods of data analysis, our models and our paradigms' (Estes et al., 1980). The use of remotely acquired digital data for rangeland management will surely increase as its benefits and capabilities are further uncovered and incorporated into various natural resource management plans.
APPENDIX A
Study Site Background Information

A.1 Park Geography

Yellowstone National Park (YNP) is primarily a forested volcanic plateau, with an average elevation of over 7,600 feet. The plateau itself contains mountains which reach over 11,300 feet (Eagle Peak 11,358) and is carved by river canyons and wide valleys to as low as 5,300 feet (near Gardner). The proposed analysis will concentrate on an area documented as being within the grazing ranges of the Northern Yellowstone Elk (Houston, 1982). This region contains both Slough and Soda Butte Creeks and portions of the drainages of the Gardner, Yellowstone and Lamar Rivers (See Figure 3.2).

A.2 Climate

The high elevation and spatial location deep within the interior of the North American continent is responsible for the generally cold and moderately moist climate of the area (United States NPS, 1982). Summer precipitation is more often dominated by local showers and thunderstorms from orographic processes rather than frontal systems. However, the complex topography creates significant localized departures from the areal norm, and many times forms sub-regional microclimates.

The highest mean annual precipitation (50 inches) in the study area occurs near the Mirror Plateau and Specimen Ridge and also in the headwaters area of Soda Butte Creek in the Beartooth Mountains. Greater amounts of precipitation undoubtedly occur high in the mountains, but accurate data are not available for these remote locations (U.S. NPS, 1982). Much lower
precipitation totals are received in the lower lying areas such as along the Lamar River valley (12.5 inches) and near the confluence of the Lamar and Yellowstone Rivers (15.0 inches). There is seasonality to precipitation within the Northern Range. Most areas of the study site receive more precipitation during the winter months than in summer. Snow accumulations in the study area range from 100 to over 400 inches of mean annual snow per year, although these accumulations are highly variable both temporally and spatially (Despain, 1986).

A.3 Vegetation

The physical geography and climate of the Northern Range has a distinct influence on the surface climate, and hence, the type and amount of vegetative cover that occupies the region. The herbaceous vegetative cover of this region is not only phenologically different from that of a prairie environment, but the underlying soil, composed mostly of glacial till, and the substrate of rhyolite, also contribute unique spectral characteristics.

Lightning and dry conditions have exposed the vegetation of YNP to natural fires, subjecting much of the forested plateaus to a 200 to 400 year fire cycle. This may explain the continued presence of lodgepole pine (Pinus contorta) and the limited distribution of other less fire-resistant species which dominate when fire is not an acting agent in an ecosystem. The open grassland areas of the Northern Range have undergone more recent wildfires. The approximate quantitative coverage of both forested and nonforested vegetation types and the characteristic vegetation of the Northern Range is presented in Table A.1.
A.3.1 Forest Vegetation

Within the Northern Range, diverse climate, topography and other biotic and abiotic factors provide for a rich diversity of vegetative cover. Most of the forested vegetation in the northern range is dominated by stands of douglas fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), engelmann spruce (*Picea engelmannii*), and lodgepole pine.

A3.2 Nonforested Areas

The nonforested areas of the Northern Range can be placed into one of five classes: wetland meadow, sagebrush/grassland, subalpine/alpine meadow, thermal area and talus. This research is primarily interested in the first three classes because of the inability of the thermal and talus regions to produce sufficient amounts of herbaceous vegetation.

The distribution of grassland species is affected by various factors, such as those listed for forested areas. The lowland drainage areas have large concentrations of Idaho Fescue (*Festuca idahoensis*), Bluebunch Wheatgrass (*Agropyron spicatum*), Bearded Wheatgrasss (*Agropyron canium*) and Big Sagebrush (*Artemisia tridentata*) habitat types. Other common grassland vegetation types within the study area are junegrass (*Koearia cristata*), sandberg's bluegrass (*Poa sandbergii*), western needlegrass (*Stipa occidentalis*), timber oatgrass (*Danthonia intermedia*) and california brome (*Bromus carinatus*) (Despain, 1983). Forbs such as prairie smoke (*Geum triforum*), yarrow (*Achillea millefolium*), western stickseed (*Lappula redowskii*), yampa (*Perideridia gairdneri*) and sticky geranium (*Geranium viscosissimum*), are also common.
<table>
<thead>
<tr>
<th>Vegetation Type</th>
<th>Vegetation Characteristic</th>
<th>Approximate Coverage (1)</th>
<th>% of Total Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upland Forest</strong></td>
<td>Douglas fir assns.</td>
<td>39783</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Lodgepole Pine assns</td>
<td>26192</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Engelmann Spruce/subalpine fir assns.</td>
<td>16308</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Aspen associes</td>
<td>3459</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Whitebark pine assns.</td>
<td>988</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Upland steppe</strong></td>
<td>Idaho fescue/bearded whitegrass assn. and others</td>
<td>40277</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Bluebunch wheatgrass/Idaho fescue assn. - xeric phase</td>
<td>10131</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>bluebunch wheatgrass/Sandberg bluegrass assn.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other native steppes</td>
<td>3706</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Exotic grasslands (old fields)</td>
<td>1235</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Shrub steppe</strong></td>
<td>Big sage/Idaho fescue assn.</td>
<td>45220</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Big sage/bluebunch wheatgrass assn.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Wet meadows</strong></td>
<td>Hair grass/sedge associés</td>
<td>7907</td>
<td>4</td>
</tr>
<tr>
<td><strong>Riparian shrub</strong></td>
<td>Willow species and other vegetation</td>
<td>741</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Miscellaneous vegetation</strong></td>
<td></td>
<td>1482</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

(1) in acres
APPENDIX B
Vegetation Indices Formulae

RV65 = MSS Band 6 / MSS Band 5
RV75 = MSS Band 7 / MSS Band 5

DVI = (2.4 * MSS7 - MSS5)
AVI = (2.0 * MSS7 - MSS5)

ND6 = [(MSS Band 6 - MSS Band 5) / (MSS Band 6 + MSS Band 5)]
ND7 = [(MSS Band 7 - MSS Band 5) / (MSS Band 7 + MSS Band 5)]

TVI6 = [(((MSS 6 - MSS 5) / (MSS 6 + MSS 5)) + 0.5) / ABS(((MSS 6 - MSS 5) / (MSS 6 + MSS 5)) + 0.5)] * SQRT(ABS(((MSS 6 - MSS 5) / (MSS 6 + MSS 5)) + 0.5))
TVI7 = [(((MSS 7 - MSS 5) / (MSS 7 + MSS 5)) + 0.5) / ABS(((MSS 7 - MSS 5) / (MSS 7 + MSS 5)) + 0.5)] * SQRT(ABS(((MSS 7 - MSS 5) / (MSS 7 + MSS 5)) + 0.5))

SBI = [(0.332 * MSS4) + (0.632 * MSS5) + (0.675 * MSS6) + (0.262 * MSS7)]
GVI = [(-0.283 * MSS4) - (0.660 * MSS5) + (0.577 * MSS6) + (0.388 * MSS7)]
YVI = [(0.899 * MSS4) + (0.428 * MSS5) + (0.076 * MSS6) - (0.041 * MSS7)]
NSI = [(-0.016 * MSS4) + (0.131 * MSS5) - (0.452 * MSS6) - (0.882 * MSS7)]

MSBI = [(0.406 * MSS4) + (0.6 * MSS5) + (0.645 * MSS6) + (0.243 * MSS7)]
MGVI = [(-0.386 * MSS4) - (0.530 * MSS5) + (0.535 * MSS6) + (0.532 * MSS7)]
MYVI = [(0.723 * MSS4) - (0.597 * MSS5) + (0.206 * MSS6) - (0.278 * MSS7)]
MNSI = [(0.404 * MSS4) - (0.309 * MSS5) - (0.505 * MSS6) + (0.762 * MSS7)]

PVI6 = (1.091 * MSS6 - MSS5 - 5.49) / (√(1.091² + 1²))
PVI7 = (2.4 * MSS7 - MSS5 - .01) / (√(2.4² + 1²))

SSBI = [(0.437 * MSS4) + (0.564 * MSS5) + (0.661 * MSS6) + (0.233 * MSS7)]
SGVI = [(0.337 * MSS4) - (0.664 * MSS5) + (0.678 * MSS6) + (0.262 * MSS7)]
SYVI = [(-0.437 * MSS4) + (0.564 * MSS5) - (0.661 * MSS6) + (0.233 * MSS7)]
SNSI = [(-0.437 * MSS4) + (0.564 * MSS5) - (0.661 * MSS6) + (0.233 * MSS7)]

GRABS = (GVI - (0.09178 * SBI) + 5.58959)
GIN = GVI - soil line
GVBS = GVI / SBI
APPENDIX C
Vegetation Indices Programs

PROGRAM VEGIND
C
CHARACTER*1 DEC
INTEGER VIT
C
WRITE(7,*)' VEGETATION INDICES
WRITE(7,*)' THIS PROGRAM UTILIZES SEPARATE SUB-PROGRAMS TO
WRITE(7,*)' ESTIMATE THE BIOPHYSICAL PARAMETERS WITHIN A
WRITE(7,*)' LANDSAT MSS SUBSCENE. THERE ARE THIRTY-FOUR
WRITE(7,*)' POSSIBLE RATIO-BASED AND ORTHOGONAL VEGETATION
WRITE(7,*)' INDICES THAT CAN BE PERFORMED WITH THIS PROGRAM
WRITE(7,*)' WRITTEN BY: BRIAN L. SOLIDAY
WRITE(7,*)' UNO RSAL
WRITE(7,*)'
C
WRITE(7,*)' THE FOUR MSS CHANNELS MUST BE REPRESENTED
WRITE(7,*)' BY THE FOLLOWING FILES:
WRITE(7,*)' P1 = MSS BAND 4
WRITE(7,*)' P2 = MSS BAND 5
WRITE(7,*)' P3 = MSS BAND 6
WRITE(7,*)' P4 = MSS BAND 7
WRITE(7,*)'
C
WRITE(7,*)' DO YOU WANT TO CONTINUE?(Y/N)
READ(5,'(A1)')DEC
IF(DEC.EQ.'Y',OR.DEC.EQ.'y,')THEN
CONTINUE
ELSE
GOTO 90
ENDIF
C
WRITE(7,*)' WHAT VEGETATION INDEX DO YOU WANT TO PERFORM?'
WRITE(7,*)' 1 = RATIO (RVI)
WRITE(7,*)' 2 = DIFFERENCE VEGETATION INDEX (DVI)
WRITE(7,*)' 3 = ASHBURN VEGETATION INDEX (AVI)
WRITE(7,*)' 4 = NORMALIZED DIFFERENCE INDEX (ND6, ND7)
WRITE(7,*)' 5 = TRANSFORMED VEGETATION INDEX (TVI6, TVI7)
WRITE(7,*)' 6 = TASSLED CAP TRANSFORMATION(SBI, GVI, YVI, NSI)
WRITE(7,*)' 7 = PRINCIPAL COMPONENTS ANALYSIS(MSBI,MGVI,MYVI,MNSI)
WRITE(7,*)' 8 = BRIGHTNESS/CONTRAST (SSBI, SGVI, SYVI, SNSI)
WRITE(7,*)' 9 = GREENNESS ABOVE BARE SOIL (GRABS)
WRITE(7,*)' 10 = GVBS (Badwar, 1981)
WRITE(7,*)' 11 = PERPENDICULAR VEGETATION INDEX (PVI6,PVI7)
WRITE(7,*)' 12 = EXIT THE PROGRAM
WRITE(7,*)'
READ (5, '(A1)') VIT
IF(VIT.EQ.12)THEN
GOTO 90
ELSE
CONTINUE
ENDIF
IF(VIT.LT.1.AND.VIT.GT.12)THEN
WRITE(7,*)' YOU HAVE MADE AN INVALID CHOICE!!
WRITE(7,*)' PLEASE CHOOSE AGAIN
WRITE(7,*)'
READ(5, '(A1)') VIT
ELSE CONTINUE ENDIF

C IF(VIT.EQ.1)THEN CALL RATIO ELSEIF(VIT.EQ.2)THEN CALL DIFF ELSEIF(VIT.EQ.3)THEN CALL ASHBURN ELSEIF(VIT.EQ.4)THEN CALL NORMAL ELSEIF(VIT.EQ.5)THEN CALL TRANSF ELSEIF(VIT.EQ.6)THEN CALL TASSLE ELSEIF(VIT.EQ.7)THEN CALL VEGPCA ELSEIF(VIT.EQ.8)THEN CALL BRIGHT ELSEIF(VIT.EQ.9)THEN CALL GRABS ELSEIF(VIT.EQ.10)THEN CALL GVBS ELSEIF(VIT.EQ.11)THEN CALL PERPEN ELSE CONTINUE ENDIF

90 STOP

100 END

PROGRAM RATIO

BYTE IBUFF1(5120),IBUFF2(5120),IBUFF3(5120),IBUFF4(5120),IBUFF5(5120)
CHARACTER*1 DEC,NUM,DEN
INTEGER*2 IMIN,IMAX

PROGRAM RATIO

THIS PROGRAM READS IN THE DATA FROM THE SELECTED MSS BANDS AND PERFORMS A RATIO OF THE DIGITAL VALUES WRITTEN BY BRIAN L. SOLIDAY, UNIVERSAL YOU HAVE SELECTED THE RATIO VEGETATION INDEX DO YOU WANT TO CONTINUE?(Y/N)

READ(5,'(A1)')DEC IF(DEC.EQ.,Y.OR.DEC.EQ.Y)THEN CONTINUE ELSE GOTO 310 ENDIF

OPEN(UNIT=11,FILE='P1',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)

C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN1=ILUN(11)
ICHAN2=ILUN(12)
ICHAN3=ILUN(13)
ICHAN4=ILUN(14)

WRITE(7,*)'WHAT BAND DO YOU WANT TO USE AS THE NUMERATOR?
WRITE(7,*)'1 = MSS BAND4'
WRITE(7,*)'2 = MSS BAND5'
WRITE(7,*)'3 = MSS BAND6'
WRITE(7,*)'4 = MSS BAND7'
READ(5,'(A 1 )')NUM
IF(NUM.LT.'1'.OR.NUM.GT.'4')THEN
   WRITE(7,*)' YOU HAVE MADE AN INVALID CHOICE
   WRITE(7,*)' PLEASE CHOOSE AGAIN
   WRITE(7,*)
   READ(5,'(A1)')NUM
ELSE
   CONTINUE
ENDIF

WRITE(7,*)'WHAT BAND DO YOU WANT TO USE AS THE DENOMINATOR?
WRITE(7,*)'1 = MSS BAND4'
WRITE(7,*)'2 = MSS BAND5'
WRITE(7,*)'3 = MSS BAND6'
WRITE(7,*)'4 = MSS BAND7'
READ(5,'(A 1 )')DEN
IF(DEN.LT.'1'.OR.DEN.GT.'4')THEN
   WRITE(7,*)' YOU HAVE MADE AN INVALID CHOICE
   WRITE(7,*)' PLEASE CHOOSE AGAIN
   WRITE(7,*)
   READ(5,'(A1)')DEN
ELSE
   CONTINUE
ENDIF

CALL MPIOPS

WRITE(7,*)'PERFORMING INITIAL CALCULATIONS'
IMIN=10000
IMAX=-10000
DO 100 L=0,639,10
   LL=L
   IF(NUM.EQ.'1')THEN
      ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
   ELSEIF(NUM.EQ.'2')THEN
      ISTAT=IREADW(2560,IBUFF1,LL,ICHAN2)
   ELSEIF(NUM.EQ.'3')THEN
      ISTAT=IREADW(2560,IBUFF1,LL,ICHAN3)
   ELSEIF(NUM.EQ.'4')THEN
      ISTAT=IREADW(2560,IBUFF1,LL,ICHAN4)
   ELSE
      GOTO 310
   ENDIF

   IF(DEN.EQ.'1')THEN
      ISTAT=IREADW(2560,IBUFF2,LL,ICHAN1)
   ELSEIF(DEN.EQ.'2')THEN
      ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
   ELSEIF(DEN.EQ.'3')THEN
      ISTAT=IREADW(2560,IBUFF2,LL,ICHAN3)
   ELSEIF(DEN.EQ.'4')THEN
      ISTAT=IREADW(2560,IBUFF2,LL,ICHAN4)
   ELSE
      GOTO 310
   ENDIF

ENDIF
DO 50 J=1,5120
  I=IBUFF1(J).AND."377
  O=I
  I=IBUFF2(J).AND."377
  P=I
  IF(P.LT.1)P=1
  IBUFF3(J)=O/P
  INTGR=IBUFF3(J)
  IF(INTGR.LT.IMIN)IMIN=IBUFF3(J)
  IF(INTGR.GT.IMAX)IMAX=IBUFF3(J)
CONTINUE
CALL TDOUT(1,IBUFF3,L,10)
100 CONTINUE
C
WRITE(7,')''IMIN=',IMIN
WRITE(7,')''IMAX=',IMAX
WRITE(7,')''RANGE=',RANGE
WRITE(7,')''DO YOU WANT TO CONTRAST STRETCH THIS IMAGE?'
READ(5,'(A1 )')DEC
IF(DEC.EQ.&#39;Y'.OR. DEC. EQ.y )THEN
  CONTINUE
ELSE
  GOTO 310
ENDIF
WRITE(7,')''THE CONTRAST STRETCH IS BEING PERFORMED'
C
DO 200 L=0,639,10
  LL=L
  IF(NUM.EQ.'1')THEN
    ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
  ELSEIF(NUM.EQ.'2')THEN
    ISTAT=IREADW(2560,IBUFF1,LL,ICHAN2)
  ELSEIF(NUM.EQ.'3')THEN
    ISTAT=IREADW(2560,IBUFF1,LL,ICHAN3)
  ELSEIF(NUM.EQ.'4')THEN
    ISTAT=IREADW(2560,IBUFF1,LL,ICHAN4)
  ELSE
    GOTO 310
  ENDIF
C
IF(DEN.EQ.&#39;1')THEN
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN1)
ELSEIF(DEN.EQ.&#39;2')THEN
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
ELSEIF(DEN.EQ.&#39;3')THEN
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN3)
ELSEIF(DEN.EQ.&#39;4')THEN
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN4)
ELSE
  GOTO 310
ENDIF
C
125 DO 150 J=1,5120
  I=IBUFF1(J).AND."377
  O=I
  I=IBUFF2(J).AND."377
  P=I
  IF(P.LT.1)P=1
  IBUFF3(J)=O/P
  INTGR=INT(255*((IBUFF3(J)-IMIN)/RANGE)+.5)
  IF(INTGR.GE.255)INTGR=255
  IBUFF4(J)=INTGR
150 CONTINUE
PROGRAM DIFF

BYTE IBUFF1(5120),IBUFF2(5120),IBUFF3(5120),IBUFF4(5120),IBUFF5(5120)
CHARACTER*1 DEC
INTEGER*2 IMIN,IMAX

WRITE(7,*)' YOU HAVE SELECTED THE DIFFERENCE VEGETATION INDEX
WRITE(7,*)' DO YOU WANT TO CONTINUE?(Y/N)
READ(5,'(A1)')DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.y)THEN
  CONTINUE
ELSE
  GOTO 310
ENDIF

OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)

OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN2=ILUN(12)
ICHAN4=ILUN(14)

CALL MPIOPS
WRITE(7,*)'PERFORMING INITIAL CALCULATIONS'
WRITE(7,*)'

IMIN=10000
IMAX=-10000
DO 100 L=0,639,10
  LL=L
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
  ISTAT=IREADW(2560,IBUFF1,LL,ICHAN4)
  DO 50 J=1,5120
    L=IBUFF1(J).AND."377
    O=I
    IF(O.LT.1)O=1
    L=IBUFF2(J).AND."377
    P=I
    INTGR=INT(2.4*O)-P
    IBUFF3(J)=INTGR
    IF(INTGR.LT.IMIN)IMIN=IBUFF3(J)
    IF(INTGR.GT.IMAX)IMAX=IBUFF3(J)
  CONTINUE
CALL TDOUT(1,IBUFF3,L,10)

WRITE(7,')'"' IMIN=",IMIN
WRITE(7,')'"' IMAX=",IMAX
WRITE(7,')'"'
PROGRAM ASHBURN

BYTE IBUFF1 (5120), IBUFF2(5120), IBUFF3(5120), IBUFF4(5120), IBUFF5(5120)
CHARACTER*1 DEC
INTEGER*2 IMIN,IMAX

WRITE(7,*)' 
WRITE(7,*)' 
WRITE(7,*)' THE CONTRAST STRETCH IS BEING PERFORMED' 
C
DO 200 L=0,639,10
   LL=L
   ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
   ISTAT=IREADW(2560,IBUFF1,LL,ICHAN4)
   DO 150 J=1,5120
      L=IBUFF1(J).AND."377
      O=L
      IF(O.LT.1)O=1
      L=IBUFF2(J).AND."377
      P=L
      IBUFF3(J)=INT(2.4*O)-P
      INTGR=INT(255*((IBUFF3(J)-IMIN)/RANGE)+.5)
      IBUFF4(J)=INTGR
      IF(INTGR.GE.255)IBUFF4(J)=255
   150 CONTINUE
   195 CALL TDOUT(1,IBUFF4,L,10)
200 CONTINUE
310 CALL EXIT
325 END

OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT,RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT,RECL=128)
C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN2=ILUN(12)
ICHAN4=ILUN(14)

YOU HAVE SELECTED THE ASHBURN VEGETATION INDEX
DO YOU WANT TO CONTINUE? (Y/N)
READ(5,'(A1))DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'y')THEN
   CONTINUE
ELSE
   GOTO 310
ENDIF

THIS PROGRAM SUBTRACTS OF THE DATA IN MSS BAND 5 FROM THE VALUE OF 
2 TIMES THE MSS BAND 7 VALUES
WRITTEN BY BRIAN L. SOLIDAY
UNO RSAL

YOU HAVE SELECTED THE ASHBURN VEGETATION INDEX
DO YOU WANT TO CONTINUE? (Y/N)
READ(5,'(A1))DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'y')THEN
   CONTINUE
ELSE
   GOTO 310
ENDIF

PROGRAM ASHBURN

THIS PROGRAM SUBTRACTS OF THE DATA IN MSS BAND 5 FROM THE VALUE OF 
2 TIMES THE MSS BAND 7 VALUES
WRITTEN BY BRIAN L. SOLIDAY
UNO RSAL

YOU HAVE SELECTED THE ASHBURN VEGETATION INDEX
DO YOU WANT TO CONTINUE? (Y/N)
READ(5,'(A1))DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'y')THEN
   CONTINUE
ELSE
   GOTO 310
ENDIF

OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT,RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT,RECL=128)
C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN2=ILUN(12)
ICHAN4=ILUN(14)
PROGRAM NORMAL

BYTE IBUFF1(5120), IBUFF2(5120), IBUFF3(5120), IBUFF4(5120), IBUFF5(5120)
CHARACTER*1 DEC, IND
INTEGER*2 IMIN, IMAX
C
WRITE(7,'')
PROGRAM NORMALIZED

THIS PROGRAM PERFORMS A NORMALIZED DIFFERENCE INDEX ON THE DIGITAL DATA FROM THE SELECTED MSS BANDS.

WRITTEN BY BRIAN L. SOLIDAY.

YOU HAVE SELECTED THE NORMALIZED VEGETATION INDEX.

DO YOU WANT TO CONTINUE?(Y/N)

C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN2=ILUN(12)
ICHAN3=ILUN(13)
ICHAN4=ILUN(14)

C

WRITE(7,*) 'WHAT NORMALIZED INDEX DO YOU WANT TO PERFORM?'
WRITE(7,*) '1 = ND6 (MSS6 - MSS5/ MSS6 + MSS5)'
WRITE(7,*) '2 = ND7 (MSS7 - MSS5/ MSS7 + MSS5)'
READ(5,'(A1)')IND
IF(IND.LT.'1'.OR.IND.GT.'2')THEN
  WRITE(7,*) 'YOU HAVE MADE AN INVALID CHOICE'
  WRITE(7,*) 'PLEASE CHOOSE AGAIN'
  READ(5,'(A1)')IND
ELSE
  CONTINUE
ENDIF

CALL MPIOPS
IMIN=10000
IMAX=-10000
WRITE(7,*) 'PERFORMING INITIAL CALCULATIONS'

DO 100 L=0,639,10
  LL=L
  ISTAT=IREADW(2560,IBUFF1,LL,ICHAN2)
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN3)
  ISTAT=IREADW(2560,IBUFF3,LL,ICHAN4)
  DO 50 J=1,512
    I=IBUFF1(J).AND.377
    O=I
    IF(IND.EQ.'1')O=1
    IF(IND.EQ.'2')THEN
      I=IBUFF2(J).AND.377
    ELSEIF(IND.EQ.'1')THEN 35
      I=IBUFF3(J).AND.377
    ELSE
      CONTINUE
    ENDIF
    45 P=I
    INTGR=(O+P)
    IF(INTGR.LT.1)INTGR=1
    IBUFF4(J)=INTGR
  ENDIF

28 DO 100 L=0,639,10
C

```c
INTGR=INT((O-P)/INTGR)
IBUFF5(J)=INTGR
IF(INTGR.LT.IMIN)IMIN=IBUFF5(J)
IF(INTGR.GT.IMAX)IMAX=IBUFF5(J)
CONTINUE
CALL TDOUT(1,IBUFF5,L,10)
100 CONTINUE
C
WRITE(7,*)'IMIN=',IMIN
WRITE(7,*)'IMAX=',IMAX
RANGE=IMAX-IMIN
WRITE(7,*)'RANGE=',RANGE
WRITE(7,*)'DO YOU WANT TO CONTRAST STRETCH THIS IMAGE?(Y/N)'
READ(5,'(A 1 )')DEC
IF(DEC.EQ.,Y.OR.DEC.EQ.,y')THEN
  CONTINUE
ELSE
    GOTO 310
ENDIF
WRITE(7,*)'PERFORMING THE CONTRAST STRETCH'
C
125 DO 200 L=0,639,10
   LL=L
   ISTAT=IREADW(2560,IBUFF1,LL,ICHAN2)
   ISTAT=IREADW(2560,IBUFF2,LL,ICHAN3)
   ISTAT=IREADW(2560,IBUFF3,LL,ICHAN4)
200 DO 150 J=1,5120
   I=IBUFF1(J).AND.377
   O=I
   IF(O.LT.1)O=1
   IF(IND.EQ.,2)THEN
     I=IBUFF3(J).AND.377
     ELSEIF(IND.EQ.,1)THEN
     I=IBUFF2(J).AND.377
     ELSE
     CONTINUE
   ENDIF
   P=I
   INTGR=(O+P)
   IF(INTGR.LT.I)INTGR=I
   IBUFF5(J)=INT((O-P)/INTGR)
   INTGR=INT(255*((IBUFF5(J)-IMIN)/RANGE)+.5)
   IBUFF1(J)=INTGR
   IF(INTGR.GE.255)IBUFF1(J)=255
CONTINUE
CALL TDOUT(1,IBUFF1,L,10)
200 CONTINUE
310 CALL EXIT
325 END
```

**PROGRAM TRANSF**

```
BYTE IBUFF1(5120),IBUFF2(5120),IBUFF3(5120),IBUFF4(5120), IBUFF5(5120)
CHARACTER*1 DEC,IND
INTEGER*2 IMIN,IMAX C
WRITE(7,*)
WRITE(7,*) PROGRAM TRANSFORMED
WRITE(7,*) THIS PROGRAM PERFORMS A
WRITE(7,*) TRANSFORMED VEGETATION INDEX ON
WRITE(7,*) THE SELECTED MSS BANDS
```
WRITE(7,*)' YOU HAVE SELECTED THE TRANSFORMED VEGETATION INDEX  
WRITE(7,*)' DO YOU WANT TO CONTINUE?(Y/N) 
READ(5,'(A1)')DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'Y')THEN
  CONTINUE 
ELSE
  GOTO 310 
ENDIF
C
OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)
C
OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)
C
WRITE(7,*)' WHICH TRANSFORMED VEGETATION INDEX DO YOU WANT TO PERFORM?' 
WRITE(7,*)' 1 - TVI6 
WRITE(7,*)' 2 - TVI7 
READ (5,'(A 1 )')IND
IF(IND.NE.1.AND.IND.NE.2)THEN
  WRITE(7,*)' YOU HAVE MADE AN INVALID CHOICE 
  WRITE(7,*)' PLEASE CHOOSE AGAIN 
  READ(5,'(A1)')IND
ELSE
  CONTINUE 
ENDIF
C
CALL MPIOPS 
WRITE(7,*)' PERFORMING INITIAL CALCULATIONS' 
WRITE(7,*)' IMIN=10000 
WRITE(7,*)' IMAX=-10000 
DO 100 L=-0,639,10 
  ISTAT=IREADW(2560,IBUFF1,LL,ICHAN2) 
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN3) 
  ISTAT=IREADW(2560,IBUFF3,LL,ICHAN4)
  DO 50 J=1,5120 
    I=IBUFF1(J).AND.*377 
    O=I 
    IF(IND.EQ.2)THEN 
      I=IBUFF3(J).AND.*377 
    ELSE IF(IND.EQ.1)THEN 
      I=IBUFF2(J).AND.*377 
    ELSE 
      GOTO 310 
    ENDIF 
    P=I 
    IF(P.LT.1.AND.P.LT.1)P=1 
    Q=((P-O)/(P+O))+.5 
    R=ABS(Q) 
    IF(R.LT.1)R=1 
    S=(Q/R) 
    T=SQR(T(R)) 
    IF(T.LT.1)T=1 
    INTGR=INT(S*T) 
    IBUFF4(J)=INTGR 
    IF(IBUFF4(J).LT.IMIN)IMIN=IBUFF4(J) 
    IF(IBUFF4(J).GT.IMAX)IMAX=IBUFF4(J) 
  CONTINUE 

CALL TDOUT(1,IBUFF4,L,10)
CONTINUE
WRITE(7,*)'IMAX=',IMAX
WRITE(7,*)'IMIN=',IMIN C
RANGE=IMAX-IMIN
WRITE(7,*)'RANGE=',RANGE
WRITE(7,*)'DO YOU WANT TO CONTRAST STRETCH THIS IMAGE?'
READ(5,*)DEC
IF(DEC.EQ.,Y,.OR.DEC.EQ.,y')THEN
    CONTINUE
    ELSE
        GOTO 310
ENDIF
WRITE(7,*)'  *
WRITE(7,*)'PERFORMING THE CONTRAST STRETCH'
DO 200 L=0,639,10
    LL=L
    ISTAT=IREADW(2560,IBUFF1,LL,ICHAN2)
    ISTAT=IREADW(2560,IBUFF2,LL,ICHAN3)
    ISTAT=IREADW(2560,IBUFF3,LL,ICHAN4)
130 DO 150 J=1,5120
    L=IBUFF1(J).AND.377
    O=L
    IF(IND.EQ.,2)THEN
        L=IBUFF3(J).AND.377
    ELSEIF(IND.EQ.,1)THEN
        L=IBUFF2(J).AND.377
    ELSE
        GOTO 310
    ENDIF
140 P=L
    IF(O.LT.1 .AND.P.LT.1)P=1
    Q=((P-O)/(P+O))+.5
    R=ABS(Q)
    IF(R.LT.1)R=1
    S=R/T
    T=SORT(R)
    IF(T.LT.1)T=1
    INTGR=INT(S*T)
    IBUFF4(J)=INTGR
    INTGR=INT(255*((IBUFF4(J)-IMIN)/RANGE)+.5)
    IBUFF5(J)=INTGR
    IF(INTGR.GE.255)IBUFF5(J)=255
150 CONTINUE
CALL TDOUT(1,IBUFF5,L,10)
200 CONTINUE
310 CALL EXIT
325 END

PROGRAM TASSLE
C
BYTE IBUFF1(5120),IBUFF2(5120),IBUFF3(5120),IBUFF4(5120),IBUFF5(5120)
CHARACTER*1 DEC,IND
INTEGER*2 IMIN,IMAX
C
WRITE(7,*)'PROGRAM TASSLE'
WRITE(7,*)'THIS PROGRAM PERFORMS THE SELECTED TASSLED CAP TRANSFORMATION OF THE FOUR MSS BANDS'
WRITE(7,*)'WRITTEN BY BRIAN L. SOLIDAY'
WRITE(7,*) YOU HAVE SELECTED THE TASSLED CAP TRANSFORMATION SERIES OF VEGETATION INDICES.
WRITE(7,*) DO YOU WANT TO CONTINUE?(Y/N)
READ(5,'(A1)') DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'y') THEN CONTINUE
ELSE GOTO 310
ENDIF
C
OPEN(UNIT=11,FILE='P1',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)
C
... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN1=ILUN(11)
ICHAN2=ILUN(12)
ICHAN3=ILUN(13)
ICHAN4=ILUN(14)
C
WRITE(7,*) WHICH TASSLED CAP TRANSFORMATION DO YOU WANT TO PERFORM?
WRITE(7,*)
WRITE(7,*) 1 = SOIL BRIGHTNESS INDEX (SBI)
WRITE(7,*) 2 = GREEN VEGETATION INDEX (GVI)
WRITE(7,*) 3 = YELLOW STUFF INDEX (YVI)
WRITE(7,*) 4 = NON-SUCH INDEX (NSI)
C
READ (5,'(A1)') IND
IF (IND.LT.'1'.OR.IND.GT.'4') THEN
WRITE(5,*) YOU HAVE MADE AN INVALID CHOICE
WRITE(5,*) PLEASE CHOOSE AGAIN
WRITE(5,*)
READ(5,'(A1)') IND
ELSE CONTINUE
ENDIF
C
IMIN=10000
IMAX=-10000
CALL MPIONS
WRITE(7,*) PERFORMING INITIAL CALCULATIONS
WRITE(7,*)
DO 100 L=0,639,10
LL=L
ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
DO 75 J=1,5120
O=IBUFF1(J).AND.377
P=IBUFF2(J).AND.377
Q=IBUFF3(J).AND.377
R=IBUFF4(J).AND.377
IF (IND.EQ.'1') THEN
INTGR=INT((.332# O)+(.632*P)+(.675*Q)+(.262*R))
ELSE IF (IND.EQ.'2') THEN
INTGR=INT((-.283# O)-(1.660*P)+(1.577*Q)-(1.388*R))
ELSE IF (IND.EQ.'3') THEN
INTGR=INT((1.899# O)-(1.428*P)-(1.407*Q)-(1.301*R))
ELSE IF (IND.EQ.'4') THEN
INTGR=INT((.016# O)-(1.131*P)+(1.452*Q)-(1.882*R))
ELSE
ENDIF
END
GOTO 310
ENDIF
IBUFF5(J)=INTGR
IF(INTGR.LT.1)IBUFF5(J)=1
IF(INTGR.LT.IMIN)IMIN=IBUFF5(J)
IF(INTGR.GT.IMAX)IMAX=IBUFF5(J)
CONTINUE
CALL TDOUT(1,IBUFF5,L,10)
CONTINUE
WRITE(7,*)'IMAX=',IMAX
WRITE(7,*)'IMIN=',IMIN
WRITE(7,*)'RANGE=',RANGE
WRITE(7,*)'
WRITE(7,*)'DO YOU WANT TO CONTRAST STRETCH THE OUTPUT OF THIS IMAGE?'
READ(5,'(A1)')DEC
IF(DEC.EQ.'Y' OR DEC.EQ.'y')THEN
    CONTINUE
ELSE
    GOTO 310
ENDIF
WRITE(7,*)'
WRITE(7,*)'NOW PERFORMING THE CONTRAST STRETCH '
DO 200 L=0,639,10
    LL=L
    ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
    ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
    ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
    ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
    DO 175 J=1,5120
        O=IBUFF1(J).AND.377
        P=IBUFF2(J).AND.377
        Q=IBUFF3(J).AND.377
        R=IBUFF4(J).AND.377
        IF(IND.EQ.1)THEN
            INTGR=INT(332*O)+.632*P)+.675*Q)+.262*R
        ELSEIF(IND.EQ.2)THEN
            INTGR=INT(-.283*O)-.660*P)+.577*Q)+.388*R
        ELSEIF(IND.EQ.3)THEN
            INTGR=INT(-.899*O)+.428*P)+.076*Q)-.041*R
        ELSEIF(IND.EQ.4)THEN
            INTGR=INT(-.016*O)+.131*P)-.452*Q)-.882*R
        ELSE
            GOTO 310
        ENDIF
        IBUFF5(J)=INTGR
        IF(INTGR.LT.1)IBUFF5(J)=1
        INTGR=IBUFF5(J)
        IF(IBUFF4(J).GE.255)IBUFF4(J)=255
    175 CONTINUE
    CALL TDOUT(1,IBUFF4,L,10)
200 CONTINUE
310 CALL EXIT
325 END

PROGRAM VEGPCA
BYTE IBUFF(512),IBUFF1(5120),IBUFF2(5120),IBUFF3(5120),IBUFF4(5120),IBUFF5(5120)
CHARACTER*1 DEC,IND
INTEGER*2 IMIN,IMAX
WRITE(7,*)
WRITE(7,*) 'PROGRAM VEGPCA
WRITE(7,*) 'THIS PROGRAM PERFORMS A PRINCIPAL
WRITE(7,*) 'COMPONENTS ANALYSIS OF THE FOUR
WRITE(7,*) 'MSS BANDS
WRITE(7,*) 'WRITTEN BY BRIAN L. SOLIDAY
WRITE(7,*) 'UNO RSAL
WRITE(7,*)
C
WRITE(7,*) 'YOU HAVE SELECTED THE PRINCIPAL COMPONENTS ANALYSIS
WRITE(7,*) 'SERIES OF VEGETATION INDICES
WRITE(7,*) 'DO YOU WANT TO CONTINUE?(Y/N)
READ(5,'(A1)')DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'Y')THEN
  CONTINUE
ELSE
  GOTO 310
ENDIF
C
OPEN(UNIT=11,FILE='P1',STATUS='OLD',ACCESS='DIRECT,RECL=128)
OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT,RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT,RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT,RECL=128)
C
C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN1=ILUN(11)
ICHAN2=ILUN(12)
ICHAN3=ILUN(13)
ICHAN4=ILUN(14)
C
WRITE(7,*) 'WHICH PRINCIPAL COMPONENTS TRANSFORMATION DO YOU
WRITE(7,*) 'WANT TO PERFORM?
WRITE(7,*) '1 = SOIL BRIGHTNESS INDEX (MSBI)
WRITE(7,*) '2 = GREEN VEGETATION INDEX (MGVI)
WRITE(7,*) '3 = YELLOW STUFF INDEX (MYVI)
WRITE(7,*) '4 = NON-SUCH INDEX (MNSI)
READ (5,'(A1)')IND
IF(IND.LT.'1'.OR.IND.GT.'4')THEN
  WRITE(7,*) 'YOU HAVE MADE AN INVALID CHOICE!!
  PLEASE CHOOSE AGAIN
  READ(5,'(A1)')IND
ELSE
  CONTINUE
ENDIF
C
WRITE(7,*) 'PERFORMING INITIAL CALCULATIONS'
CALL MPIOPS
IMIN=10000
IMAX=10000
25 DO 100 L=0,639,10
  LL=L
  ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
  ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
  ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
  DO 75 J=1,5120
    O=IBUFF1(J).AND.377
    P=IBUFF2(J).AND.377
    Q=IBUFF3(J).AND.377
    R=IBUFF4(J).AND.377
    IF(IND.EQ.'1')THEN
      INTGR=INT((.406*O)+(.600*P)+(.645*Q)+(.243*R))
    ELSEIF(IND.EQ.'2')THEN
      INTGR=INT((.056*O)+(.400*P)+(.600*Q)+(.243*R))
    ELSEIF(IND.EQ.'3')THEN
      INTGR=INT((.056*O)+(.400*P)+(.600*Q)+(.243*R))
    ELSEIF(IND.EQ.'4')THEN
      INTGR=INT((.056*O)+(.400*P)+(.600*Q)+(.243*R))
    ELSE
      INTGR=INT((.056*O)+(.400*P)+(.600*Q)+(.243*R))
    ENDIF
  END}
`INTGR=INT((-386*O)+.530*P)+.535*Q)+.532*R))
ELSEIF(IND.EQ.'3')THEN
  INTGR=INT((.723*O)+.597*P)+.206*Q)-.0278*R) ELSEIF(IND.EQ.'4')THEN
  INTGR=INT((.404*O)+.309*P)-.505*Q)+.762*R)) ELSE
  GOTO 310 ENDIF
IBUFF5(J)=INTGR IF(IBUFF5(J).LT.1)IBUFF5(J)=1 IF(INTGR.LT.IMIN)IMIN=IBUFF5(J) IF(INTGR.GT.IMAX)IMAX=IBUFF5(J)
CONTINUE CALL TDOUT(1,IBUFF5,L,10)
CONTINUE WRITE(7,*)IMIN=',IMIN WRITE(7,*)'IMAX=',IMAX WRITE(7,*)'RANGE=',RANGE WRITE(7,*)'DO YOU WANT TO CONTRAST STRETCH THIS IMAGE?
READ(5,'(A1)')DEC IF(DEC.EQ.'Y')THEN CONTINUE ELSE GOTO 310
do 200 L=0,639,10
  LL=L
  ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
  ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
  ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
do 175 J=1,5120
  O=IBUFF1(J).AND.377
  P=IBUFF2(J).AND.377
  Q=IBUFF3(J).AND.377
  R=IBUFF4(J).AND.377
  IF(IND.EQ.'1')THEN
    INTGR=((.406*O)+.600*P)+.645*Q)+.243*R)) ELSEIF(IND.EQ.'2')THEN
    INTGR=INT((-386*O)+.530*P)+.535*Q)+.532*R)) ELSEIF(IND.EQ.'3')THEN
    INTGR=INT((.723*O)+.597*P)+.206*Q)-.0278*R)) ELSEIF(IND.EQ.'4')THEN
    INTGR=INT((.404*O)+.309*P)-.505*Q)+.762*R)) ELSE
    GOTO 310 ENDIF
IBUFF5(J)=INTGR INTGR=INT(255*((IBUFF5(J)-IMIN)/RANGE)+.5)
IBUFF4(J)=INTGR IF(INTGR.GE.255)IBUFF4(J)=255
CONTINUE CALL TDOUT(1,IBUFF4,L,10)
do 200 L=0,639,10
  CALL EXIT
325 END`
PROGRAM BRIGHT

BYTE IBUFF1(5120), IBUFF2(5120), IBUFF3(5120), IBUFF4(5120), IBUFF5(5120)
CHARACTER*1 DEC,IND
INTEGER*2 IMIN,IMAX

WRITE(7,*)
WRITE(7,*) PROGRAM BRIGHT/CON
WRITE(7,*) THIS PROGRAM PERFORMS A TRANSFORMATION OF
WRITE(7,*) THE FOUR MSS BANDS BASED ON SPECTRAL
WRITE(7,*) BRIGHTNESS AND CONTRAST
WRITE(7,*) WRITTEN BY BRIAN L. SOLIDAY
WRITE(7,*) UNOS AIR
WRITE(7,*)
WRITE(7,*)
WRITE(7,*) YOU HAVE SELECTED THE BRIGHTNESS/CONTRAST
WRITE(7,*) TRANSFORMATION SERIES OF VEGETATION INDICES
WRITE(7,*) DO YOU WANT TO CONTINUE?(Y/N)
READ(5,'(A1)')DEC
IF(DEC.EQ.,r.OR.DEC.EQ.'y,')THEN
   CONTINUE
ELSE
   GOTO 310
ENDIF

WRITE(7,*) WHICH BRIGHTNESS/CONTRAST TRANSFORMATION DO
WRITE(7,*) YOU WANT TO PERFORM?
WRITE(7,*)
WRITE(7,*) 1 = SOIL BRIGHTNESS INDEX (SSBI)
WRITE(7,*) 2 = GREEN VEGETATION INDEX (SGVI)
WRITE(7,*) 3 = YELLOW STUFF INDEX (SYVI)
WRITE(7,*) 4 = NON-SUCH INDEX (SNSI)
READ (5, '(A1)') IND
IF(IND.LT.'1,.OR.IND.GT.,4')THEN
   WRITE(7,*) YOU HAVE MADE AN INVALID CHOICE
   WRITE(7,*) PLEASE CHOOSE AGAIN
   READ(5, '(A1)') IND
ELSE
   CONTINUE
ENDIF

OPEN(UNIT=11,FILE='P1',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)

C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN1=ILUN(11)
ICHAN2=ILUN(12)
ICHAN3=ILUN(13)
ICHAN4=ILUN(14)

C CALL MPIOPS
IMIN=10000
IMAX=10000
WRITE(7,*) NOW PERFORMING INITIAL CALCULATIONS'
DO 100 L=0,639,10
   LL=L
   ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
   ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
   ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
   ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
DO 75 J=1,5120
  O=IBUFF1(J).AND."377
  P=IBUFF2(J).AND."377
  Q=IBUFF3(J).AND."377
  R=IBUFF4(J).AND."377
  IF(IND.EQ.'1')THEN
    INTGR=INT((.437*O)+(564*P)+(661*Q)+(233*R))
  ELSEIF(IND.EQ.'2')THEN
    INTGR=INT((-.437*O)+(564*P)+(661*Q)+(233*R))
  ELSEIF(IND.EQ.'3')THEN
    INTGR=INT((-.437*O)-(564*P)-(661*Q)+(233*R))
  ELSEIF(IND.EQ.'4')THEN
    INTGR=INT((-.437*O)+(564*P)-(661*Q)-(233*R))
  ELSE
    GOTO 310
  ENDIF
  IBUFF5(J)=INTGR
  IF(INTGR.LT.IMIN)IMIN=IBUFF5(J)
  IF(INTGR.GT.IMAX)IMAX=IBUFF5(J)
  CONTINUE
75 CALL TDOUL(1,IBUFF5,L,10)

DO 100 L=0,639,10
  CONTINUE
100 WRITE(7,*),(L.MIN=0,IMIN
  WRITE(7,*),(L.MAX=0,IMAX
  WRITE(7,*),(L.RANGE=0,RANGE
  WRITE(7,*),(L.DO YOU WANT TO CONTRAST STRETCH THE OUTPUT OF THIS IMAGE?
  WRITE(7,*),(L
  READ(5,('A1'))DEC
  IF(DEC.EQ.'Y'.OR.DEC.EQ.'y')THEN
    CONTINUE
  ELSE
    GOTO 310
  ENDIF
END

WRITE(7,*),(L.NOW PERFORMING THE CONTRAST STRETCH'
DO 200 L=0,639,10
  CONTINUE
200 ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
  ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
  ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
  DO 175 J=1,5120
    O=IBUFF1(J).AND."377
    P=IBUFF2(J).AND."377
    Q=IBUFF3(J).AND."377
    R=IBUFF4(J).AND."377
    IF(IND.EQ.'1')THEN
      INTGR=INT((.437*O)+(564*P)+(661*Q)+(233*R))
    ELSEIF(IND.EQ.'2')THEN
      INTGR=INT((-.437*O)+(564*P)+(661*Q)+(233*R))
    ELSEIF(IND.EQ.'3')THEN
      INTGR=INT((-.437*O)-(564*P)-(661*Q)+(233*R))
    ELSEIF(IND.EQ.'4')THEN
      INTGR=INT((-.437*O)+(564*P)-(661*Q)-(233*R))
    ELSE
      GOTO 310
    ENDIF
    IBUFF5(J)=INT(255*((INTGR-IMIN)/RANGE)+.5)
    IF(IBUFF5(J).GE.255)IBUFF5(J)=255
    CONTINUE
200 CALL TDOUL(1,IBUFF5,L,10)
STOP
END
PROGRAM GRABS

BYTE IBUFF(512), IBUFF1(5120), IBUFF2(5120), IBUFF3(5120), IBUFF4(5120), IBUFF5(5120)

CHARACTER*1 DEC
INTEGER*2 IMIN, IMAX

WRITE(7,*)
WRITE(7,*) PROGRAM GRABS
WRITE(7,*) THIS PROGRAM PERFORMS THE GREENNESS
WRITE(7,*) ABOVE BARE SOIL TRANSFORMATION OF THE
WRITE(7,*) FOUR MSS BANDS
WRITE(7,*) WRITTEN BY BRIAN L. SOLIDAY
WRITE(7,*) UNO RSAL
WRITE(7,*) YOU HAVE SELECTED THE GRABS
WRITE(7,*) TRANSFORMATION VEGETATION INDEX
WRITE(7,*)
WRITE(7,*) DO YOU WANT TO CONTINUE?(Y/N)
READ(6,'(A1)') DEC
IF(DEC.EQ.'Y' OR DEC.EQ.'Y') THEN
    CONTINUE
ELSE
    GOTO 310
ENDIF

OPEN(UNIT=11, FILE='P1', STATUS='OLD', ACCESS='DIRECT', RECL=128)
OPEN(UNIT=12, FILE='P2', STATUS='OLD', ACCESS='DIRECT', RECL=128)
OPEN(UNIT=13, FILE='P3', STATUS='OLD', ACCESS='DIRECT', RECL=128)
OPEN(UNIT=14, FILE='P4', STATUS='OLD', ACCESS='DIRECT', RECL=128)

OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN1=ILUN(11)
ICHAN2=ILUN(12)
ICHAN3=ILUN(13)
ICHAN4=ILUN(14)

IMIN=10000
IMAX=-10000
CALL MPIOPS
WRITE(7,*) 'PERFORMING INITIAL CALCULATIONS'
DO 100 L = 0, 639, 10
   LL=L
   ISTAT=IREADW(2560, IBUFF1, LL, ICHAN1)
   ISTAT=IREADW(2560, IBUFF2, LL, ICHAN2)
   ISTAT=IREADW(2560, IBUFF3, LL, ICHAN3)
   ISTAT=IREADW(2560, IBUFF4, LL, ICHAN4)
   DO 75 J = 1, 5120
      O=IBUFF1(J,AND,'377'
      P=IBUFF2(J,AND,'377'
      Q=IBUFF3(J,AND,'377'
      R=IBUFF4(J,AND,'377'
      IBUFF1(J)=INT((.332*O)+(.632*P)+(.675*Q)+(.262*R))
      S=IBUFF1(J)
      IBUFF2(J)=INT((.283*O)+(.660*P)+(.577*Q)+(.388*R))
      T=IBUFF4(J)
      IBUFF3(J)=(S-(.09178*T))+5.58959
      IF(ABS(IBUFF3(J)).LT.IMIN) IMIN=IBUFF3(J)
      IF(ABS(IBUFF3(J)).GT.IMAX) IMAX=IBUFF3(J)
   CONTINUE
   CALL TDOUT(1, IBUFF3, L, 10)
100 CONTINUE

WRITE(7,*) 'IMIN=', IMIN
WRITE(7,*) 'IMAX=', IMAX
WRITE(7,*) RANGE=IMAX-IMIN
WRITE(7,*)

WRITE(7,"'RANGE=",RANGE
WRITE(7,"'.
WRITE(7,"'DO YOU WANT TO CONTRAST STRETCH THIS IMAGE?"
READ(5,'(A1))DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'y')THEN
  CONTINUE
ELSE
  GOTO 310
ENDIF
WRITE(7,"'PERFORMING THE CONTRAST STRETCH'

C
125  DO 200 L=0,639,10
    LL=L
    ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
    ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
    ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
    ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
    DO 175 J=1,5120
      O=IBUFF1(J).AND."377
      P=IBUFF2(J).AND."377
      Q=IBUFF3(J).AND."377
      R=IBUFF4(J).AND."377
      IBUFF1(J)=INT((.332*O)+(.632*P)+(.675*Q)+(.262*R))
      S=IBUFF1(J)
      IBUFF4(J)=INT((-.283*O)+(.660*P)+(.577*Q)+(.388*R))
      T=IBUFF4(J)
      IBUFF3(J)=((S-(.09178*T))+5.58959)
      IBUFF5(J)=INT(255*((IBUFF3(J)-lMlN)/RANGE)+.5)
      IF(IBUFF5(J).GE.255)IBUFF5(J)=255
    CONTINUE
  CALL TDOUT(1,IBUFF5,L,10)
200  CONTINUE
310  CALL EXIT
325  END

PROGRAM GVBS
C
BYTE IBUFF1(5120),IBUFF2(5120),IBUFF3(5120),IBUFF4(5120)
CHARACTER*1 DEC
INTEGER*2 IMIN,IMAX
C
WRITE(7,"'.
WRITE(7,"'PROGRAM GVBS
WRITE(7,"'.
WRITE(7,"'THIS PROGRAM PERFORMS THE GVBS
WRITE(7,"'TRANSFORMATION OF THE FOUR MSS BANDS
WRITE(7,"'BY DIVIDING THE GVI BY THE SBI
WRITE(7,"'WRITTEN BY BRIAN L. SOLIDAY
WRITE(7,"'UNO RSAL
WRITE(7,"'.
C
WRITE(7,"'YOU HAVE SELECTED THE GVBS
WRITE(7,"'TRANSFORMATION VEGETATION INDEX
WRITE(7,"'DO YOU WANT TO CONTINUE?(Y/N)
READ(5,'(A1))DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'y')THEN
  CONTINUE
ELSE
  GOTO 310
ENDIF
C
OPEN(UNIT=11,FILE='P1',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)
C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN1=ILUN(11)
ICHAN2=ILUN(12)
ICHAN3=ILUN(13)
ICHAN4=ILUN(14)

CALL MPIOPS
IMIN=10000
IMAX=-10000
WRITE(7,’*’’PERFORMING INITIAL CALCULATIONS’’)
25          DO 100 L=0,639,10
            LL=L
            ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
            ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
            ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
            ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
            DO 75 J=1,5120
               O=IBUFF1(J).AND.”377
               P=IBUFF2(J).AND.”377
               Q=IBUFF3(J).AND.”377
               R=IBUFF4(J).AND.”377
               IBUFF1(J)=INT((.332*O)+(.632*P)+(.675*Q)+(.262*R))
               S=IBUFF1(J)
               IBUFF4(J)=INT((-.283*O)-(660*P)+(577*Q)+(388*R))
               T=IBUFF4(J)
               IF(T.LT.1)T=1
               IBUFF3(J)=S/T
               IF(IBUFF3(J).LT.IMIN)IMIN=IBUFF3(J)
               IF(IBUFF3(J).GT.IMAX)IMAX=IBUFF3(J)
            CONTINUE
100          CALL TDOUT(1,IBUFF3,L,10)
            CONTINUE

WRITE(7,’*’’IMIN=’,IMIN
WRITE(7,’*’’IMAX=’,IMAX
WRITE(7,’*’’RANGE=IMAX-IMIN
WRITE(7,’*’’DO YOU WANT TO CONTRAST STRETCH THIS IMAGE?’
READ(5,’(A1)’)DEC
IF(DEC.EQ.’Y’.OR.DEC.EQ.’y’)THEN
   CONTINUE
ELSE
   GOTO 310
ENDIF
WRITE(7,’*’’PERFORMING THE CONTRAST STRETCH’’
125          DO 200 L=0,639,10
            LL=L
            ISTAT=IREADW(2560,IBUFF1,LL,ICHAN1)
            ISTAT=IREADW(2560,IBUFF2,LL,ICHAN2)
            ISTAT=IREADW(2560,IBUFF3,LL,ICHAN3)
            ISTAT=IREADW(2560,IBUFF4,LL,ICHAN4)
            DO 175 J=1,5120
               O=IBUFF1(J).AND.”377
               P=IBUFF2(J).AND.”377
               Q=IBUFF3(J).AND.”377
               R=IBUFF4(J).AND.”377
               IBUFF1(J)=INT((.332*O)+(.632*P)+(.675*Q)+(.262*R))
               S=IBUFF1(J)
               IBUFF4(J)=INT((-.283*O)-(660*P)+(577*Q)+(388*R))
               T=IBUFF4(J)
               IF(T.LT.1)T=1
               IBUFF3(J)=S/T
               IF(IBUFF3(J).LT.IMIN)IMIN=IBUFF3(J)
               IF(IBUFF3(J).GT.IMAX)IMAX=IBUFF3(J)
               IBUFF4(J)=INT(255*((IBUFF3(J)-IMIN)/RANGE)+.5)
               IF(IBUFF4(J).GE.255)IBUFF4(J)=255
            CONTINUE
200          CALL TDOUT(1,IBUFF4,L,10)
PROGRAM PERPEN

BYTE IBUFF1(5120),IBUFF2(5120),IBUFF3(5120),IBUFF4(5120),IBUFF5(5120)
CHARACTER*1 DEC,IND
INTEGER*2 IMIN,IMAX
CALL MPIOPS

WRITE(7,*) PROGRAM PERPENDICULAR
WRITE(7,*) THIS PROGRAM DETERMINES THE PERPENDICULAR
WRITE(7,*) VEGETATION INDEX OF THE SELECTED MSS BANDS
WRITE(7,*) WRITTEN BY BRIAN L. SOLIDAY
WRITE(7,*) UNO RSAL

WRITE(7,*) YOU HAVE SELECTED THE PERPENDICULAR VEGETATION INDEX'
WRITE(7,*) DO YOU WANT TO CONTINUE?(Y/N)
READ(5,'(A1)')DEC
IF(DEC.EQ.'Y'.OR.DEC.EQ.'y')THEN
  CONTINUE
ELSE
  GOTO 310
ENDIF

OPEN(UNIT=12,FILE='P2',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=13,FILE='P3',STATUS='OLD',ACCESS='DIRECT',RECL=128)
OPEN(UNIT=14,FILE='P4',STATUS='OLD',ACCESS='DIRECT',RECL=128)

C... OBTAIN THE RT-11 SYSTEM CHANNEL NUMBERS
ICHAN2=LUN(12)
ICHAN3=LUN(13)
ICHAN4=LUN(14)

WRITE(7,*) WHAT PERPENDICULAR INDEX DO YOU WANT TO PERFORM? '
WRITE(7,*)' 1 = PVI6 '
WRITE(7,*)' 2 = PVI7 '
READ(5,'(A1)')IND
IF(IND.NE.'1'.AND.IND.NE.'2')THEN
  WRITE(7,*) ' YOU HAVE MADE AN INVALID CHOICE '
  WRITE(7,*) ' PLEASE CHOOSE AGAIN '
  WRITE(7,*) ' '
  READ(5,'(A1)')IND
ELSE
  CONTINUE
ENDIF

IMIN=10000
IMAX=10000
WRITE(7,*)'PERFORMING INITIAL CALCULATIONS'

DO 100 L=0,639,10
  ISTAT=IREADW(2560,IBUFF1,LL,ICHAN2)
  ISTAT=IREADW(2560,IBUFF2,LL,ICHAN3)
  ISTAT=IREADW(2560,IBUFF3,LL,ICHAN4)
  DO 50 J=1,5120
    I=IBUFF1(J).AND.'377
    O=I
    IF(IND.EQ.'1')THEN
      I=IBUFF2(J).AND.'377
    ENDIF
  END}
P = I
Q = (1.091*P)
R = (O-5.49)
S = (Q-R)
T = ((1.091*1.091)+(1*1))
Q = SQRT(T)
INTGR = INT(S/Q)
ELSE IF (IND.EQ.'2') THEN
I = IBUFF3(J).AND.'377'
P = I
Q = (2.4*P)
R = (O-.01)
S = (Q-R)
T = ((2.4*2.4)+(1*1))
Q = SQRT(T)
INTGR = INT(S/Q)
ELSE
GOTO 310
ENDIF
IF (INTGR.LT.IMIN) IMIN = INTGR
IF (IMIN.LT.1) IMIN = 1
IF (INTGR.GT.IMAX) IMAX = INTGR
IBUFF4(J) = INTGR
CONTINUE
CALL TOUT(1,IBUFF4,L,10)
CONTINUE
C
WRITE(7,'*') IMIN='.',IMIN
WRITE(7,'*') IMAX='.',IMAX
RANGE = IMAX-IMIN
WRITE(7,'*') RANGE='.',RANGE
WRITE(7,')') 'DO YOU WANT TO CONTRAST STRETCH THIS IMAGE?'
READ(5,'(A1)') DEC
IF (DEC.EQ.'Y'.OR.DEC.EQ.'y') THEN
CONTINUE
ELSE
GOTO 310
ENDIF
READ(5,'(A1)') DEC
IF (DEC.EQ.'Y'.OR.DEC.EQ.'y') THEN
CONTINUE
ELSE
GOTO 310
ENDIF
WRITE(7,'*') 'PERFORMING THE CONTRAST STRETCH'
C
DO 200 L = 0, 639, 10
LL = L
ISTAT = IREADW(2560,IBUFF1,LL,ICHAN2)
ISTAT = IREADW(2560,IBUFF2,LL,ICHAN3)
ISTAT = IREADW(2560,IBUFF3,LL,ICHAN4)
DO 150 J = 1, 5120
L = IBUFF1(J).AND.'377'
O = I
IF (IND.EQ.'1') THEN
I = IBUFF2(J).AND.'377'
P = I
Q = (1.091*P)
R = (O-5.49)
S = (Q-R)
T = ((1.091*1.091)+(1*1))
Q = SQRT(T)
INTGR = INT(S/Q)
ELSE IF (IND.EQ.'2') THEN
I = IBUFF3(J).AND.'377'
P = I
Q = (2.4*P)
R = (O-.01)
S = (Q-R)
T = ((2.4*2.4)+(1*1))
Q = SQRT(T)
INTGR = INT(S/Q)
ELSE
I = ((2.4*2.4)+(1*1))
Q = SQRT(T)
IF (INTGR.LT.1) IBUFF4(J)=1
IF (INTGR.GE.1) IBUFF4(J)=INTGR
IBUFF5(J)=INT(255*((IBUFF4(J)-IMIN)/RANGE)+.5)
IF (IBUFF5(J).GE.255) IBUFF5(J)=255
CONTINUE
CALL TDOUT(1,IBUFF5,L,10)
CONTINUE
CALL EXIT
END
### APPENDIX D

**CORRELATION MATRICES**

AND

**UNIVARIATE STATISTICAL ANALYSES**

---

**Table D.1**

Spearman Correlation Matrix for Study Site A

<table>
<thead>
<tr>
<th></th>
<th>RV65</th>
<th>RV75</th>
<th>AVI</th>
<th>DVI</th>
<th>PVI6</th>
<th>PVI7</th>
<th>SBI</th>
<th>GVI</th>
<th>MSBI</th>
<th>MGVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV65</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV75</td>
<td>0.849</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVI</td>
<td>0.881</td>
<td>0.888</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVI</td>
<td>0.876</td>
<td>0.885</td>
<td>0.999</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI6</td>
<td>0.913</td>
<td>0.893</td>
<td>0.965</td>
<td>0.964</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI7</td>
<td>0.878</td>
<td>0.886</td>
<td>0.997</td>
<td>0.998</td>
<td>0.963</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBI</td>
<td>0.766</td>
<td>0.781</td>
<td>0.928</td>
<td>0.932</td>
<td>0.925</td>
<td>0.932</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GVI</td>
<td>0.913</td>
<td>0.898</td>
<td>0.985</td>
<td>0.984</td>
<td>0.922</td>
<td>0.983</td>
<td>0.926</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSBI</td>
<td>0.757</td>
<td>0.773</td>
<td>0.921</td>
<td>0.925</td>
<td>0.920</td>
<td>0.925</td>
<td>0.997</td>
<td>0.919</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>MGVI</td>
<td>0.900</td>
<td>0.894</td>
<td>0.988</td>
<td>0.987</td>
<td>0.989</td>
<td>0.986</td>
<td>0.932</td>
<td>0.997</td>
<td>0.925</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>RV65</td>
<td>RV75</td>
<td>AVI</td>
<td>DVI</td>
<td>PVI6</td>
<td>PVI7</td>
<td>SBI</td>
<td>GVI</td>
<td>MSBI</td>
<td>MGVI</td>
</tr>
<tr>
<td>-----</td>
<td>------</td>
<td>------</td>
<td>-------</td>
<td>-------</td>
<td>------</td>
<td>------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>RV65</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV75</td>
<td>.805</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVI</td>
<td>.778</td>
<td>.792</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVI</td>
<td>.773</td>
<td>.787</td>
<td>.999</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI6</td>
<td>.774</td>
<td>.759</td>
<td>.968</td>
<td>.969</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI7</td>
<td>.761</td>
<td>.784</td>
<td>.997</td>
<td>.998</td>
<td>.968</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBI</td>
<td>.569</td>
<td>.611</td>
<td>.891</td>
<td>.896</td>
<td>.925</td>
<td>.900</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GVI</td>
<td>.795</td>
<td>.788</td>
<td>.982</td>
<td>.928</td>
<td>.992</td>
<td>.980</td>
<td>.914</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSBI</td>
<td>.554</td>
<td>.601</td>
<td>.882</td>
<td>.887</td>
<td>.919</td>
<td>.892</td>
<td>.993</td>
<td>.905</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>MGVI</td>
<td>.773</td>
<td>.781</td>
<td>.985</td>
<td>.985</td>
<td>.992</td>
<td>.984</td>
<td>.923</td>
<td>.997</td>
<td>.916</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Tabel D.2
Spearman Correlation Matrix for Study Site B
<table>
<thead>
<tr>
<th></th>
<th>RV65</th>
<th>RV75</th>
<th>AVI</th>
<th>DVI</th>
<th>PVI6</th>
<th>PVI7</th>
<th>SBI</th>
<th>GVI</th>
<th>MSBI</th>
<th>MGVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV65</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV75</td>
<td>.897</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVI</td>
<td>.890</td>
<td>.838</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVI</td>
<td>.886</td>
<td>.835</td>
<td>.999</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI6</td>
<td>.907</td>
<td>.840</td>
<td>.971</td>
<td>.971</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVI7</td>
<td>.886</td>
<td>.841</td>
<td>.997</td>
<td>.996</td>
<td>.965</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBI</td>
<td>.843</td>
<td>.807</td>
<td>.955</td>
<td>.959</td>
<td>.966</td>
<td>.954</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GVI</td>
<td>.909</td>
<td>.844</td>
<td>.981</td>
<td>.981</td>
<td>.991</td>
<td>.977</td>
<td>.962</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSBI</td>
<td>.847</td>
<td>.811</td>
<td>.958</td>
<td>.962</td>
<td>.967</td>
<td>.957</td>
<td>.997</td>
<td>.963</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>MGVI</td>
<td>.894</td>
<td>.835</td>
<td>.986</td>
<td>.986</td>
<td>.984</td>
<td>.981</td>
<td>.963</td>
<td>.992</td>
<td>.965</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table D.3
Spearman Correlation Matrix for Study Site C
<table>
<thead>
<tr>
<th></th>
<th>MAXIMUM VALUE</th>
<th>MINIMUM VALUE</th>
<th>RANGE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV65</td>
<td>255</td>
<td>43</td>
<td>212</td>
<td>160.44</td>
<td>45.59</td>
</tr>
<tr>
<td>RV75</td>
<td>255</td>
<td>0</td>
<td>255</td>
<td>149.25</td>
<td>51.99</td>
</tr>
<tr>
<td>AVI</td>
<td>240</td>
<td>73</td>
<td>167</td>
<td>179.23</td>
<td>42.67</td>
</tr>
<tr>
<td>DVI</td>
<td>245</td>
<td>135</td>
<td>110</td>
<td>203.22</td>
<td>28.75</td>
</tr>
<tr>
<td>PVI6</td>
<td>246</td>
<td>107</td>
<td>139</td>
<td>191.74</td>
<td>33.17</td>
</tr>
<tr>
<td>PVI7</td>
<td>246</td>
<td>134</td>
<td>112</td>
<td>203.36</td>
<td>29.52</td>
</tr>
<tr>
<td>SBI</td>
<td>168</td>
<td>109</td>
<td>59</td>
<td>144.17</td>
<td>15.41</td>
</tr>
<tr>
<td>GVI</td>
<td>248</td>
<td>133</td>
<td>115</td>
<td>208.45</td>
<td>28.14</td>
</tr>
<tr>
<td>MSBI</td>
<td>164</td>
<td>107</td>
<td>57</td>
<td>141.62</td>
<td>14.87</td>
</tr>
<tr>
<td>MGVI</td>
<td>245</td>
<td>133</td>
<td>112</td>
<td>204.66</td>
<td>29.12</td>
</tr>
</tbody>
</table>

Table D.4
Univariate Analysis of Study Site A
<table>
<thead>
<tr>
<th></th>
<th>MAXIMUM VALUE</th>
<th>MINIMUM VALUE</th>
<th>RANGE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV65</td>
<td>213</td>
<td>85</td>
<td>128</td>
<td>143.2</td>
<td>35.88</td>
</tr>
<tr>
<td>RV75</td>
<td>255</td>
<td>64</td>
<td>191</td>
<td>128.5</td>
<td>41.76</td>
</tr>
<tr>
<td>AVI</td>
<td>240</td>
<td>67</td>
<td>173</td>
<td>149.43</td>
<td>38.67</td>
</tr>
<tr>
<td>DVI</td>
<td>245</td>
<td>125</td>
<td>120</td>
<td>182.83</td>
<td>26.68</td>
</tr>
<tr>
<td>PVI6</td>
<td>232</td>
<td>93</td>
<td>139</td>
<td>172.15</td>
<td>31.85</td>
</tr>
<tr>
<td>PVI7</td>
<td>246</td>
<td>121</td>
<td>125</td>
<td>182.34</td>
<td>27.54</td>
</tr>
<tr>
<td>SBI</td>
<td>161</td>
<td>68</td>
<td>93</td>
<td>129.49</td>
<td>21.74</td>
</tr>
<tr>
<td>GVI</td>
<td>245</td>
<td>129</td>
<td>116</td>
<td>191.42</td>
<td>25.74</td>
</tr>
<tr>
<td>MSBI</td>
<td>157</td>
<td>69</td>
<td>88</td>
<td>127.49</td>
<td>21.25</td>
</tr>
<tr>
<td>MGVI</td>
<td>241</td>
<td>122</td>
<td>119</td>
<td>186.40</td>
<td>27.45</td>
</tr>
</tbody>
</table>

Table D.5
Univariate Analysis of Study Site B
<table>
<thead>
<tr>
<th></th>
<th>MAXIMUM VALUE</th>
<th>MINIMUM VALUE</th>
<th>RANGE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV65</td>
<td>255</td>
<td>43</td>
<td>212</td>
<td>120.54</td>
<td>51.29</td>
</tr>
<tr>
<td>RV75</td>
<td>255</td>
<td>64</td>
<td>191</td>
<td>104.22</td>
<td>52.34</td>
</tr>
<tr>
<td>AVI</td>
<td>234</td>
<td>21</td>
<td>213</td>
<td>101.83</td>
<td>72.20</td>
</tr>
<tr>
<td>DVI</td>
<td>239</td>
<td>92</td>
<td>147</td>
<td>149.04</td>
<td>50.23</td>
</tr>
<tr>
<td>PVI6</td>
<td>241</td>
<td>65</td>
<td>176</td>
<td>130.46</td>
<td>59.54</td>
</tr>
<tr>
<td>PVI7</td>
<td>241</td>
<td>88</td>
<td>153</td>
<td>147.50</td>
<td>51.35</td>
</tr>
<tr>
<td>SBI</td>
<td>163</td>
<td>43</td>
<td>120</td>
<td>93.57</td>
<td>44.31</td>
</tr>
<tr>
<td>GVI</td>
<td>248</td>
<td>105</td>
<td>143</td>
<td>158.78</td>
<td>47.9</td>
</tr>
<tr>
<td>MSBI</td>
<td>160</td>
<td>43</td>
<td>117</td>
<td>92.67</td>
<td>43.25</td>
</tr>
<tr>
<td>MGVI</td>
<td>245</td>
<td>92</td>
<td>153</td>
<td>150.58</td>
<td>51.53</td>
</tr>
</tbody>
</table>

Table D.6
Univariate Analysis of Study Site C
<table>
<thead>
<tr>
<th>Site</th>
<th>Maximum Value</th>
<th>Minimum Value</th>
<th>Range</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV65</td>
<td>255</td>
<td>43</td>
<td>212</td>
<td>141.39</td>
<td>47.47</td>
</tr>
<tr>
<td>RV75</td>
<td>255</td>
<td>0</td>
<td>255</td>
<td>127.35</td>
<td>52.15</td>
</tr>
<tr>
<td>AVI</td>
<td>240</td>
<td>21</td>
<td>219</td>
<td>143.63</td>
<td>62.01</td>
</tr>
<tr>
<td>DVI</td>
<td>245</td>
<td>92</td>
<td>153</td>
<td>178.36</td>
<td>42.96</td>
</tr>
<tr>
<td>PVI6</td>
<td>246</td>
<td>65</td>
<td>181</td>
<td>164.78</td>
<td>50.29</td>
</tr>
<tr>
<td>PVI7</td>
<td>246</td>
<td>88</td>
<td>158</td>
<td>177.73</td>
<td>44.10</td>
</tr>
<tr>
<td>SBI</td>
<td>168</td>
<td>43</td>
<td>125</td>
<td>122.39</td>
<td>36.58</td>
</tr>
<tr>
<td>GVI</td>
<td>248</td>
<td>105</td>
<td>143</td>
<td>186.21</td>
<td>40.83</td>
</tr>
<tr>
<td>MSBI</td>
<td>164</td>
<td>43</td>
<td>121</td>
<td>120.59</td>
<td>35.59</td>
</tr>
<tr>
<td>MGVI</td>
<td>245</td>
<td>92</td>
<td>153</td>
<td>180.54</td>
<td>43.77</td>
</tr>
</tbody>
</table>

Table D.7
Composite Univariate Analysis For All study Sites
REFERENCES


Cole, Glen F., (1972), "An Ecological Rationale For The Natural Or Artificial Regulation of Native Ungulates in Parks“, Department of the Interior, Office of Natural Science Studies, National Park Service.


MiIner, C., and R. Elfyn Hughes, (1968), "Methods for the Measurement of the Primary Production of Grassland", Abingdon, Berkshire: Burgess and Son Ltd.


