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An Assessment of Thematic Mapper Satellite Data For Classifying Conifer Types in Northern Utah

Madeline R. Mazurski

Utah State University

AN ASSESSMENT OF THEMATIC MAPPER SATELLITE DATA FOR CLASSIFYING CONIFER TYPES IN NORTHERN UTAH

by

Madeline R. Mazurski

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Madeline R. Mazurski

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ABSTRACT

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Classifying Conifer Types in Northern Utah

by

Madeline R. Mazurski, Master of Landscape Architecture

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Major Professor: Craig Johnson
Department: Landscape Architecture and Environmental Planning

Land-cover identification and mapping are an integral part of natural resource planning and management. Satellite imagery provides a way to obtain land cover information, particularly for large tracts of land such as those administered by federal and state agencies.

This study assesses the usefulness of the Brightness/Greenness Transformation of Landsat Thematic Mapper data for differentiating conifer forest types in northern Utah. Satellite data for the Logan Ranger District of the Wasatch-Cache National Forest were classified into 27 vegetation classes. Of these, nine were determined to be conifer classes and were used in subsequent analyses. Ten sites of each conifer class type were field checked and vegetation and physical site characteristics recorded.

The Brightness/Greenness Transformation was able to distinguish conifer areas from other vegetation types. High-density conifer classes were classified at 94 percent accuracy. Low-density conifer classes were classified correctly 65 percent of the time. The Brightness/Greenness Transformation alone met with limited success in distinguishing between conifer species. Each class showed great variability with respect to major overstory species. Analysis of variance indicated that none of the site factors measured consistently corresponded with the spectrally designated classes. While several factors differed significantly among classes, no factor was significantly different for all class-pair combinations.

Correlation analysis revealed that brightness, greenness, and wetness values related more to environmental values than to conifer species. Brightness was highly correlated with percent of exposed soil on the site. Greenness was highly correlated to the presence of deciduous and herbaceous vegetation. Wetness was highly correlated to total tree and conifer cover values.

Adding slope and aspect data to the Brightness/Greenness Transformation classes with the highest percentages of canopy cover did allow separation of lodgepole pine and Douglas fir. High percentage canopy cover sites on slopes less than 35 percent were classified as lodgepole pine with 89 percent accuracy. On slopes greater than or equal to 35 percent, Douglas fir was found with 79 percent accuracy.

(170 pages)

INTRODUCTION

Background of the Problem

Management of natural resources must be based on the most accurate and current information possible. Land cover identification and mapping, especially of vegetation, are an integral part of natural resource planning and management. For large tracts of land, such as those administered by many federal and state agencies, mapping land cover has historically been a costly, cumbersome, and lengthy process. The use of satellite imagery offers an alternative to these traditional methods. Satellite sensors record the earth's reflected and emitted radiation as characteristic patterns dependent upon land cover materials. Several of the channels of the Landsat Thematic Mapper (TM) sensor are particularly appropriate for discerning vegetative cover types. Numerous data enhancements and transformations have been generated to more accurately obtain vegetation information from the satellite imagery. The Brightness/Greenness Transformation (based on the Tasseled Cap or Kauth-Thomas Transformation, Kauth and Thomas 1976) is one method used to separate vegetation cover types (Jensen 1986). The transformation has been used successfully to discriminate among agricultural crops and is proposed to be useful in discerning other vegetative types as well (Crist and Cicone 1984b).

Statement of the Problem

Presently the Logan District of the Wasatch-Cache National Forest is working on an integrated management plan. The plan will outline future planning and management directions for the forest and will incorporate as much resource information as possible. An essential component of the work is an accurate land cover map, with particular emphasis on the conifer resource. Timber management objectives will be based on conifer forest type information. The data required include identification of conifer types, density of timber, and location and areal extent of each type. The district is searching for an accurate, timely, cost-effective means of determining conifer types and preserving this information in a format that can be analyzed using a Geographic Information System (GIS). TM data have shown good potential in identifying forest cover types (Walsh 1980, Nelson et al. 1984, Spanner et al. 1984, Benson and DeGloria 1985, Horler and Ahern 1986); however, little information exists on the use of TM data for defining conifer forest types in the Intermountain Region. The appropriateness of the Brightness/Greenness Transformation in differentiating conifer species types is also unknown. Additionally, the diverse terrain of Utah offers an opportunity to assess the impact of slope, aspect, and elevation upon TM spectral data and its usefulness for mapping land cover types. Ancillary information, such as slope, aspect, and elevation, is also expected to aid in vegetation classification, particularly when an area is topographically diverse.

Purpose of the Study

The purpose of the study is to assess the use of the Brightness/ Greenness Transformation of TM data in describing conifer cover types in northern Utah. The work also addresses the effects of integrating slope, aspect, and elevational data upon the accuracy of vegetation classification.

LITERATURE REVIEW

Natural resource planning and management involve designating the present and future uses of large tracts of land. These lands are usually administered by state and federal agencies which must respond to complex and sometimes contradictory management directives. These management decisions should ideally be based on accurate, thorough knowledge of the natural resources (Goodenough 1988). Problems occur when this information is not available, when it is composed of various data categories in noncompatible formats, when the quality of the data is highly variable, when the information is expensive to obtain, or when it is difficult to manipulate in a meaningful manner (i.e., when numerous categories of complex information must be synthesized). Conventional information-gathering and recording techniques usually require considerable time and money. Computer technology, particularly through the use of Geographic Information Systems (GIS), is providing the key to acquiring, recording, and manipulating natural resource information (Burrough 1986, Ross 1986, Shumway 1987, Smith and Prisley 1987, Dulaney 1987). A computerized system allows work with large databases and removes many previous limitations. GISs combine and compare different categories of data in order to extract the needed information. Additional information may be tied to data categories and updated and changed when the data manipulations occur. The speed of GIS is an added advantage, particularly for comparing alternative land management proposals and their projected outcomes.

Any system, whether automated or not, is only as good as the quality of data provided to it; the current need is to develop accurate, detailed databases for resource management. In particular, land cover data are important for nearly all land planning and resource management work, as understanding the landscape is basic to any resource decision (Woodcock et al. 1983). In natural resource management, vegetation is often the land cover component of major interest. Land cover information serves as the foundation for all types of resource planning work. For example, timber management, visual assessment, and models for wildlife suitability and watershed analysis are based on land cover information (Thompson et al. 1980, Ford et al. 1983, Lyon 1983, Ross 1986, Cibula and Nyquist 1987, Hendrix and Price 1987, Smith and Prisley 1987, Johnston 1988). Methods are needed to rapidly and accurately identify and classify vegetation into pertinent categories for the various aspects of resource management.

Satellite imagery can be an important source of land cover data; applications of this imagery are just beginning in the land planning and resource management fields. Planners can benefit from the knowledge of what this technology does and how it can be used to provide needed information (Woodcock et al. 1983, van den Brink et al. 1986). The challenge lies in developing and applying methods that extract information pertinent to the field of study and then refining these methods for specific geographical areas.

Satellite sensors have been developed that record wavelengths of electromagnetic energy according to physical and biological characteristics of the earth's surface. Of particular interest are the MultiSpectral Scanner (MSS), Thematic Mapper (TM) and, more recently, SPOT (a French satellite sensor). MSS coverage is for the visible and near-infrared portions of the spectrum at a ground resolution of 56 by

79 meters. The more recent TM sensor adds information in the mid-infrared and thermal portions of the spectrum, while refining the spectral resolution of the sensors in the visible and near-infrared areas. The TM sensor was designed to provide better separation of vegetation classes, particularly for forested areas (Horler and Ahern 1986). In addition, TM data are available at a spatial resolution of 30 by 30 meters. SPOT data are available at an even finer spatial resolution (20 by 20 m. for multispectral data and even 10 by 10 m. for single band panchromatic data) but do not reach the spectral resolution of the TM data.

TM sensors record information for six channels of reflective and one channel of emitted electromagnetic energy. The seven TM spectral bands were chosen to gather specific information about the earth's surface. Various surface materials, such as vegetation, water, rock, soil, and urban features, absorb, reflect, and emit radiation in recognizable and consistent signatures. These signatures can be used to map the occurrence of these materials on large tracts of land to a resolution fine enough for planning and management needs.

TM satellite imagery has the added advantage of recording each site every 16 days, with the information available to users shortly afterward. In addition, these data are in a digital format that is compatible with computer systems. The use of satellite imagery has been shown to be cost effective when compared with traditional land cover mapping methods (Fox et al. 1983, Nelson et al. 1984, Franklin et al. 1986). Such timely, repetitive, and cost-effective coverage at a useful spatial and spectral resolution presents unique opportunities for gathering land cover information.

TM data can be used in a variety of ways. As raw data, all seven bands may be used together or in various combinations. Vegetation indexes have been developed, as have band differences and band ratios. All these techniques serve as ways to bring out the desired information from the recorded data. In addition to the use of raw data, enhancements have been developed to bring out various aspects of the data for more complete interpretation. Processing can remove redundancy due to high interband correlations and extract information that is unique to each band. Some enhancements have been developed to compress the information present in the six reflective bands (thermal data are often treated separately). These special transformations decrease redundancy and the overall amount of data recorded, thus greatly reducing processing time and computer storage space needed. Additionally, enhancements which present the data structure orthogonally (that is, as features independent of each other) can aid in meeting the assumptions of some statistical tests.

Much work with actual and simulated TM data has concentrated on determining optimum band combinations, ratios, differences, transformations, and/or other enhancements for improved differentiation of land surface features. For defining forest classes, several studies have shown a three-band combination, with one band from the visible (Band 1, 2, or 3), one from the near-infrared (Band 4), and one from the mid-infrared (Band 5 or 7), to yield the best results (Nelson et al. 1984, Benson and DeGloria 1985, Horler and Ahern 1986). TM Bands 5 and 7 appear to be most sensitive to forest vegetation density, especially during early successional stages (Horler and Ahern 1986, Lathrop et al.

1987). TM Bands 5, 7, and 1 are sensitive to variations in forest canopy cover (Butera 1986).

Kaufmann and Pfeiffer (1986) compared raw, enhanced, and preprocessed band data and found no significant difference in the amount of information each provided. Of interest was the conclusion that nearly all the information was found in a three-band or three-component combination. In Principal Components Analysis (PCA), a transformation is applied that compresses the multiband sensor data into an uncorrelated data set. The components that describe this new data set are based on its variance properties (Jensen 1986). Horler and Ahern (1986) found that most of the variability in band values could be explained by the first three components in PCA. Studies by Lathrop et al. (1987) support this conclusion by presenting evidence that TM data have a three-dimensional structure with respect to their information content. Anuta et al. (1984) had also proposed a significant dimensionality of between three and four dimensions for TM data. Their studies found that the first three principal components explained 97 percent of the variance within a scene.

The Tasseled Cap Transformation maximizes brightness, greenness, and wetness information while compressing the data set (Kauth and Thomas 1976). The transformation was originally developed for the MSS sensor system but the concept has been found applicable to TM data (Crist and Cicone 1984a). When applied to TM data, it is often referred to as the Brightness/Greenness (BG) Transformation, a transformation structure that captures 95 percent or more of the data variation (Crist and Kauth 1986). The BG Transformation describes the six-band TM data within a three-dimensional space (Figure 1), defined by a plane of soils (the brightness

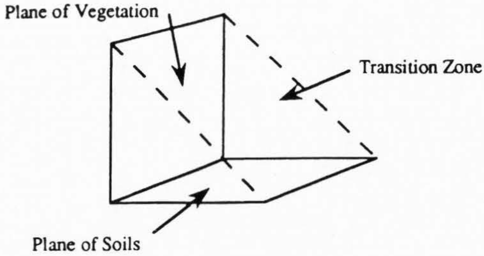


Figure 1. The three-dimensional space defined by the Brightness/ Greenness Transformation (from Crist and Cicone 1984b).

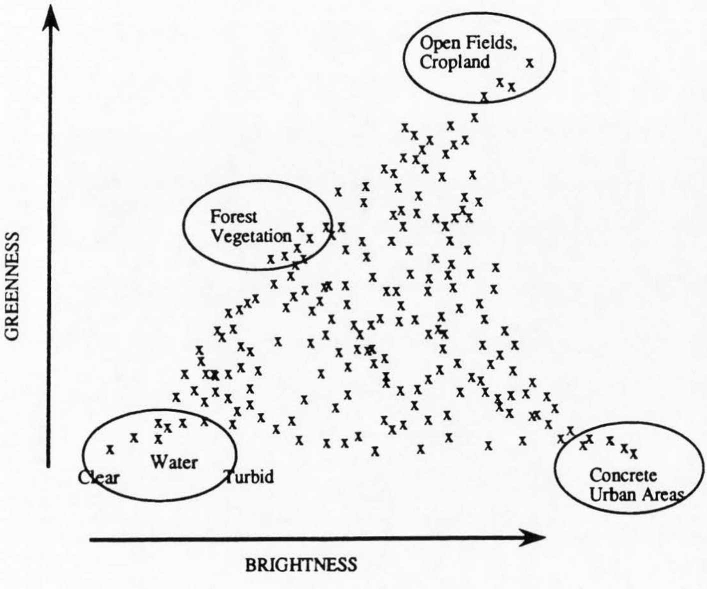


Figure 2. Areas within the three-dimensional BGW space where land cover types are predicted to occur (from Crist and Cicone 1984b).

component) and a plane of vegetation (the greenness component). The wetness component defines a zone of transition between the two planes. Different land cover types are found to fall consistently in areas defined by this space (Figure 2). The value of the BG Transformation lies in the connection of the three axes to observable physical attributes. This makes it possible to compare scenes from different dates and areas.

Principal Components Analysis identifies major axes of scene differences but is not directly and consistently tied to scene attributes, although Horler and Ahern (1986) proposed that the first and second components found in their research are strongly analogous to the brightness and greenness characteristics. The TC and BG Transformations may overcome the limitations of PCA while sharing its strengths in explaining scene variance. Crist and Cicone (1984b) discussed the use of the BG Transformation to discriminate among agricultural crops and soils and proposed its expected usefulness in defining other vegetative classes.

The significance of the thermal band in providing information appears to vary with the time of day the data were recorded (DeGloria 1984, Spanner et al. 1984). Increased separability is likely more important at a Level I classification, such as in differentiating clearcuts or open meadows from forest (Spanner et al. 1984). It is doubtful that thermal differences would be shown between conifer species. Altamira et al. (1986) found that including Band 7 in clustering statistics improved separability of classes for certain land cover types.

The choice of a classification process is another important consideration. Supervised and unsupervised classification systems are the two most commonly used techniques. In supervised classification, class types are identified from known sites, with the reflectance information from these sites used to describe the class. All other picture elements or pixels that match the statistics of the class are assigned to that class. Supervised classification is dependent on a priori knowledge of vegetation classes. One of the most popular unsupervised classification techniques uses a clustering algorithm to find mathematical similarities between pixels, grouping those that most resemble each other into the same class. This type of classification is useful when no prior knowledge of the site exists or when existing classifications are to be tested. Each of these two methods can be modified, resulting in a large array of possible classification schemes. Furthermore, once classes have been established, either by supervised or unsupervised methods, there are several major methods used for assigning pixels to class groups, including the maximum likelihood, minimum distance to means, and parallelepiped classifiers. It can be seen that comparisons of research on the use of TM data can be confounded by variety in the choice of band data and classification methods. In addition, methods found satisfactory for one geographic area or one season may not be appropriate in another.

Ancillary data can play an important role in improving cover type designations. Different slope angles and aspects influence the amount of energy received and reflected or radiated (Karaska et al. 1986, Walsh 1987, Leprieur et al. 1988). Considering this information in classifying vegetative types can lead to improved accuracy, especially in areas of topographic diversity such as northern Utah. These data can be added before classifying procedures, used as one or more of the features to be classified, or added after classification of band values (Skidmore and Turner 1988). Ancillary data improved classification accuracy of TM data 0.2 to 5.0 percent (Kenk et al. 1988) but only when they were added post classification.

Another major consideration in classifying vegetation is the level of classification detail desired. Anderson et al. (1976) established a hierarchical system for describing land cover. Level I of this classification system provides a general overview of cover classes, such as water, forest land, rangeland, or urban materials. Level II further divides each of these categories; for example, forested lands would be separated into deciduous, conifer and mixed deciduous/conifer classes. At Level III these classes are further subdivided, i.e., the conifer class would be separated into types by species such as Douglas fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and subalpine fir (*Abies lasiocarpa*). Classes describing forest structure that are subdivided from Level II classes are also considered to be Level III classes. For example, this would include the separation of a conifer class into several categories of canopy cover or tree size. When speaking of the accuracy of a given classification system, it is necessary to know at what level the work has been done.

The use of satellite data in classifying land cover classes has mainly addressed Level I concerns. MSS data have been used to obtain classes with 80 percent and higher accuracies (Walsh 1980, Pettinger 1982). Classification accuracy for conifer forest at Levels II and III is more uneven. Impressive Level II and III results with MSS data were obtained by Fox et al. (1983) in classifying conifer forest in northern California. Species type classification accuracy was 88 percent. In southeastern Idaho, Pettinger (1982), also using MSS data, obtained a much lower Level II and III classification accuracy of 52 percent, although Level I classification accuracy was 83 percent. Cibula and Nyquist (1987), working with MSS data, were able to obtain satisfactory Level II and III classification of northwest conifer species when topographic and climatological information was added to the original spectral classification. Classification accuracy of conifer classes ranged from 84 percent to 92 percent when MSS data were used in conjunction with site environmental factors, such as slope, elevation, aspect, tree size, and canopy cover (Walsh 1980).

Studies using TM data to determine conifer land cover classes are still in their infancy but, thus far, results have not been as successful as the greater spatial, spectral, and radiometric resolution might have suggested. As with MSS data, TM Level I classifications have shown acceptable accuracies ranging to 90 percent (DeGloria 1984, Tommervik 1986) but accuracy at Levels II and III has not been consistent. Accuracies of classes distinguishing conifer species types showed a range of 58 percent (Nelson et al. 1984) to 90 percent (Stibig and Schardt 1986). Identification of tree types appeared to vary with the size and homogeneity of forested areas, and with environmental site characteristics of slope, elevation, and aspect (Nelson et al. 1984, Stibig and Schardt 1986, Frank 1988). Classifications based on conifer size and canopy cover showed similar variation, ranging from 57 percent to 74 percent accuracy for cover classes (Butera 1986) and 71 percent to 74 percent for size classes (Spanner et al. 1984). Again, environmental variables were found to be of prime importance in obtaining higher Level II and III classification accuracy.

The BG Transformation has not been widely used in classification studies. The one study using the BG Transformation to classify vegetation determined wood stork foraging habitat, which included mostly wetland and open water areas (Hodgson et al. 1988). Classification accuracy of Level II cover classes ranged from 74 percent to 88 percent for different water regime years. However, the number of site samples for ground-truthing varied greatly, with some classes having so few (e.g., two or three) as to be statistically questionable. To date, the use of the BG Transformation to describe forest cover classes has not been addressed.

Much work remains to be done using TM data for classifying land cover classes. Improving the classification detail at Levels II and III is needed to fulfill the needs of resource managers and planners. Studies indicate that continued use of various band data processing, such as the TC Transformations, can provide more information for classification work. In addition, topographical variables appear to be the key to separating cover classes in a mountainous environment.

STUDY AREA

The study site is located in northern Utah in the northeastern section of the Logan District of the Wasatch-Cache National Forest (Figure 3). The study area encompasses approximately 35,750 ha or nearly a quarter of the district's area. This particular area contains the majority of the conifer resource found in the district. The identification of conifer types within the area has environmental and economic significance.

The area lies in the Bear River Range of the Wasatch Mountains, which consists of a thrust-faulted and folded syncline uplifted by block faulting (Mauk and Henderson 1984). The study area includes the upland plateau area found in the center of the range and the western edge of the range, which is dissected by small canyons leading to the Bear Lake Valley. Elevations in the study area range from 1580 to 2750 m (Mauk and Henderson 1984).

Limestones, shales, and sandstones are the dominant parent material of the area. Soils on the site belong to the Argic Cryoborolls, Pachic Cryoborolls, and Cryic Paleborolls associations. These soils range from strongly acid to mildly alkaline, with moderate to excessive drainage (Wilson et al. 1975).

The climate is characterized by warm, dry summers and cold, snowy winters. Most of the 50-80 cm of moisture comes as snow in the months between December and March (U.S.D.A. Soil Conservation Service 1974). Snow accumulation varies with aspect and exposure to wind. The combination of these factors, together with soil characteristics, provides a great variety of conditions for vegetation. The vegetation

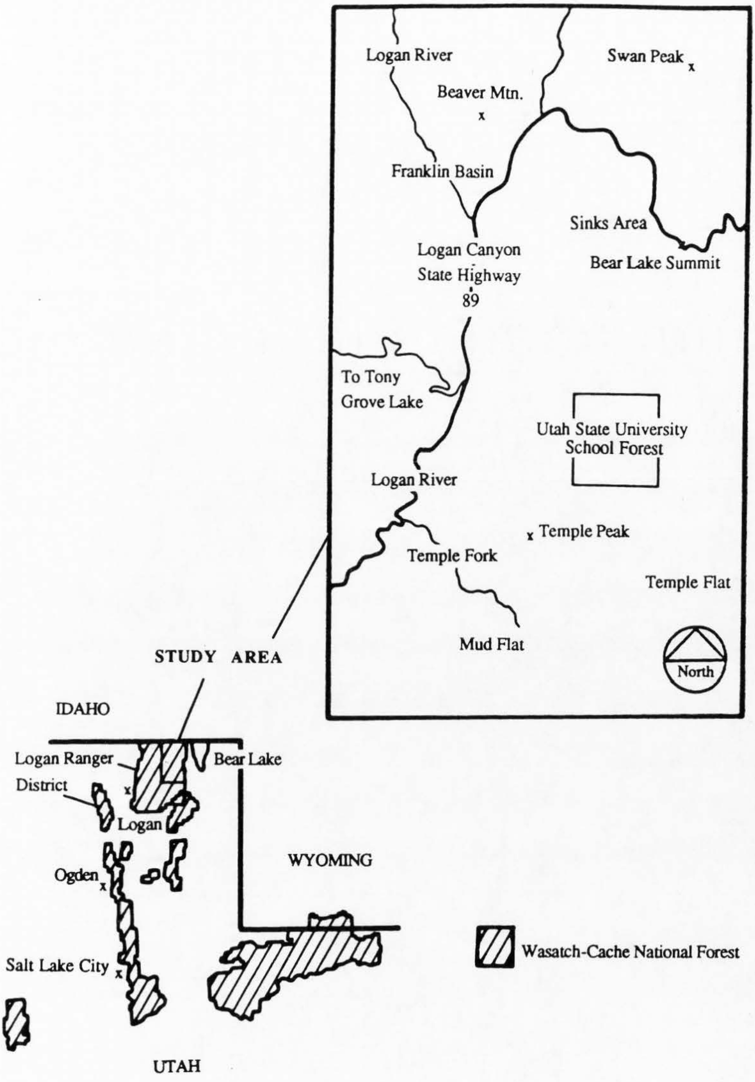


Figure 3. Study area location in northern Utah.

forms a mosaic on the landscape, with conifers generally found on cooler, moister sites, aspen on warmer, moist areas, and shrubs and grasses on the warmest and driest sites.

Subalpine fir, the major conifer species at the higher elevations of 2000 m. and above, forms the major habitat type of the study area (Mauk and Henderson 1984). Regeneration of subalpine fir can occur in conditions ranging from full sun to full shade, which makes the species very adaptable and widespread. The two major desirable timber species in this area are Douglas fir and lodgepole pine.

Historically and to the present, this region has been used for grazing livestock and harvesting timber. The area supports a variety of wildlife, and several critical winter range sites for deer, elk, and moose are found within the study area.

METHODS

Introduction

This project was divided into three phases: 1) image processing to determine conifer classes, 2) field work to ground-truth the classes, and 3) data analysis. Image processing, which involved extracting information from the satellite image, included preparation of the image so it could be used easily and accurately, and the choice and use of procedures to obtain the needed classification information. The final result of image processing was a classification system that theoretically related directly to site environmental variables. Ground-truthing the data--obtaining on-site information that corresponded to the satellite information for that site--was done during the field-work phase. The data analysis portion of the work assessed how well the satellite information was able to determine actual site parameters.

Image Processing

This study used Landsat IV Thematic Mapper (TM) data for northern Utah taken on July 1, 1986 at 10:31 a.m. Since the majority of coniferous forest types are located in the northeastern corner of the Logan District, a subscene of this section of the forest was used for the research. Hereafter, this subscene will be referred to as the "conifer scene." Image processing and map production were done with the ERDAS software program. A flow diagram of the work process is shown in Figure 4.

TM data provide seven channels of information in the visible, near- and middle-infrared, and thermal-infrared portions of the spectrum. The

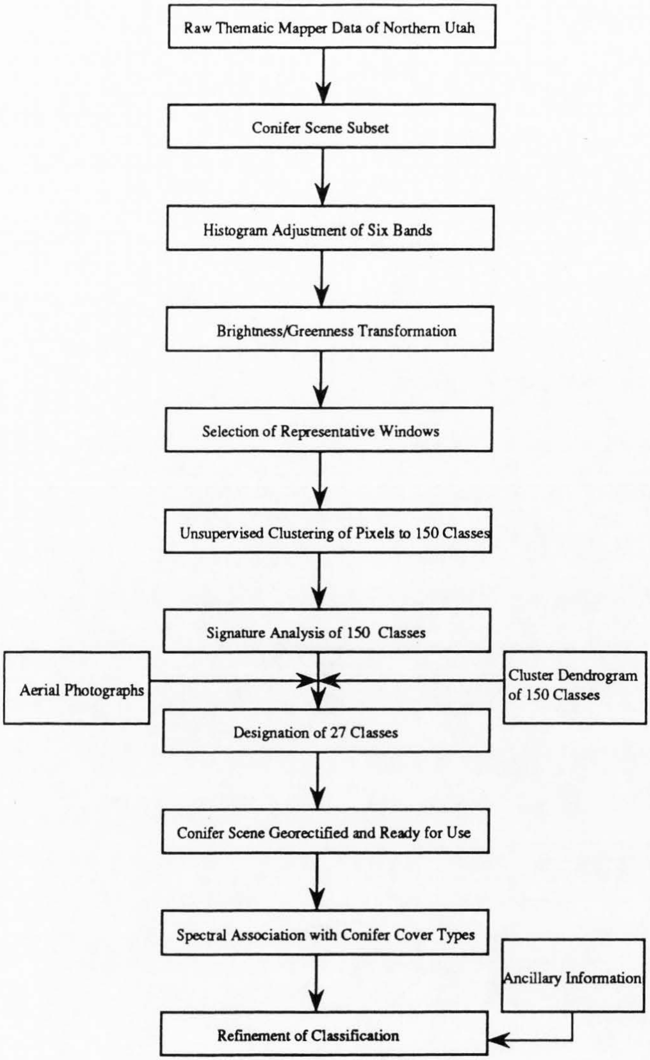


Figure 4. Flow diagram of the image-processing and classification procedure.

thermal information was not used in this analysis. The bands used were: Band 1 (0.45-0.52 *um*), Band 2 (0.52-0.60 *um*), Band 3 (0.63-0.69 *um*), Band 4 (0.76-0.90 *um*), Band 5 (1.55-1.75 *um*), and Band 7 (2.08-2.35 *um*). All six TM bands have a spatial ground resolution of 30 m X 30 m. These bands provide information about the biomass, internal structure, and water content of vegetation (Jensen 1986). Figure 5 illustrates the placement of these bands along the electromagnetic spectrum and their relationship to vegetation characteristics.

Use of the Histogram Minimum Method (Jensen 1986) decreased the noise, or attenuation of the signal, introduced by atmospheric haze and resultant scattering.

The Brightness/Greenness Transformation (Crist and Cicone 1984a) was performed on the conifer scene, using the coefficients listed in Table 1. The transformation compresses the six channel data into three channels representing brightness, greenness, and wetness (BGW) in the image.

Table 1. Brightness/Greenness Transformation coefficients for Thematic Mapper data (Jensen 1986).

Thematic Mapper Band	Brightness	Feature Greenness	Wetness
1	0.33183	-0.24717	0.13929
2	0.33121	-0.16263	0.22490
3	0.55177	-0.40639	0.40359
4	0.42514	0.85468	0.25178
5	0.48087	0.05493	-0.70133
7	0.25252	-0.11749	-0.45732

A modified clustering method reduced processing time and increased clustering accuracy, a modified clustering method (Fleming et al. 1975).

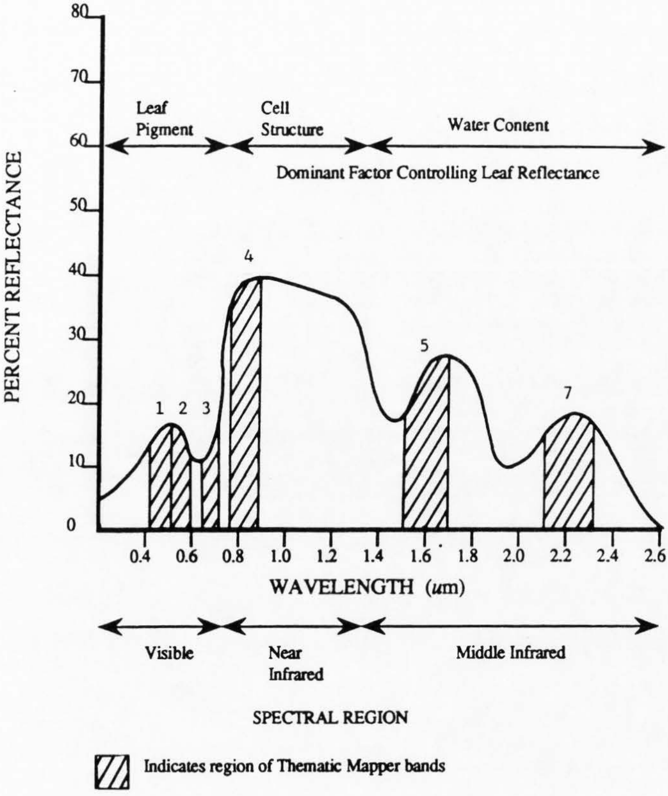


Figure 5. Spectral response characteristics of green vegetation and associated Thematic Mapper bands (from Jensen 1986).

Eight "windows" of 100 by 100 pixels each, subjectively chosen to represent the variability present in the entire scene, were selected from the conifer scene and placed together in one data file. A clustering algorithm, using an unsupervised classification approach, grouped the data into 150 spectral classes. To obtain a more manageable number of classes, several different methods were used to consolidate similar classes. The 150 classes were grouped according to the similarity of their BGW signature curves. These groups were compared with the groupings indicated by the BGW relationships illustrated in Figures 6, 7, and 8, and by similarity as indicated by a cluster analysis dendrogram of the 150 classes. Twenty-seven classes were finally derived by comparing these groupings with the appearance of the areas in aerial photographs. The entire conifer scene was classified into the 27 classes, using a minimum distance classifier; of these classes, nine appeared to be conifer or mixed conifer types.

For map scaling and overlay purposes, the conifer scene was rectified to the proper ground reference Universal Transverse Mercator (UTM) coordinates. The georeferencing process used ground control points to associate each map pixel with its correct ground coordinate. Maps output at the 1:24,000 scale corresponded to USGS 7 1/2-minute quadrangle maps of the area. Field sampling sites were located on maps by overlaying the classification map onto their corresponding 7 1/2-minute quadrangles.

Field Work

The field work phase included all ground-truthing activities; this work began in June and was finalized by October 1988. Ten sites for

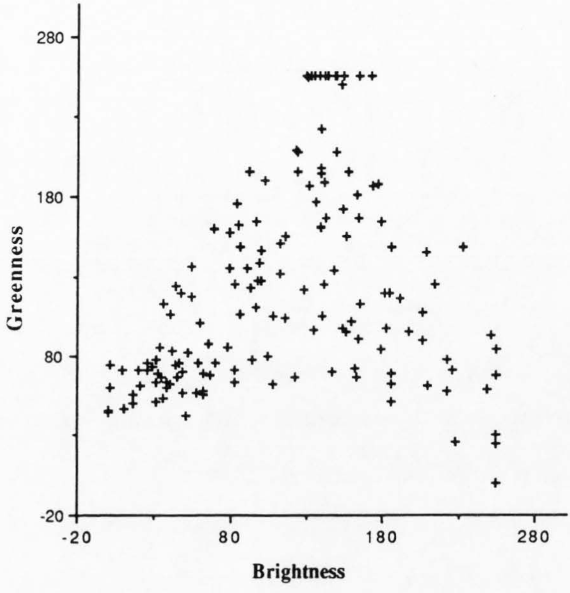


Figure 6. Brightness and greenness relationships of the 150 classes from cluster analysis of the satellite image.

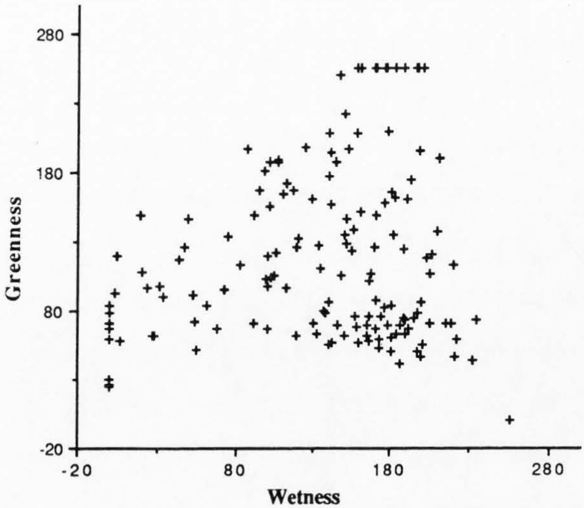


Figure 7. Wetness and greenness relationships of the 150 classes from cluster analysis of the satellite image.

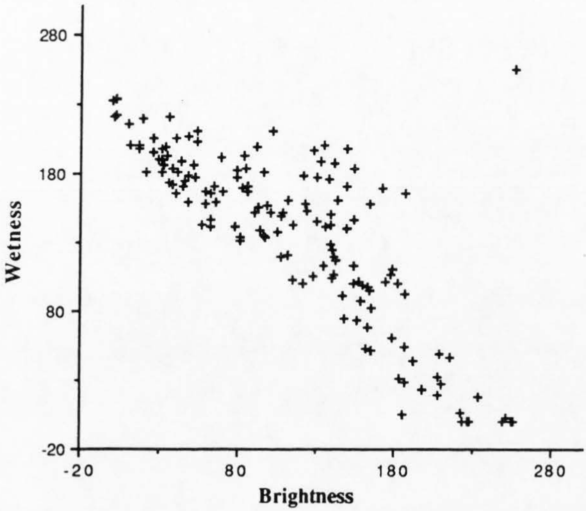


Figure 8. Brightness and wetness relationships of the 150 classes from cluster analysis of the satellite image.

each of the nine conifer classes were sampled, with sampling sites randomly selected from areas within one-half mile of roads that were at least 10 pixels (2 acres) in size. Sites were located either by their proximity to known landmarks, or by taking compass readings from known landmarks to the center of the sampling site and pacing the distance to that point as determined from the topographic map. Aerial photographs of the area aided in both these processes. Areas that had obviously been disturbed since the date of the satellite image, such as logging sites, were not used.

The data form used for the ground-truthing work (Appendix A) was developed from the U.S. Forest Service Ecosystem Classification Handbook (1987). This document presents standardized methods (ECODATA Sampling Methods) for gathering ecological site information in Region I of the Forest Service.

At the sampling area, a circular 0.1 acre representative site was selected. Anomalies, such as thick regeneration in one small section of the area, were avoided in choosing sampling sites. From the center point of the sampling plot, measurements of slope, aspect, and elevation were recorded. Descriptions of geomorphic landform, and slope position and shape (convex, concave, consistent) were made. From the center of the plot, tree basal area estimates were made using a relascope (Chambers and Brown 1983). Tree diameter at breast height (DBH) was measured for the predominant age class represented at each site.

Cover estimates were made using a line point transect method (Heady et al. 1959). From the center of the plot, a transect was run in a random compass direction until it reached the plot boundary (Figure 9). Here, the transect was continued 20 degrees to the side of the previous

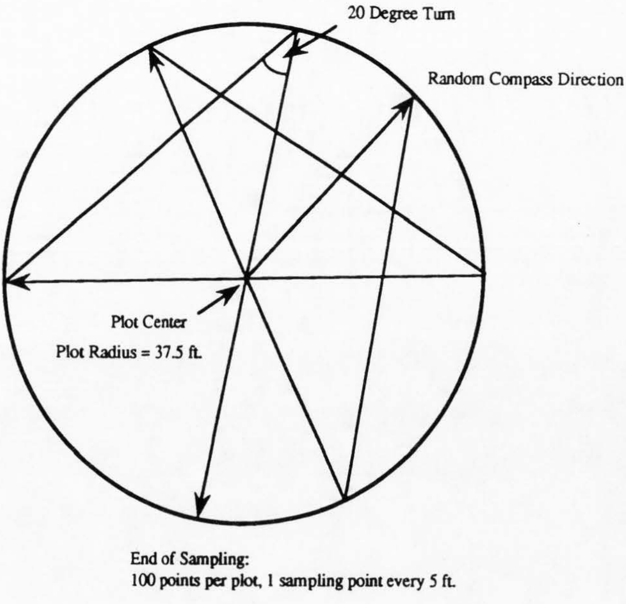


Figure 9. Plot sampling protocol for all sites.

direction, either right or left as randomly chosen. The transect continued to the plot boundary where it again changed direction 20 degrees off the previous line. Measurements were taken every 5 feet, starting at the plot center. The line transect continued until 100 points were sampled, with the uppermost overstory and understory species recorded at each point. Overstory was considered to be the highest tree canopy layer; on all sites, this layer was distinctly higher than the other vegetation present. Understory included all lower vegetation on the site; generally 15 feet tall or less, with the few exceptions being young trees reaching to three quarters of the overstory height. Within the understory, height stratifications were found; all these vegetation layers were not recorded due to time and budget constraints. The uppermost understory layer was recorded to provide a general index of understory differences between sites and was not meant to be a thorough species inventory.

After sampling for overstory and understory cover, general comments on habitat type (Mauk and Henderson 1984), fuel loads, animal use, and ground disturbance were recorded. A description of each site was written, including a listing of plant species present, and one or two photographs taken of each site.

Aspect is difficult to assess statistically because the values occur on a circular scale where very unlike values may actually be very similar; for example, aspects of 358 degrees and 2 degrees are both very close to north. To avoid this problem in subsequent analyses, the following adjustments were made. The azimuth angle for the date of the conifer scene was 117 degrees. This aspect was assumed to receive maximum solar energy; 297 degrees (the aspect opposite from 117 degrees) was assumed to receive the minimum solar energy. Based on the relative amount of solar energy each site might receive, aspect values were recalculated to range from 0 to 180 degrees (Figure 10), starting with 0 at 297 degrees and 180 at 117 degrees. Thus it was assumed that points located at equal distances from 117 degrees, even though in different cardinal directions, received an equivalent amount of solar energy. For subsequent analyses, adjusted values were linearized by conversion to radians.

Data Analysis

The primary purpose of the data analysis was to assess the usefulness of transformed TM data for detecting conifer types. The data set consisted of field and spectral measurements collected from ten sampling sites for each of the nine conifer spectral classes. Spatz's quantitative modification of Jaccard's Similarity Index (Mueller-Dombois and Ellenberg 1974), used to compare the vegetation of the sites within each class, incorporates both the quantitative and qualitative differences between sites. The method compares both the number of species that are common between two sites and how many of each species are present. The test provides a measure of the vegetal cohesiveness associated with each class.

Analysis of variance (ANOVA) was used to test for differences among the nine conifer classes. Factors used in the test included vegetation, spectral class, and physical site characteristics. The Studentized Range Test (Sokal and Rohlf 1981) was used to measure for significant differences between pairs of classes.

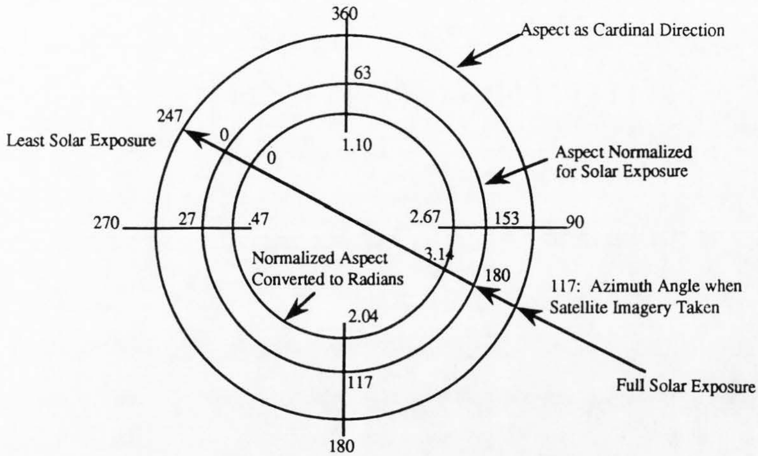


Figure 10. Diagram of the procedure for normalizing aspects with comparable solar exposure.

A test for association between site factors was performed using the Pearson's Product Moment Correlation Formula and all measurements from the 90 sites. The correlation results were examined for collinearity between environmental and spectral factors. For factors that were found to be correlated, a regression formula was used to calculate the least squares equation, and the data were displayed in a scatterplot format.

To determine if BGW values were directly related to the dominant tree species, the 90 sites were grouped into vegetation classes based on the presence or absence of the six major tree species: aspen (Populus tremuloides), Douglas fir, Englemann spruce (Picea englemannii), limber pine (Pinus flexilis), lodgepole pine, and subalpine fir. The groupings were created by comparing percent occurrence of each tree species and combining sites with similar percentages. A cluster analysis algorithm was used to calculate the similarity between sites.

ANOVA of the vegetation classes was done using all site variables, as listed above, with the GT2-Method (Sokal and Rohlf 1981) used to determine which pairs of classes were significantly different. Discriminant function analysis was used to test the predictability of grouping the sites into the designated vegetation classes. Two analyses were performed, one based only on the spectral BGW values and one based on the combination of spectral BGW values, and slope and aspect information (Hurst 1989).

RESULTS

Map Classification

Figures 11, 12, and 13 present two-dimensional scatterplot combinations of brightness, greenness, and wetness components. Each graph displays the location, in feature space, of the 27 original spectral classes. Although the axes change, in general the same classes remain grouped together; for example, classes 5, 8, 16, 18, and 19 remain grouped in the same general area, as do classes 10, 14, 24, and 26 (Figures 11-13). The classified image was compared with aerial photographs to determine general vegetation classes (Figure 14). The darkest classes, occurring at the lower left edge of the triangle, include densely vegetated conifer areas, heavily shadowed areas, and surface water features. The brightest classes, found in the lower right corner, are those containing snow patches, bare ground, and exposed light-colored rock. The highest greenness values, located at the top of the triangle, are aspen woodland types. As the amount of deciduous leaf material decreases, greenness values decrease; therefore, greenness has little association with conifer cover. Classes in the middle of the triangle appeared to be varying mixes of conifers, aspen, shrubs, forbs, and exposed ground. Placement of the general vegetation classes along the other axes results in similar vegetation groupings and similar trends for relationships between classes (Figures 15 and 16).

From the vegetation characteristics suggested by the scatterplots, ten classes were judged to include areas where conifers were the major overstory species. The spectral classes selected were: 5, 8, 16, 17, 18, 19, 20, 21, 22, and 27. Class 27 included a mix of surface water

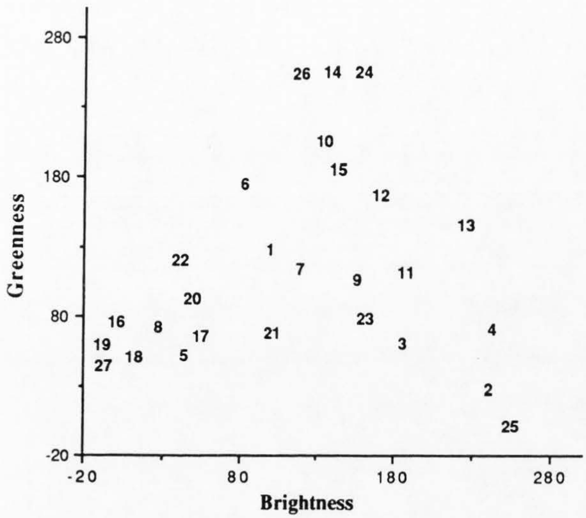


Figure 11. Location of the 27 BGW classes on brightness and greenness axes.

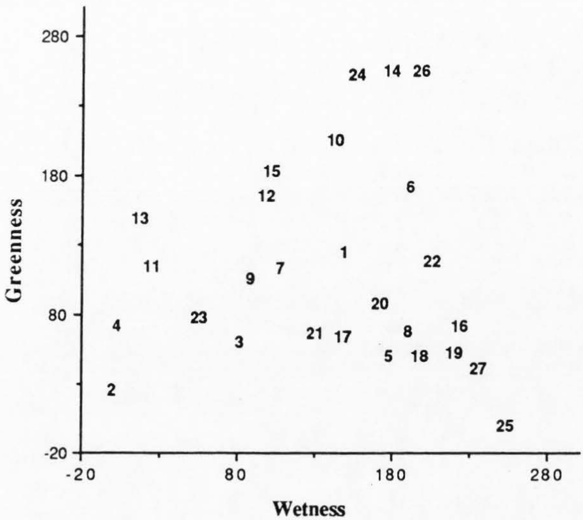


Figure 12. Location of the 27 BGW classes on wetness and greenness axes.

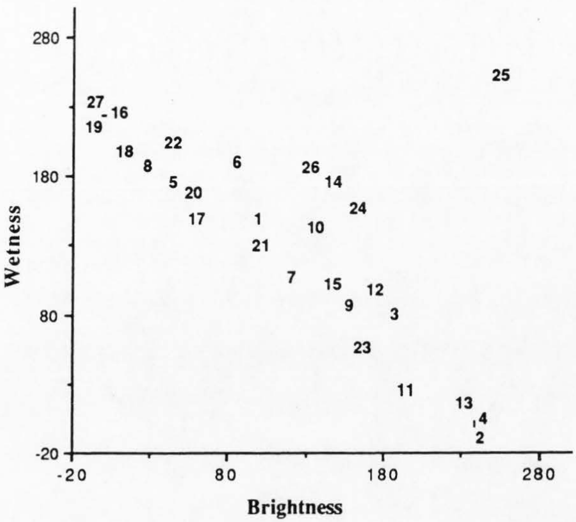


Figure 13. Location of the 27 BGW classes on brightness and wetness axes.

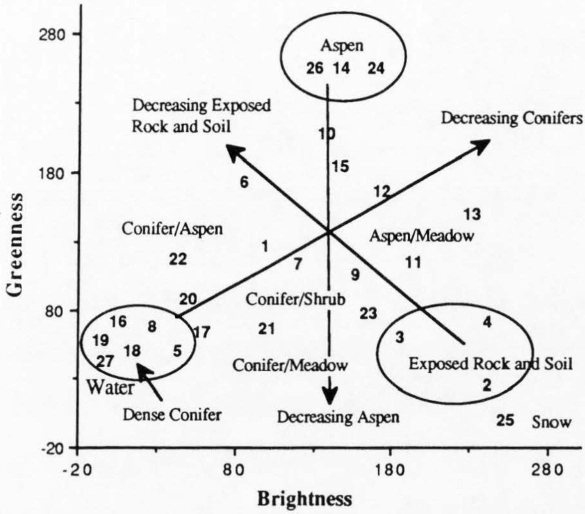


Figure 14. Suggested vegetation classification of the 27 BGW classes along the brightness and greenness axes.

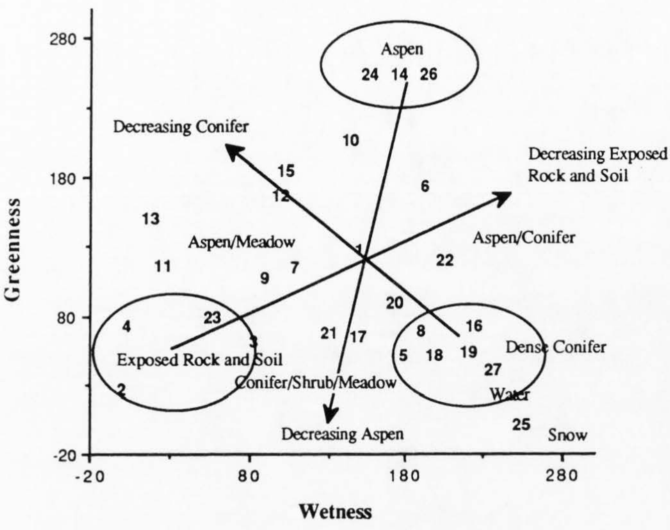


Figure 15. Suggested vegetation classification of the 27 BGW classes along the wetness and greenness axes.

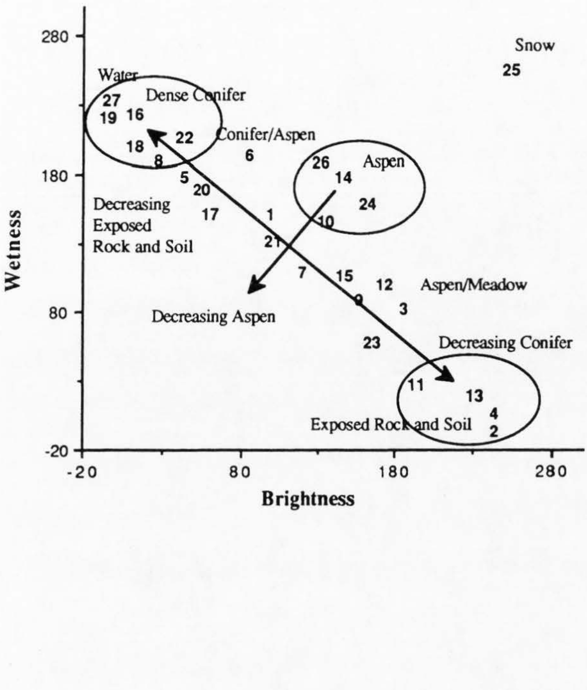


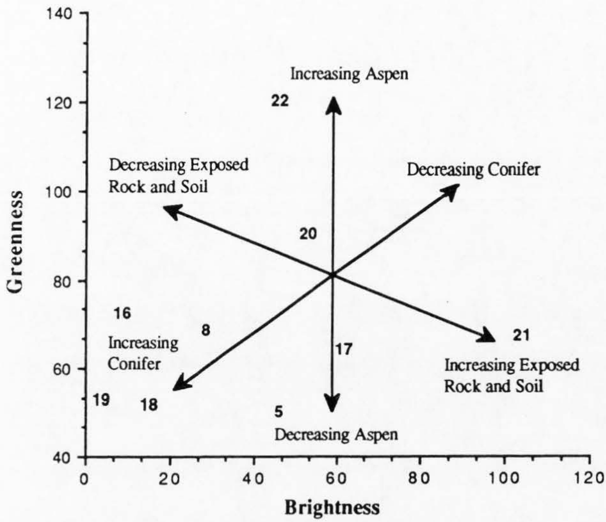
Figure 16. Suggested vegetation classification of the 27 BGW classes along the brightness and wetness axes.

features and dense conifer areas. By comparing aerial photographs with the spectrally classified image, the conifer sites of class 27 were found adjacent to and intermixed with class 19 pixels. For ease of sampling, class 27 was merged into class 19 for this study. The presence of large water bodies in this region is easily identifiable, and any possible confusion of a water body as a conifer site was avoided by referring to topographic and existing forest maps. The final result was the nine conifer classes that were used for the study. Twenty-five percent of the 35,750 ha study area was included in these conifer classes. Class 20 comprised the greatest area at 4.28 percent of the site, and Class 19 the smallest area at 1.34 percent (Table 2).

Table 2. Percent area of the study site occupied by each of the nine conifer classes.

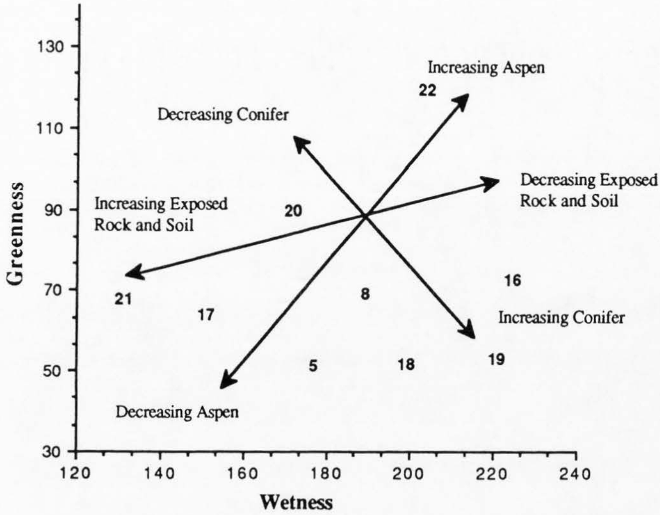
Class	Area in Hectares	Percent Area
5	647	1.81
8	1395	3.90
16	648	1.81
17	925	2.59
18	794	2.22
19	497	1.34
20	1530	4.28
21	1325	3.71
22	1286	3.60
Total	9047	25.26

Conifer classes were expected to vary according to their places along the Brightness, Greenness, and Wetness axes (Figure 17). Classes 19, 18, and 16 were expected to include areas of the most dense conifers with the most complete overstory coverage. Classes 5, 17, and 21 were

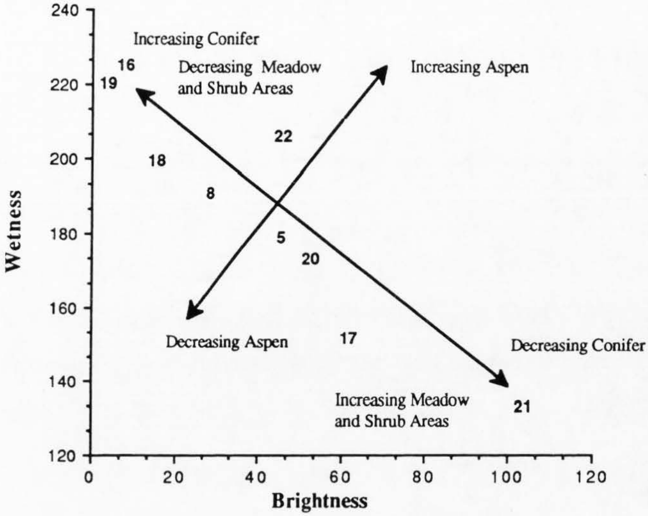


a)

Figure 17. Suggested differentiation between the nine BGW conifer classes: a) along the brightness and greenness axes, b) along the wetness and greenness axes, c) along the brightness and wetness axes.


Greenness
130
110
90
70
50
30
120
140
160
180
200
220
240
Wetness
Increasing Aspen
Decreasing Aspen
Decreasing Conifer
Increasing Conifer
Increasing Exposed
Rock and Soil
Decreasing Exposed
Rock and Soil
22
20
21
17
8
16
5
18
19

b)


240
220
200
180
160
140
120
0
20
40
60
80
100
120
Wetness
Brightness
Increasing Conifer
Decreasing Meadow and Shrub Areas
Increasing Aspen
Decreasing Aspen
Decreasing Conifer
Increasing Meadow and Shrub Areas
16
19
22
18
8
5
20
17
21

c)

expected to show decreasing amounts of conifers, accompanied by increases in shrub and forb components. Class 22 was projected to include more aspen than the other sites. Classes 8 and 20 were expected to present varying degrees of aspen, shrub, and forb coverage. These expectations are based on the BGW values of each class and on the proposed ability of the Brightness/Greenness Transformation to determine classes based on plant species composition. Subsequent tests and analyses assess the accuracy of these assumptions for the nine classes.

Similarity Tests

Ten sites for each of the nine spectral classes were ground-truthed, using the revised ECODATA sampling methods described earlier. Sixty-nine plant species were identified, and physiognomic life forms were designated for each species (Appendix B). Using Spatz' modification of Jaccard's Similarity Index (Mueller-Dombois and Ellenberg 1974), similarity values for all site pairs within each of the nine classes were calculated. For this index, possible values range between 0 and 100; total similarity between sites, with respect to both species presence and numbers of species, would result in a score of 100. Site pairs having few species in common, with the numbers of common species varying greatly, have low similarity values. Each class showed great variability of vegetation between sites (Appendix C). All nine classes included at least one pair of sites with very low similarity values of near zero (0 to 1.15 percent). Class 17 exhibited the smallest range of similarity ratings of 0.21 to 18.93 percent, and class 5 had the largest similarity range, with values from 0.01 to 47.15 percent. This indicates that spectral classes derived from the BG Transformation are not based exclusively on the vegetation of the sites but must also include other factors.

Level II Classification Accuracy

Level II classification accuracy was assessed for the 90 sites. For the purposes of this study, a site was considered a conifer site if the conifer canopy cover was 50 percent or greater. Sixty of the 90 sites, or 67 percent, met this criterion. The nine classes varied as to the percent of sites which could be classified as conifer (Table 3).

Table 3. Percent of the BGW classes that contain at least 50 percent conifer cover.

BGW Class	Percent of Class as Conifer
5	80
8	90
16	100
17	50
18	100
19	100
20	30
21	10
22	50

Two general groups stand out from these data: a high-density conifer group (classes 5, 8, 16, 18, and 19) with the majority of sites identified as dominated by conifer species, and a second, low-density conifer group consisting of classes 17, 20, 21, and 22. These groupings follow the general trends shown earlier (Figure 17), which indicate that those classes of low greenness, low brightness, and high wetness values are more likely to be dense conifer.

For the high-density conifer group, Level II classification accuracy is 94 percent (47 of 50 sites), while for the low-density conifer group, 35 percent of the sites support a high density conifer canopy cover. The sites in this group include a mixture of high density conifer sites, open meadow sites with scattered conifers, and mixed conifer/aspen sites.

As a tool for Level II classification, the spectral classes separate well the high density conifer from low density conifer classes. The high density sites appear to form a cohesive group, particularly classes 16, 18, and 19. The low density conifer group shows great variety in vegetation and may be difficult to subdivide further without additional information.

Presence x Frequency

To determine which plant species were most prevalent on all sites, a presence times frequency (P x F) value (Warner and Harper 1972) was calculated for each of the 69 species (Appendix D). Since plant sampling was divided into overstory and understory counts, the six tree species are listed twice, once for the times they appeared as overstory species and once for the times they occurred as understory species. Tree species were considered as understory if they were seedlings or saplings or were of heights three-quarters or less than the top of the existing overstory canopy. The three major overstory species are lodgepole pine, Douglas fir, and subalpine fir (Table 4). Aspen and Englemann spruce occurred much less often, and limber pine was fairly uncommon.

Table 4. Presence X Frequency values for the six tree species.

Douglas fir (*Pseudotsuga menziesii*)	1917
Lodgepole pine (*Pinus contorta*)	1826
Subalpine fir (*Abies lasiocarpa*)	1400
Aspen (*Populus tremuloides*)	616
Englemann spruce (*Picea englemannii*)	227
Limber pine (*Pinus flexilis*)	45

There was an average of ten understory species per site. The ten most common understory species, those with the highest P x F values (Table 5), will be used in subsequent comparison analyses of the sites. Subalpine fir (P x F = 1104) regeneration was overwhelmingly the most prevalent understory species. *Abies lasiocarpa* is a major component of northern Utah forests, occurring on all aspects, usually from 2000 to 3350 m on gentle to steep slopes and on a variety of soils (Mauk and Henderson 1984). It is absent only on the warmest and driest exposures and at lower elevations. The *Abies lasiocarpa* series is considered the most prevalent forest climax community in northern Utah, occurring in a variety of successional stages. Of the 90 sample sites, 79 were identified as stages in the subalpine fir climax series as described by Mauk and Henderson (1984). The success of *Abies lasiocarpa* in this environment is reflected by the very high presence of subalpine fir regeneration on the study sites.

Table 5. Presence X Frequency values of the ten most frequent understory species.

Subalpine fir regeneration (Abies lasiocarpa)	1104
Mountain snowberry (Symphoricarpos oreophilus)	346
Arnica species (Arnica spp.)	265
Parrot's beak (Pedicularis racemosa)	254
Lanzwert sweetpea (Lathyrus lanzwertii)	183
Sedge species (Carex spp.)	162
Sweetroot species (Osmorhiza spp.)	156
Aspen regeneration (Populus tremuloides)	146
Bluegrass species (Poa spp.)	108
Mountain mahogany (Cercocarpus ledifolius)	103

Class Descriptive Statistics

Descriptive statistics for 42 site factors (Appendix E) have been divided into five categories (Table 6). Overstory characteristics include the average cover percentages for all tree species, all conifer species, each tree species, and basal areas. Understory characteristics include cover percentages for the ten most frequent species and for all ground cover as cover percentages of exposed soil, rock, moss, and litter. Physiognomic characteristics present the vegetative cover percentages in terms of plant structure and in average numbers of the different representative plant structure types. Plant structure categories are: trees, shrubs, forbs, grasses, and tree regeneration species. Physical site characteristics include solar exposure (aspect values normalized and converted to radians), average slope, and elevational information for each class. Transformed spectral values list the average brightness, greenness, and wetness (BGW) values for each class. These 42 factors are used in the subsequent analyses of the classes and sites.

Table 6. Forty-two site characteristics recorded for each of the 90 sites.

Overstory Characteristics
- Percent total tree cover
- Percent conifer cover
- Percent cover of:
  - Douglas fir
  - Englemann spruce
  - Limber pine
  - Lodgepole pine
  - Subalpine fir
  - Aspen
- Basal area (m^2/ha)

Understory Characteristics
- Percent cover of:
  - Exposed soil
  - Litter
  - Moss
  - Rock
  - Wood
  - Arnica species
  - Aspen regeneration
  - Bluegrass species
  - Mountain lover
  - Parrot's beak
  - Sedge species
  - Sweetroot species
  - Tuber starwort
  - Snowberry
  - Subalpine regeneration

Physiognomic Characteristics
- Total number of species per site
- Number of tree species per site
- Number of tree regeneration species per site
- Number of understory vegetation species per site
- Number of forb species per site
- Number of grass species per site
- Number of shrub species per site
- Percent cover of:
  - Forbs
  - Grasses
  - Shrubs
  - Tree regeneration
  - Understory vegetation

Physical Site Characteristics
- Elevation
- Normalized aspect, in radians
- Percent slope

Transformation Values
- Brightness
- Greenness
- Wetness

Statistical Analyses

Analysis of Variance. Since plant species were not the major determining factors for the designated classes, the significance of additional site characteristics was analyzed to determine their contribution to the spectral variation. The factors compared between classes were grouped into the previously mentioned five categories: overstory characteristics, understory characteristics, plant physiognomic characteristics, physical site characteristics, and transformed spectral values (Table 6). An analysis of variance (ANOVA) determined 21 characteristics to be significantly different between classes (Table 7). The studentized range test was used to determine which class pairs among the nine differed significantly from each other (Table 8).

The transformed values of brightness, greenness, and wetness show the most striking separation between the classes but this does not provide new information. Since BGW values were used to define classes by cluster analysis, the significance between classes is to be expected.

The ANOVA results do not clearly indicate other factors that consistently separate the nine classes. For each significant factor, different pairs exhibit significant differences but no factor shows significance for all class pairs. The results suggest that classes with less dense conifer cover and more deciduous foliage can be differentiated from the more dense conifer cover classes. These differences become even more evident when classes are grouped into high- and low-density conifer groups. For the overstory characteristics, histograms of the five significant factors (Figure 18) illustrate the differences among classes, but also underscore the fact that the differences vary and are often not great. Class 21 was the most easily separated from the other classes due

Table 7. The 21 significant factors based on ANOVA of the nine spectral classes ($p < 0.05$).

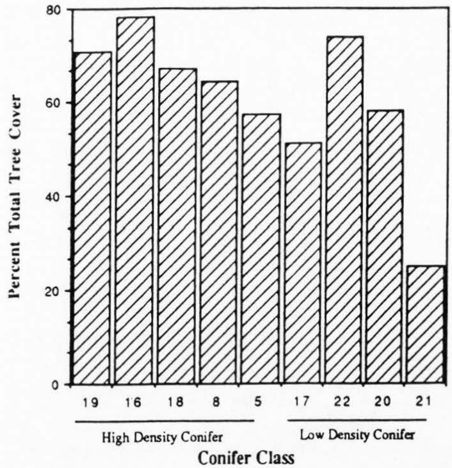
Overstory Characteristics
- Basal area
- Percent total tree cover
- Percent conifer cover
- Percent cover of:
  - Douglas fir
  - Aspen

Understory Characteristics
- Percent cover of:
  - Exposed soil
  - Litter
  - Aspen regeneration
  - Bluegrass species
  - Sedge species

Physiognomic Characteristics
- Total number of species per site
- Number of understory vegetation species per site
- Number of grass species per site
- Percent cover of:
  - Forbs
  - Grasses

Physical Site Characteristics
- Elevation
- Normalized aspect, converted to radians
- Percent slope

Transformation Values
- Brightness
- Greenness
- Wetness



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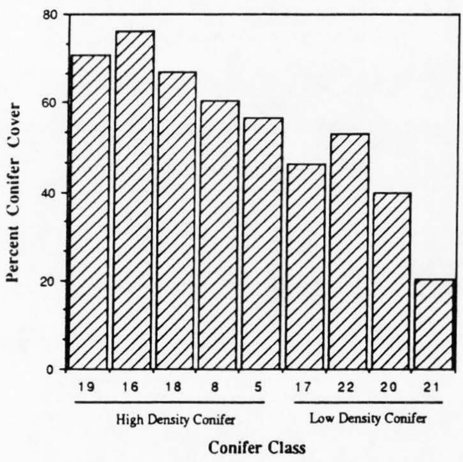
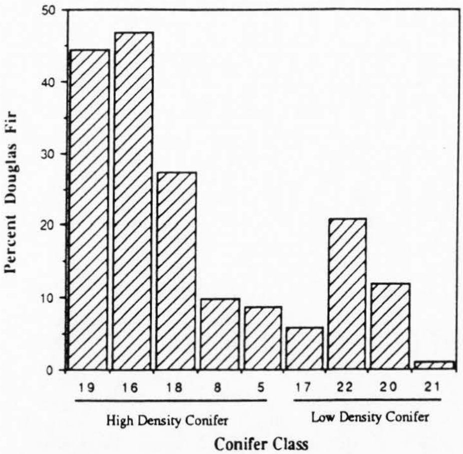


b)

Figure 18. Histograms of the five significant overstory factors: a) percent tree cover, b) percent conifer cover, c) percent Douglas fir cover, d) percent aspen cover, e) basal area.



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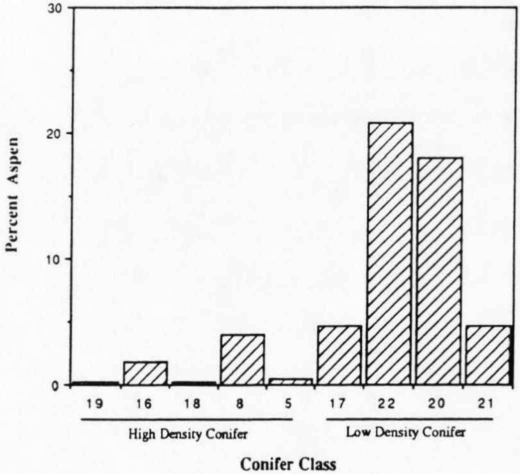

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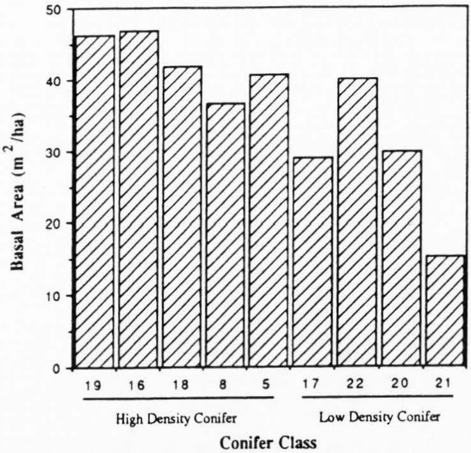
Figure 18. Continued.



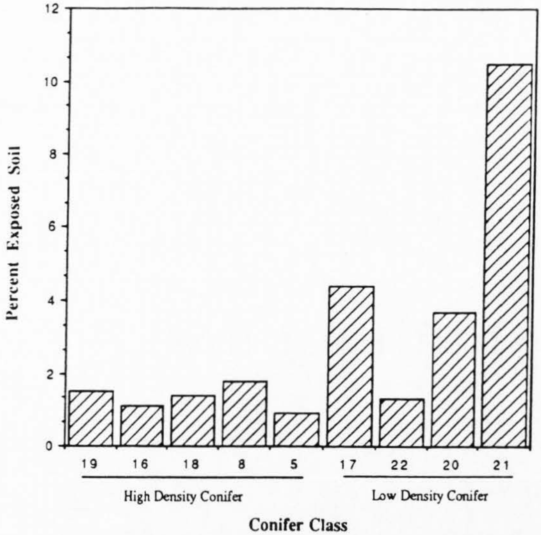
e)

Figure 18. Continued.

to its low tree and conifer canopy cover, low Douglas fir and subalpine fir cover, and low basal area. Class 21 was also markedly different from other classes in the amount of conifer cover, especially in comparison with the dense conifer classes 16, 18, and 19. Classes 20 and 22 stand out due to their high aspen canopy cover values.

Understory characteristics also showed some separation of classes (Figure 19). Percent aspen regeneration clearly separated class 20 from classes 5, 8, 16, 18, and 19. The percent exposed soil of class 21 significantly differed from that of classes 5, 16, 18, and 19. The percent litter cover differed significantly between class 21 and classes 5, 16, 18, and 19. These results reinforce the difference between the more open-canopied classes and those with a higher density of conifers. Contrasts in the percent cover of sedge and bluegrass species were noted but the overall low amounts of these species suggest that these factors are not meaningful in differentiating between classes.

Physiognomic characteristics of class vegetation exhibited much the same patterns (Figure 20). Classes 20, 21, and 22 most often differ significantly from the other classes, particularly from classes 18, 19, 16, and 5. Physical site factors (Figure 21) show few significant differences between classes, although elevation appears to be of importance in separating class 22 from classes 20, 21, and 17. Slope characteristics show a few differences but these do not appear to be tied to site conifer density or particular tree species. The solar exposure of classes 16, 18, and 19 show consistent significant differences from classes 8, 17, and 20, which could aid in separating dense from less dense conifer cover classes.



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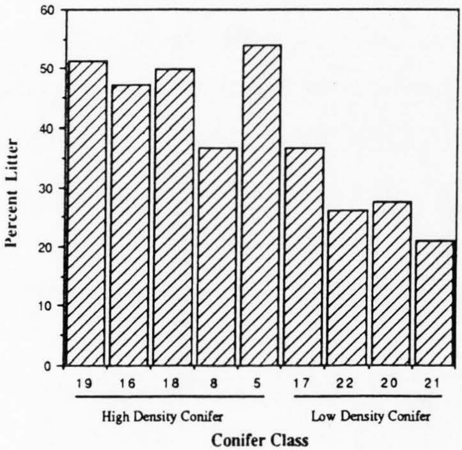
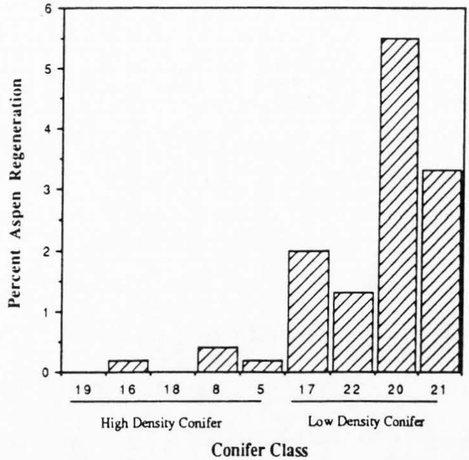


b)

Figure 19. Histograms of the five significant understory factors: a) percent exposed soil, b) percent litter cover, c) percent aspen regeneration, d) percent bluegrass species cover, e) percent sedge species cover.



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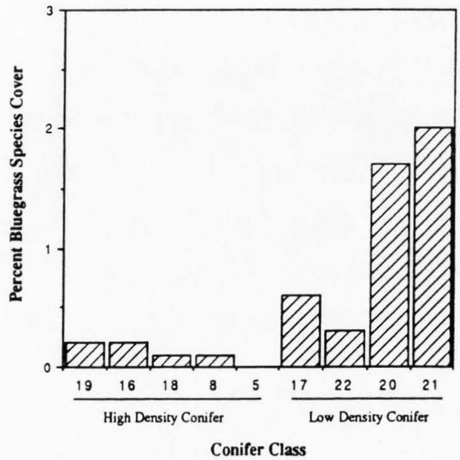

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Figure 19. Continued.

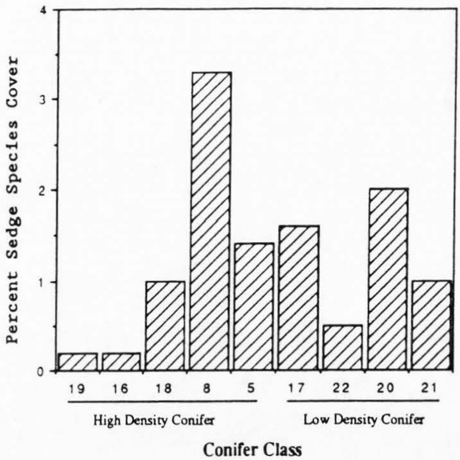

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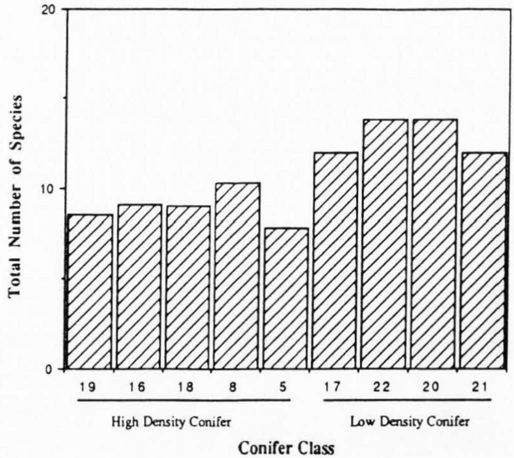
Figure 19. Continued.



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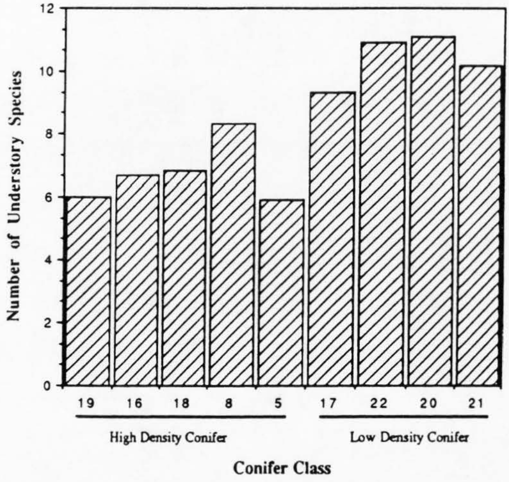
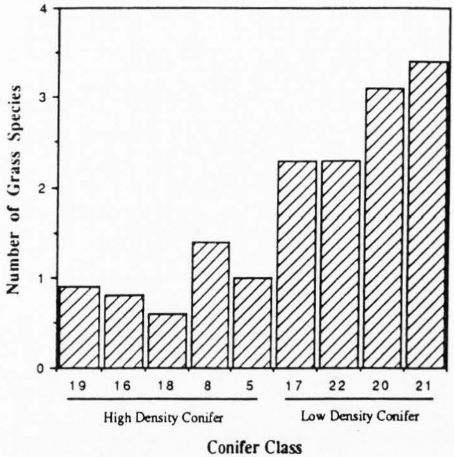


b)

Figure 20. Histograms of the five significant plant physiognomic factors: a) total number of species per site, b) number of understory species per site, c) number of grass species per site, d) percent forb cover, e) percent grass cover.



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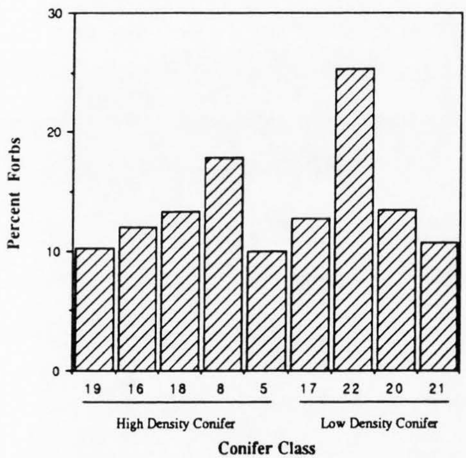

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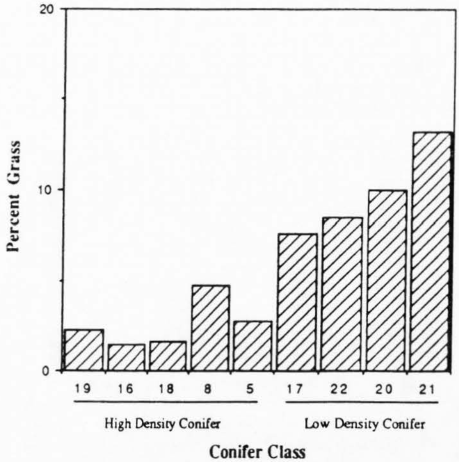

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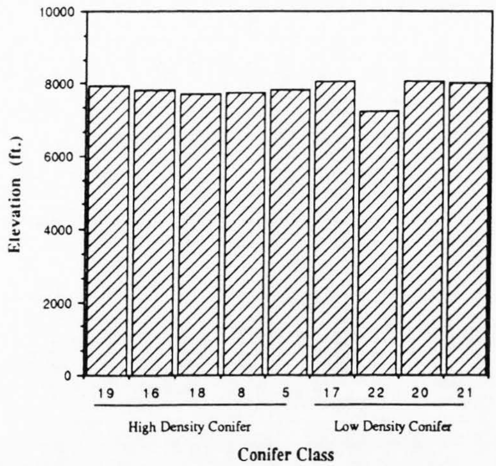

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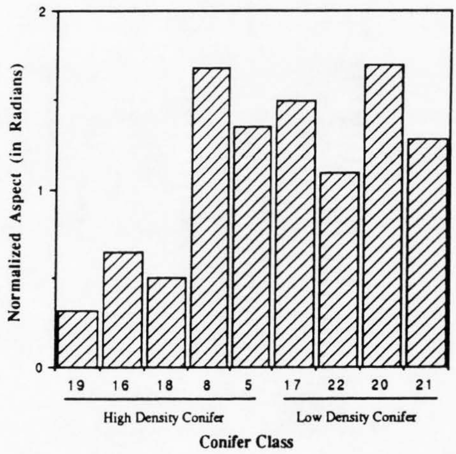
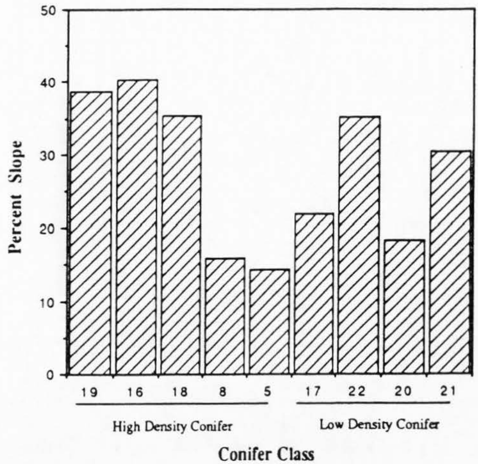


b)

Figure 21. Histograms of the three significant physical site factors: a) elevation (ft.), b) normalized aspect (in radians), c) percent slope.



c)

Figure 21. Continued.

In summary, the ANOVA results reveal no consistent factors for distinguishing between the nine classes, although the results follow the patterns suggested in Figure 17. Classes 16, 18, and 19 include dense conifer areas, as reflected in high values for basal area and percent cover for conifers, Douglas fir, and litter. These conifer sites tended to have less aspen regeneration and supported fewer grasses. Classes 20, 21, and 22 also showed pronounced differences from the other classes (Figure 17). In general, they supported fewer conifers, less litter, and more grass species. Class 22 was predicted to contain more aspen than the other classes, based on its position along the BGW axes, and this was confirmed by the field data. Class 21 was expected to have fewer trees, more grasses, and more exposed soil, and this also was confirmed. Class 20 fell between the two extremes of classes 21 and 22, showing contrasts and similarities to both classes. Aspen regeneration was high in class 20, suggesting that, as the vegetation matures, these sites would be classified as class 22. Overall, classes 20, 21, and 22 appear to be more open conifer stands than the other classes. Classes 5, 8, and 17 occupy a transition zone between dense and open conifer stands (Figure 17). Grouping the nine classes into conifer cover density classes may clarify the differences noted.

Correlation Analysis. Correlation analysis on data from all 90 sites was used to determine which site factors were most closely tied to the brightness, greenness, and wetness components. Table 9 lists those factors found to be significantly correlated at the $p < 0.05$ level. Although several factors were found to be significant, the scatterplots of these correlations (Appendix F) show that many of the correlations are weak. Study of both the scatterplots and the correlation coefficients

Table 9. Significant correlations of brightness, greenness, and wetness values with site factors ($p < 0.05$).

Site Factor	r Value	r^2 Value
<u>Brightness</u>		
Percent exposed soil	0.5860	0.3433
No. grass species	0.5595	0.3130
Percent grass cover	0.5423	0.2941
No. understory species/site	0.4555	0.2074
Total no. species/site	0.4159	0.1730
Normalized aspect (radians)	0.4066	0.1654
Percent basal vegetation	0.4018	0.1615
Percent bluegrass species	0.3485	0.1215
Greenness	0.2777	0.0771
Percent shrub cover	0.2528	0.0639
Percent aspen cover	0.2451	0.0601
Percent limber pine cover	-0.2301	0.0529
Percent arnica species cover	-0.2429	0.0590
Percent Douglas fir	-0.4679	0.2189
Percent litter	-0.5125	0.2626
Percent tree cover	-0.6791	0.4611
Basal area (m^2/ha)	-0.6893	0.4751
Percent conifer cover	-0.7568	0.5727
Wetness	-0.8196	0.6717
<u>Greenness</u>		
Percent aspen	0.6002	0.3602
Percent basal vegetation	0.4911	0.2411
Total no. of species	0.4815	0.2318
No. of understory species	0.4541	0.2062
Percent forb cover	0.3804	0.1447
No. of forb species	0.3213	0.1032
No. of grass species	0.2947	0.8680
Brightness	0.2777	0.0771
No. regeneration species	0.2727	0.0744
Percent subalpine fir cover	0.2721	0.0740
Percent grass	0.2551	0.0651
Normalized aspect (radians)	0.2297	0.0528
Percent aspen regeneration	0.2233	0.0499
Percent lodgepole pine	-0.2192	0.0480
Percent litter cover	-0.4107	0.1687
<u>Wetness</u>		
Percent tree cover	0.7033	0.4946
Percent conifer cover	0.6494	0.4217
Basal area (m^2/ha)	0.6044	0.3653
Percent Douglas fir	0.4291	0.1841
Percent limber pine	0.2452	0.0601
Percent slope	0.2357	0.0555
No. understory species	-0.2154	0.0464
Percent aspen regeneration	-0.2779	0.0772
Normalized aspect (radians)	-0.3097	0.0959
Percent bluegrass species	-0.3206	0.1028
Percent grass cover	-0.3487	0.1216
No. grass species	-0.3926	0.1541
Percent exposed soil	-0.5889	0.3468
Brightness	-0.8196	0.6717

was done to determine the strength of the correlation between factors. The significant relationships support the proposed vegetation types shown in Figure 17. Percent exposed soil explains 34 percent of the variability of brightness, which is a notable proportion of the variability found in a natural system. The importance of the amount of exposed soil present supports the BG Transformation theory of a plane of soils existing in three dimensional space. The other fairly strong positive correlations of brightness with number of grass species, percent grass cover, and number of understory species are all related to the amount of exposed soil and cannot be considered additively as they measure interrelated variability. Weak associations with bluegrass species, the number of shrub species, and greenness values support the assumption that increasing brightness values indicate an opening of the canopy where sites are drier and dominated by more deciduous species.

Fairly strong negative correlations of brightness values were found for wetness, percent tree cover, and basal area, factors which are also interrelated. High wetness values generally indicate areas of water or dense vegetation, thus yielding low brightness values, as shown by the correlation results. Areas of dense tree cover with predominantly large trees would result in low brightness values. A high percent of litter and Douglas fir cover would also produce low brightness values.

Greenness values also support the vegetation type expectations within the three-dimensional space (Figure 17). Percent aspen cover is most strongly correlated to greenness, explaining 36 percent of the variability and indicating the importance of deciduous vegetation in the greenness component. The other positive correlations found for greenness continue this trend, associating greenness with increased grass and aspen regeneration cover and total numbers of all species, understory species, and grass and forb species. Subalpine fir was the only conifer showing a positive correlation with greenness. Although weak, this may indicate the fir has some differing physiological or growth characteristics from the other conifer species in this area. Negative correlations of greenness and percent litter and lodgepole pine cover, although weak, again support the assumption that greenness values increase with increasing deciduous biomass, since both high lodgepole pine cover and high litter cover are associated with dense conifer areas.

Wetness values are assumed to depend on the amount of water and/or conifer biomass found on the site. Shadowing may also influence wetness values. Basal area and percent cover of Douglas fir, conifer cover, and tree cover were fairly strongly correlated to wetness, which supports the above assumption. These three factors are highly interrelated and the amount of variability in wetness that they explain must be considered separately. Percent conifer cover, which explains 42 percent of the variability in wetness, is of greatest interest in differentiating conifers from other land cover types. The slight positive correlation of slope to wetness suggests that steeper slopes tend to have stronger shadowing effects which are picked up as wetness. As expected, brightness values decreased as wetness increased. Exposed soil and sunlight-dependent species declined as wetness values increased, indicating dense conifer cover or shaded areas.

In summary, correlation analysis of brightness, greenness, and wetness values with other site factors corroborated previous expectations of the data (Figure 17). The correlations explained significant amounts of the variability of the BGW values. These results help determine the site factors that most affect spectral response patterns; in particular, percent cover of conifers, aspen, and all tree species appear to yield the most information.

Vegetation Classification and Analysis

The previous tests indicate low similarity within spectral classes and the lack of strongly distinguishing characteristics between classes. During the next stage of the study, sites were grouped into vegetation classes to determine whether vegetation classes could be associated with the spectral classes. The 90 sites were grouped into five vegetation classes based on dominant tree species: Douglas fir (23 sites), lodgepole pine (26 sites), subalpine fir (11 sites), mixed conifer (17 sites), and mixed conifer/aspen (9 sites). Four of the 90 sites were found to have meadow vegetation, with only 1-4 percent tree cover, and these sites were not included in subsequent analyses.

The classification by vegetation type was based on the planning needs of the Forest Service. For timber planning needs, identification of lodgepole pine, Douglas fir, and subalpine fir classes are especially important. A site was assigned to the conifer class in which the predominant tree species made up at least 50 percent of the cover. A species was considered dominant if it occurred at least twice as often as the next most prevalent species. In situations where no species was distinctly dominant, the site was classified as mixed conifer or mixed conifer/aspen, depending upon the presence of aspen.

The Douglas fir and lodgepole pine classes were generally internally consistent between sites. The usual characteristics of the lodgepole pine sites are 12 - 13" dbh trees, heavy needle litter, and little understory growth (Figure 22). On most Douglas fir sites, the trees are mature with large canopies, a heavy litter layer, and scattered shrubs (Figure 23). Mixed conifer and mixed conifer/aspen sites were differentiated by the amount of aspen present, rather than by percentages of conifer species. Understory growth for both classes was generally abundant and diverse (Figures 24 and 25). The subalpine fir class showed the greatest vegetative diversity. Some fir sites supported older trees with large quantities of downed wood (Figure 26), while others were occupied by young dense fir stands (Figure 27). The subalpine fir sites generally had more understory growth than Douglas fir and lodgepole pine sites but less understory growth than the mixed conifer or mixed conifer/aspen sites.

Analysis of Variance. The five vegetation classes were compared using ANOVA to test the same factors used in earlier comparisons (Table 6). The GT2-Method (Sokal and Rohlf 1981) for unplanned comparisons of means with unequal class sizes was used to compare class pairs to discover those pairs with significantly different site characteristics (Table 10). No factor clearly separates all classes. The percent of Douglas fir and subalpine fir differed most often between classes. Percent conifer cover differed significantly in seven out of the ten class comparisons. The mixed conifer class exhibited a significantly lower conifer cover than the lodgepole pine and Douglas fir classes. Results show the mixed conifer/aspen type to be the most different of the five classes.

The brightness, greenness, and wetness values showed few significant differences between classes (Table 10). Mixed conifer/aspen had higher brightness values than lodgepole pine and Douglas fir classes. The mixed

Figure 22. Typical lodgepole pine site.

Figure 23. Typical Douglas fir site.

Table 10. Significant differences between vegetation class pairs, based on the GT2-Method (Sokal and Rohlf 1981). X denotes pairs that differ significantly at the p <0.05 level.

A - Lodgepole pine
B - Mixed conifer
C - Mixed conifer/aspen
D - Douglas fir
E - Subalpine fir

SITE CHARACTERISTICS	VEGETATION CLASS PAIR COMBINATIONS									
	A&B	A&C	A&D	A&E	B&C	B&D	B&E	C&D	C&E	D&E
Overstory Characteristics										
Percent Tree Cover						X				
Percent Conifer Cover	X	X			X	X		X	X	X
Percent Douglas Fir Cover	X		X		X	X		X		X
Percent Englemann Spruce Cvr.	X					X	X			
Percent Limber Pine Cover			X			X				
Percent Lodgepole Pine Cover	X	X	X	X						
Percent Subalpine Fir Cover	X	X		X		X	X	X	X	X
Percent Aspen Cover		X			X			X	X	
Basal Area							X			
Understory Characteristics										
Percent Litter	X	X						X		
Percent Rock			X	X						
Percent Wood *										
Percent Aspen Regeneration		X			X			X	X	
Percent Arnica spp.				X						
Percent Carex spp.			X							
Percent Snowberry *										
Pysiognomic Characteristics										
Percent Basal Vegetation		X						X	X	
Total No. Species/Site	X	X						X		
No. of Understory Species		X								
No. Tree Species/Site	X					X				
No. Regeneration Species/Site		X						X	X	
No. Shrub Species/Site			X			X		X		X
No. Forb Species/Site						X				
No. Grass Species/Site		X			X			X	X	
Physical Site Characteristics										
Percent Slope	X		X					X		X
Aspect						X		X		X
Transformed Spectral Values										
Brightness		X				X		X		
Greenness		X						X	X	
Wetness						X		X		

* Note: No pairs found significantly different due to the conservativeness of the GT2-Method.

conifer class also had higher brightness values than the Douglas fir class. The classes with the most aspen cover or less overall cover (mixed conifer and mixed conifer/aspen) tended to have higher greenness values than the classes dominated by one conifer species (Table 10). Douglas fir had significantly higher wetness values than the mixed conifer and mixed conifer/aspen classes.

Percent slope is significantly different between the following pairs: lodgepole pine and Douglas fir, lodgepole pine and mixed conifer, Douglas fir and mixed conifer/aspen, and Douglas fir and subalpine fir. This may allow a separation of vegetation classes by topography.

In summary, ANOVA results generally distinguish between low and high conifer canopy cover classes; however, differences between conifer classes by species are not readily apparent. It is clear that vegetation classes alone are not directly related to the spectral values for brightness, greenness, and wetness.

Comparison between Vegetation and Spectral Classes

A comparison of the spectrally-based (BGW) and vegetation-based classifications (Table 11) indicates some possibilities for separating the various conifer types. Both the lodgepole pine and Douglas fir classes are spectrally heterogeneous; they consist of sites from eight of the nine spectral classes. Classes 5, 8, 16, 18, and 19 have at least 6 of their 10 sites included in these two major vegetation groups. Classes 20 21, 22, and, to a lesser degree class 17, form a smaller part of the lodgepole pine and Douglas fir groups.

Table 11. Comparison of the number of sites found in vegetation and spectral classes.

Vegetation Classes	Spectral Classes 5	8	16	17	18	19	20	21	22	Total
Lodgepole pine	5	5	2	4	4	3	1	2	0	26
Mixed conifer	1	2	2	4	2	0	3	1	2	17
Mixed conifer/aspen	0	0	1	0	0	3	2	3	0	9
Douglas fir	1	1	5	1	4	7	2	0	2	23
Subalpine fir	3	2	1	0	0	0	1	1	3	11
Total	10	10	10	10	10	10	10	6	10	86*

* Note: Four meadow sites (1-4 percent conifer) were not included in this comparison.

In contrast, the vegetation groups of subalpine fir, mixed conifer, and mixed conifer/aspen are more heavily represented by spectral classes 20, 21, and 22. Grouping the spectral classes into two categories yields one group containing classes 5, 8, 16, 18, and 19, and a second comprised of classes 17, 20, 21, and 22. This division also follows differences and trends noted previously in the class groupings with respect to brightness, greenness, and wetness (Figure 17). The first group, comprised of the dense conifer classes 5,8,16, 18, and 19, is clustered in areas of high wetness, and low greenness and brightness. The second group, consisting of more open-canopied areas with fewer conifers (classes 17, 20, 21, and 22), is clustered in areas of lower wetness, and higher values for greenness and brightness.

The results show that spectral values alone do not clearly differentiate between tree species, requiring that other stratifying factors be evaluated. Topographical features, such as aspect and slope, have a varying amount of influence upon a landscape's spectral response and its vegetation composition. As reported earlier, significant differences exist between percent slope for lodgepole pine and Douglas fir sites.

Discriminant function analysis was used to predict vegetation group membership using brightness, greenness, and wetness values as input. Discrimination was poor for all classes with the exception of the Douglas fir class (Table 12). A second analysis was performed using the BGW values plus slope and aspect data. The addition of these two factors improved the classification accuracy for lodgepole pine sites (Table 13). The accuracy of the other classes was not significantly changed by the addition of slope and aspect data.

Table 12. Discriminant function analysis of vegetation classes using brightness, greenness, and wetness values.

Actual Vegetation Class	Predicted Class Membership A	B	C	D	E	Total
A: Lodgepole pine	8	3	1	11	1	8/24 = 33%
B: Mixed conifer	1	4	3	6	2	4/16 = 25%
C: Mixed conifer/aspen	1	0	5	2	1	5/9 = 56%
D: Douglas fir	0	2	3	16	2	16/23 = 70%
E: Subalpine fir	2	0	2	3	4	4/11 = 36%

Table 13. Discriminant function analysis of vegetation classes using brightness, greenness, wetness, aspect, and slope values.

Actual Vegetation Class	Predicted Class Membership A	B	C	D	E	Total
A: Lodgepole pine	21	2	1	1	0	21/24 = 88%
B: Mixed conifer	4	5	3	2	2	5/16 = 31%
C: Mixed conifer/aspen	0	1	5	0	2	5/9 = 56%
D: Douglas fir	3	1	1	17	1	17/23 = 74%
E: Subalpine fir	3	1	2	2	3	3/11 = 27%

Graphing the sites from classes 5, 8, 16, 18, and 19 with respect to aspect and slope reveals some consistent patterns (Figure 28). The majority of sites with a west to northern aspect, on slopes greater than 30 percent are Douglas fir sites; of the 22 sites fitting the criteria, 17 are Douglas fir (77 percent). Sites with the same aspect on slopes less than 30 percent are predominantly lodgepole pine sites with 10 out of 13, or 77 percent. Sites with aspects of north to east are a mixture of lodgepole pine, subalpine fir, and mixed conifer sites: 8 of 14 (57 percent), 3 of 14 (21 percent), and 3 of 14 (21 percent), respectively.

Considering only the most dense conifer cover classes of 16, 18, and 19, similar results are found (Figure 29). The Douglas fir sites are found on west to north-facing aspects, on slopes greater than or equal to 35 percent; 15 of the 19 sites (79 percent) meeting these criteria are Douglas fir. Lodgepole pine sites occur on west to north aspects on slopes less than 35 percent; 8 of 9 sites (89 percent) with these characteristics are lodgepole pine. Of the 30 sites included in the three classes, only two would remain unassigned to either conifer class. Four mixed conifer sites are incorrectly assigned to the Douglas fir class, and one Douglas fir site is incorrectly assigned to the lodgepole pine class.

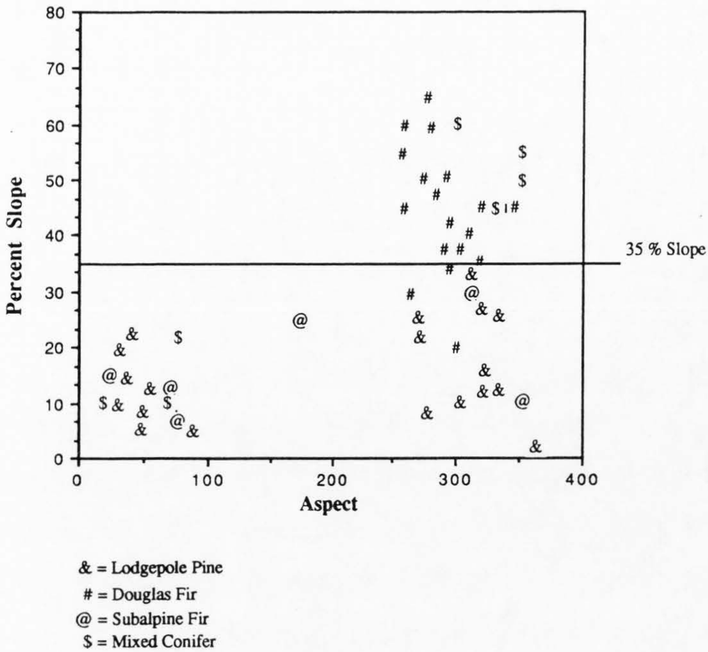


Figure 28. Sites within classes 5, 8, 16, 18, and 19 graphed with respect to their slope and aspect values.

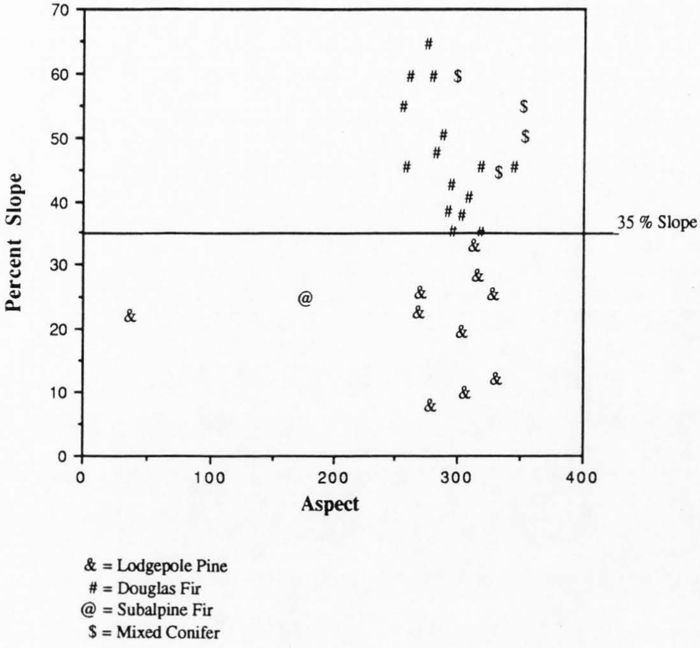


Figure 29. Sites within classes 16, 18, and 19 graphed with respect to their slope and aspect values.

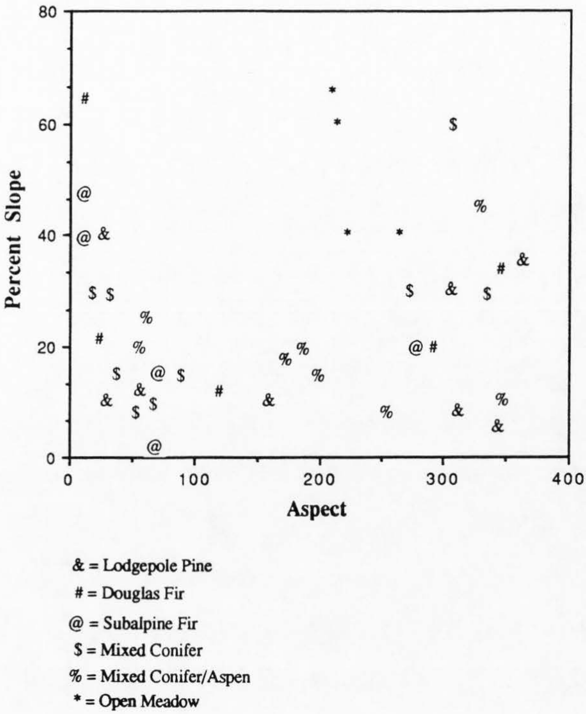


Figure 30. Sites within classes 17, 20, 21, and 22 graphed with respect to their slope and aspect values.

When the more open-canopied classes 17, 20, 21, and 22 are graphed with respect to their slope and aspect values, no discernable patterns are found (Figure 30). The sites produce an array of vegetation classes for all aspects and slopes that are not as easily separated as are the conifer classes.

Combining site spectral class with aspect and slope information leads to the separation of lodgepole pine and Douglas fir, two important conifer species classes. Other vegetation classes do not separate distinctively using aspect and slope data, and other factors must be determined to separate these classes into distinctive vegetation types.

SUMMARY AND CONCLUSIONS

The Brightness/Greenness Transformation compresses TM spectral data into brightness, greenness, and wetness values. Vegetative classes can be grouped according to their placement within the three-dimensional space formed by axes of these values. At Level II classification, which distinguishes broad patterns of conifer from deciduous vegetation, the transformation separates sites with at least 50 percent conifer cover from open conifer areas and other types of vegetation with 94 percent accuracy.

At Level III classification, which distinguishes conifer species, the use of the BG Transformation alone shows limited success. The brightness, greenness, and wetness components are generally tied to vegetation and other cover characteristics of sites but no consistent grouping of conifer species into classes was found. Within each class, sites varied considerably with respect to species presence and frequency, indicating that BGW values are influenced by more than vegetation.

The nine spectral classes used in the study follow the general trends as illustrated in Figure 17 but not to the extent of clear separation from one another. Correlation analysis indicated which site factors influenced brightness, greenness, and wetness values, but the numerous possible combinations of these factors decrease the effectiveness of using BGW values to separate vegetation types. General trends were consistently noted: brightness is associated with a low percentage of conifer canopy cover, high percent exposed soil, increased numbers and species of grasses and forbs, and a more southerly aspect. Greenness is associated with a high percentage of aspen canopy cover, increased numbers and species of grasses and forbs, and low amounts of litter. Wetness is associated with high conifer cover, increased amounts of Douglas fir, decreased numbers and species of grasses and forbs, low amounts of exposed soil, and a more northerly aspect. Further research could address the variability of these and other factors and their subsequent influence on brightness, greenness, and wetness values.

During the analysis of BGW data, the nine classes occurred along a continuum of conifer cover values. Percent conifer cover corresponded with placement within the three-dimensional BGW space. High canopy cover was indicated by low greenness and brightness, and high wetness values. A high percentage of conifer cover group classes 16, 18, and 19 contains sites of mostly pure lodgepole pine or Douglas fir. The addition of slope and aspect data aids in distinguishing between these two species. Lodgepole pine is generally found on slopes less than 35 percent, while Douglas fir is found on slopes greater than or equal to 35 percent. Use of these ancillary data results in vegetation type classification accuracy of 79 percent for Douglas fir and 89 percent for lodgepole pine.

Classes with lower conifer cover follow along the continuum but are not closely associated with a particular conifer species. Class 21 possessed the lowest conifer cover values, which are associated with high brightness and greenness and low wetness values. Classes 17, 20, and 22 have similar conifer canopy cover values but can be differentiated by considering them in BGW three-dimensional space. The classes share similar brightness values, which fall midway between the high conifer canopy cover sites and the exposed low conifer canopy cover sites. Their greenness values vary greatly, likely due to the amount of aspen found on the sites. Wetness values vary, probably attributable to the high incidence of aspen and a lush understory layer of grasses and forbs.

Along the continuum, classes 5 and 8 appear as medium conifer cover sites, with lower brightness and greenness values, and medium wetness values. This less dense conifer cover may be attributable to more exposed or rocky sites where moisture may limit conifer growth. Grouping classes along this continuum into conifer density classes appears to accentuate the differences between classes; however, these differences are not consistently tied to conifer species.

When grouping sites by the six vegetation classes, analyses of the sites showed mixed results. No one factor appeared associated with the major conifer species. Prediction of vegetation classes by BGW values was poor, except for the Douglas fir class that attained a classification accuracy of 70 percent. When slope and aspect data were added, prediction accuracy for Douglas fir remained constant but prediction of lodgepole pine class membership increased dramatically from 31 percent to 81 percent predicted correctly. The other vegetation classes may be associated with a mix of environmental factors that cannot easily be separated. It may be that, in this region, the varied terrain and overlapping environmental preferences of the conifer species result in a spectrum of varying mixtures of species that are difficult to differentiate. In addition, the mosaic of vegetation types may also depend on factors that are difficult to quantify, such as cyclical climatic regimes that encourage establishment of one species over others at a particular point in time. Another confounding factor could be the widespread presence of subalpine fir, a major climax species in the area. The reproductive success of this species could have influenced the classification results if young subalpine fir as understory reflected energy through openings in the overstory canopy. In that case, very open sites with a dense subalpine understory would have registered as dense conifer sites.

Although the TM bands were established to emphasize vegetation characteristics, other factors, such as slope, aspect, and time of day when the satellite image was taken, can influence the reflected energy measured and obscure the vegetative information. Although differences in tree canopy shape and density might be expected to influence the amount of energy reflected from a given site, this effect was not noted. Of the conifer species present in the study area, only Douglas fir seems to have physical and biological characteristics that enable its differentiation from other species by BGW values. Why only Douglas fir can be distinguished and not the other conifer species remains to be determined.

To obtain maximum information from the BG Transformation, it may be necessary to incorporate slope and aspect data before transformation. Topographic data are currently available in a digital format, although at a coarse resolution; projects for obtaining this information at a finer resolution are currently planned. These digital data are easily included into the already computerized satellite database. Whether slope and aspect information is better incorporated before the data are transformed, or treated as additional factors when clustering the data, remains to be seen.

The BG Transformation accurately classifies vegetation in the Intermountain Region for Level II needs and shows good results in discriminating between two important commercial conifer species, particularly when used with slope and aspect data. Future studies will be needed to assess whether this transformation is worth pursuing for further conifer definition or to determine differences in other land cover types. This study sets a foundation for future comparisons with other techniques, to test whether they are better suited than the BG Transformation in defining conifer species.

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APPENDICES

Appendix A. Field Sampling Form.

GENERAL PLOT DATA - FORM 3 (MODIFIED)

IDENTIFICATION AND LOCATION

F1 KEY ID 19 7 R 88 _ ___ F2 EXAMINER ___________ F3 EDIT -

F4 SURVEY AS F5 MO __ F6 DAY __ F8 PL TY 32 F9 PL RA 37

F10 PL WD 000 F12 SATE _____/_____ F13 AIR PH _____/__________

F14 SPEC CL ___ F17 UTM_______N/_______E/__ F19 TM STR _____

F20 C/S __ __ ___ F21 RA ALLOT _____/___/__ F22 RA TY ___

F25 REP _ F30 ACRES ___

ENVIRONMENTAL FEATURES

F32 ECO TY(1) _ F33 H T ___/___ F34 ECO TY(2) _ F35 H T ___/___

F36 SOIL _____ F38 P M __ F39 LA FM __ F40 PL POS _ F41 SL SH _

F42 AS ___ F43 SL % ___ F44 EL _____ F46 SOIL SUR _ F47 ER TY _

F50 G C __S + __G + __R + __L + __W + __M + __BV + __O =100% F51 SP FE __

VEGETATION STRUCTURE AND PRODUCTION

BAF__ * NO TREES ___ = F52 BA ___ F53 DBH __ F54 STRUC _ F55 VC _

F56 TOT TR COV __ F57 PO+ __ F58 SAP __ F59 SEED __

F60 TOT SH COV __ F61 TALL __ F62 MED __ F63 LOW __

F64 TOT GRAM COV __ F65 TOT FORB COV __ F72 FUELS __

ANIMAL USE AND DISTURBANCE HISTORY

F77 ANIMAL USE _____ F78 GR DIST _

ADDITIONAL INFORMATION

FASTPLOT PLANT SPECIES DATA - FORM 2 (MODIFIED)

3	4	5	6	3	4	5	6	3	4	5	6	3	4	5	6
L	Species 1	C	I	L	Species 2	C	I	L	Species 3	C	I	L	Species 4	C	I
L	Species 5	C	I	L	Species 6	C	I	L	Species 7	C	I	L	Species 8	C	I
L	Species 9	C	I	L	Species 10	C	I	L	Species 11	C	I	L	Species 12	C	I

F1 KEY ID _ _ _ _ _ _ _ _

F14 SPECTRAL CLASS _ _ _

ABIES CONCOLOR	
ABIES LASIOCARPA	
PICEA ENGELMANNII	
PICEA PUNGENS	
PINUS CONTORTA	
PINUS FLEXILIS	
PINUS PONDEROSA	
PSEUDOTSUGA MENZIESII	
POPULUS TREMULOIDES	
ACER GLABRUM	
ARCTOSTAPHYLOS PATULA	
ARCTOSTAPHYLOS UVA-URSI	
ARTEMESIA TRIDENTATA	
BERBERIS REPENS	
CERCOCARPUS LEDIFOLIUS	
JUNIPERUS COMMUNIS	
PACHISTIMA MYRSINITES	
PHYSOCARPUS MALVACEUS	
PRUNUS VIRGINIANA	
RIBES MONTEGINUM	
SORBUS SCOPULINA	
SYMPHORICARPOS OREOPHILUS	
VACCINIUM CAESPITOSUM	
VACCINIUM GLOBULARE	
VACCINIUM MEMBRANACEUM	
VACCINIUM SCOPARIUM	

FL KEY ID

FL SPECTRAL CLASS

	AGROPYRON SPICATUM
	CALAMAGROSTIS CANADENSIS
	CALAMAGROSTIS RUBESCENS
	CAREX GEYERI
	CAREX ROSSII
	FESTUCA IDAHOENSIS
	LEUCOPOA KINGII
	TRISETUM SPICATUM
	ACTEA RUBRA
	ARNICA CORDIFOLIA
	ARNICA LATIFOLIA
	CALTHA LEPTOSEPALA
	EQUISETUM ARVENSE
	OSMORHIZA CHILENSIS
	PEDICULARIS RACEMOSA
	SENECIO TRIANGULARIS
	STREPTOPUS AMPLEXIFOLIUS
	THALICTRUM FENDLERI
	BARE SOIL
	ROCK
	GRAVEL
	LITTER
	WOOD

Appendix B. List of Plants
Encountered on Sampling Sites.

Note: Plants are listed in alphabetical order by their scientific name. Common names and physiognomic life form designations are included.

Species and Common Names	Life Form #
Abies lasiocarpa (Subalpine fir)	T,R
Acer glabrum (Rocky mountain maple)	S
Achillea millefolium (Yarrow)	F
Actea rubra (Baneberry)	S
Agastache urticifolia (Giant hyssop)	F
Agropyron spicatum (Bluebunch wheatgrass)	G
* Agropyron spp. (Wheatgrass species)	G
Amelanchier alnifolia (Serviceberry)	S
* Arnica spp. (Arnica species)	F
Artemisia tridentata (Big sagebrush)	S
* Aster spp. (Aster species)	F
Balsamorhiza sagittata (Arrowleaf balsamroot)	F
Berberis repens (Oregon grape)	S
* Bromus spp. (Bromegrass species)	G
* Calamagrostis sp. (Reedgrass)	G
* Carex spp. (Sedge species)	G
Cercocarpus ledifolius (Mountain mahogany)	S
Chimaphila umbellata (Princes pine)	S
Chrysothamnus nauseosus (Rabbitbrush)	S
* Clematis sp. (Virgins-bower)	F
* Collomia sp. (Collomia)	F
Cynoglossum officinale (Houndstongue)	F
Elymus glaucus (Blue wildrye)	G
* Erigeron sp. (Fleabane)	F
* Eriogonum sp. (Wild buckwheat)	F
Frasera speciosa (Green gentian)	F
* Galium sp. (Bedstraw)	F
* Geranium sp. (Geranium)	F
* Hackelia sp. (Stickseed)	F
Hieracium scouleri (Woollyweed)	F
Juniperus scopulorum (Rocky mountain juniper)	S
Lathyrus lanzwertii (Lanzwert sweetpea)	F
Leucopoa kingii (Leucopoa)	G
Ligusticum filicinum (Lovage)	F
* Lomatium sp. (Biscuitroot)	F
Lonicera involucrata (Twinberry)	S
* Lupinus sp. (Lupine)	F
* Mitella spp. (Mitrewort)	F
* Osmorhiza spp. (Sweetroot species)	F
Pachistima myrsinites (Mountain-lover)	S
Pedicularis racemosa (Parrot's beak)	F
Physocarpus malvaceus (Ninebark)	S
Picea englemannii (Englemann spruce)	T,R
Pinus contorta (Lodgepole pine)	T,R

Pinus flexilis (Limber pine)	T,R
* *Poa spp.* (Bluegrass species)	G
Populus tremuloides (Aspen)	T,R
* *Potentilla sp.* (Cinquefoil)	F
Prunus virginiana (Chokecherry)	S
Pseudotsuga menziesii (Douglas fir)	T,R
Pyrola secunda (Sidebells pyrola)	F
* *Ribes sp.* (Currant)	S
Rosa nutkana (Nootka rose)	S
Rubus parviflorus (Thimble berry)	S
Rudbeckia occidentalis (Western coneflower)	F
Salix scouleriana (Scouler willow)	S
Sambucus caerula (Blue elderberry)	S
Shepherdia canadensis (Russet buffalo-berry)	S
Smilacina racemosa (False solomon seal)	F
Sorbus scopulina (Greenes mountain ash)	S
* *Sporobolus sp.* (Dropseed)	G
Stellaria jamesiana (Tuber starwort)	F
* *Stipa spp.* (Needlegrass)	G
Streptopus amplexifolius (Twisted stalk)	F
Symphoricarpos oreophilus (Mountain snowberry)	S
Thalictrum fendleri (Fendler meadowrue)	F
Trisetum spicatum (Trisetum)	G
* *Viola sp.* (Violet)	F
Wyethia amplexicaulis (Mulesear)	F
* Unknown grass species	G
* Unknown forb species	F
* Unknown mustard species	F

Life Form categories:

T - Trees
R - Tree regeneration (tree a member of understory)
S - Shrub (woody species, not a member of overstory)
F - Forb (annual and perennial)
G - Grass and grass-like species

* Note: Due to the extremely dry growing season, many plants showed poor characteristics for identification at the species level. Plants which were determined to be of the same species by their vegetative characteristics are grouped by the designation *sp*. When uncertain if the groupings represented one or more species, the *spp*. designation is used.

Appendix C. Plant Species Similarity
Tables for the Nine Conifer Classes.

Note: All values calculated with Spatz's quantitative modification of Jaccard's Similarity Index (Mueller-Dombois and Ellenberg 1974).

Table 1. Class 5 Similarity Index values.

	Class 5 Sites								
	2	3	4	5	6	7	8	9	10
1	16.30	10.01	.11	1.53	.28	.07	8.83	2.79	4.85
2		2.20	.08	.01	.23	.05	2.23	1.67	1.76
3			.09	.80	4.15	1.90	11.69	2.66	11.27
4				23.01	13.10	47.15	.60	5.49	.44
5					29.75	23.15	2.82	14.90	3.07
6						22.04	2.36	9.64	7.11
7							1.89	20.99	1.62
8								3.49	9.67
9									9.76

Table 2. Class 8 Similarity Index values.

	Class 8 Sites								
	2	3	4	5	6	7	8	9	10
1	.05	.30	.03	1.69	6.13	.20	.04	.04	.00
2		4.79	18.12	3.25	3.85	21.57	25.40	14.98	20.46
3			10.71	25.47	11.27	2.50	7.78	8.40	5.62
4				15.45	8.66	12.36	21.82	16.22	12.52
5					18.18	3.91	5.53	2.73	7.86
6						5.10	4.93	8.47	4.71
7							13.72	16.58	7.92
8								16.69	17.98
9									19.72

Table 3. Class 16 Similarity Index values.

	Class 16 Sites								
	2	3	4	5	6	7	8	9	10
1	6.50	1.08	12.97	4.96	1.52	12.82	10.77	.03	.04
2		2.49	14.44	4.12	7.03	5.52	8.13	1.95	1.50
3			1.84	.06	9.69	2.41	.03	9.61	1.68
4				7.14	6.12	24.64	14.49	.89	3.76
5					2.41	6.24	15.09	.13	.17
6						6.04	5.52	7.37	7.85
7							8.83	.29	.75
8								.00	.04
9									27.16

Table 4. Class 17 Similarity Index values.

	Class 17 Sites								
	2	3	4	5	6	7	8	9	10
1	17.12	6.77	10.80	3.28	6.00	2.89	6.63	6.47	6.22
2		15.98	9.50	6.89	2.29	1.90	10.24	3.11	6.23
3			6.86	10.68	12.82	9.88	2.09	7.06	6.20
4				14.21	1.08	5.70	3.24	4.29	2.59
5					2.73	2.89	.51	.55	.21
6						18.93	3.90	8.28	6.44
7							3.41	13.25	7.91
8								1.31	5.96
9									14.27

Table 5. Class 18 Similarity Index values.

	Class 18 Sites								
	2	3	4	5	6	7	8	9	10
1	11.37	8.94	14.16	2.87	.60	1.42	.07	18.96	11.94
2		14.72	1.52	7.20	2.21	9.43	.81	27.03	25.49
3			12.08	3.08	1.00	1.37	2.28	17.83	12.98
4				.00	.48	.03	.03	4.50	5.73
5					13.96	21.02	19.29	2.82	2.91
6						16.33	24.97	1.59	1.77
7							9.52	7.29	5.91
8								.71	1.40
9									17.53

Table 6. Class 19 Similarity Index values.

	Class 19 Sites								
	2	3	4	5	6	7	8	9	10
1	5.04	7.92	5.38	.01	4.73	.31	.12	7.59	4.14
2		27.49	20.02	4.15	19.50	14.71	4.56	7.02	6.34
3			13.47	3.21	13.85	7.97	4.28	14.44	11.81
4				8.21	1.96	14.01	12.41	2.69	5.37
5					1.30	31.06	14.40	.00	.12
6						6.10	3.15	4.51	14.74
7							22.50	1.11	1.06
8								.06	.76
9									28.95

Table 7. Class 20 Similarity Index values.

	Class 20 Sites								
	2	3	4	5	6	7	8	9	10
1	5.32	6.90	3.47	3.40	4.58	4.82	4.68	3.02	6.43
2		2.84	8.31	5.79	2.30	7.88	3.26	1.15	19.84
3			24.39	5.79	24.96	18.83	12.22	9.87	4.84
4				4.19	14.47	13.37	3.96	7.33	9.40
5					8.90	4.55	7.02	5.77	6.62
6						20.49	13.62	11.41	2.23
7							15.01	14.00	13.09
8								17.04	4.75
9									4.73

Table 8. Class 21 Similarity Index values.

	Class 21 Sites								
	2	3	4	5	6	7	8	9	10
1	.00	.00	.03	.05	.04	27.06	11.44	.38	20.37
2		10.41	5.07	7.11	4.13	.00	.00	8.35	.00
3			11.01	9.70	7.56	.00	.04	14.60	.00
4				.45	20.07	.00	.00	8.90	.62
5					5.51	.03	4.08	12.61	21.47
6						.00	.34	7.26	1.38
7							14.49	.03	21.47
8								4.09	10.37
9									.86

Table 9. Class 22 Similarity Index values.

	Class 22 Sites								
	2	3	4	5	6	7	8	9	10
1	8.96	9.31	5.53	4.33	3.64	.24	13.09	12.83	.58
2		9.85	5.99	13.04	3.64	.32	15.02	9.50	3.56
3			8.75	23.99	9.57	4.52	11.48	10.50	2.53
4				19.75	11.48	10.09	13.52	15.41	.00
5					9.70	4.99	12.69	10.27	1.47
6						17.97	6.48	7.40	.07
7							1.54	3.65	.00
8								.25	.00
9									.00

Appendix D. Presence X Frequency Values for Plant Species.

Note: Index values were calculated by multiplying the percent presence of a species in the study sites by the average percent frequency of a species in stands of occurrence.

OVERSTORY SPECIES	P X F INDEX VALUE
Pseudotsuga menziesii (Douglas fir)	1917
Pinus contorta (Lodgepole pine)	1826
Abies lasiocarpa (Subalpine fir)	1400
Populus tremuloides (Aspen)	616
Picea englemannii (Englemann spruce)	227
Pinus flexilis (Limber pine)	45

UNDERSTORY SPECIES	
Abies lasiocarpa (Subalpine fir) regeneration	1104
Symphoricarpos oreophilus (Mountain snowberry)	346
Arnica spp. (Arnica species)	265
Pedicularis racemosa (Parrot's beak)	254
Lathyrus lanzwertii (Lanzwert sweetpea)	183
Carex spp. (Sedge species)	162
Osmorhiza spp. (Sweetroot species)	156
Populus tremuloides (Aspen) regeneration	146
Poa spp. (Bluegrass species)	108
Cercocarpus ledifolius (Mountain mahogany)	103
Stellaria jamesiana (Tuber starwort)	100
Aster spp. (Aster species)	95
Pachistima myrsinites (Mountain-lover)	92
Bromus spp. (Bromegrass species)	86
Elymus glaucus (Blue wildrye)	84
Agropyron spp. (Wheatgrass species)	79
Physocarpus malvaceus (Ninebark)	76
Hieracium scouleri (Woollyweed)	59
Pseudotsuga menziesii (Douglas fir) regeneration	57
Picea englemannii (Englemann spruce) regeneration	43
Prunus virginiana (Chokecherry)	41
Mitella spp. (Mitrewort)	30
Acer glabrum (Rocky mountain maple)	29
Amelanchier alnifolia (Serviceberry)	28
Achillea millefolium (Yarrow)	26
Thalictrum fendleri (Fendler meadowrue)	25
Trisetum spicatum (Trisetum)	23
Unknown grass species	22
Berberis repens (Oregon grape)	21
Stipa spp. (Needlegrass)	21
Clematis sp. (Virgins-bower)	20
Artemisia tridentata (Big sagebrush)	19
Agastache urticifolia (Giant hyssop)	18

Hackelia sp. (Stickseed)	17
Ligusticum filicinum (Lovage)	17
Rosa nutkana (Nootka rose)	15
Pyrola secunda (Sidebells pyrola)	14
Pinus contorta (Lodgepole pine) regeneration	13
Rudbeckia occidentalis (Western coneflower)	13
Balsamorhiza sagittata (Arrowleaf balsamroot)	12
Galium sp. (Bedstraw)	12
Potentilla sp. (Cinquefoil)	11
Lupinus sp. (Lupine)	9
Geranium sp. (Geranium)	8
Sambucus caerula (Blue elderberry)	8
Shepherdia canadensis (Russet buffalo-berry)	8
Unknown forb species	6
Eriogonum sp. (Wild buckwheat)	5
Lomatium sp. (Biscuitroot)	4
Viola sp. (Violet)	4
Frasera speciosa (Green gentian)	3
Sporobolus sp. (Dropseed)	3
Chrysothamnus nauseosus (Rabbitbrush)	2
Cynoglossum officinale (Houndstongue)	2
Erigeron sp. (Fleabane)	2
Pinus flexilis (Limber pine) regeneration	2
Actea rubra (Baneberry)	1
Calamagrostis sp. (Reedgrass)	1
Chimaphila umbellata (Princes pine)	1
Collomia sp. (Collomia)	1
Juniperus scopulorum (Rocky mountain juniper)	1
Leucopoa kingii (Leucopoa)	1
Lonicera involucrata (Twinberry)	1
Ribes sp. (Currant)	1
Rubus parviflorus (Thimble berry)	1
Salix scouleriana (Scouler willow)	1
Smilacina racemosa (False solomon seal)	1
Sorbus scopulina (Greenes mountain ash)	1
Streptopus amplexifolius (Twisted stalk)	1
Wyethia amplexicaulis (Mulesear)	1
Unknown mustard species	1

Appendix E. Descriptive Statistics for all Study Sites.

CLASS 5

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	57.20	13.10	34.00	82.00
% Conifer Cover	56.70	14.04	30.00	82.00
% *Abies lasiocarpa*	14.20	19.88	.00	54.00
% *Picea englemannii*	4.40	9.70	.00	28.00
% *Pinus contorta*	29.40	30.95	.00	66.00
% *Pinus flexilis*	.00	.00	.00	.00
% *Populus tremuloides*	.50	1.27	.00	4.00
% *Pseudotsuga menziesii*	8.70	24.48	.00	78.00
Basal Area	182.00	40.50	120.00	240.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	10.90	8.58	1.00	24.00
% *Arnica spp*.	2.60	3.63	.00	10.00
% *Carex spp*.	1.40	2.22	.00	6.00
% *Osmorhiza spp*.	.80	1.32	.00	3.00
% *Pachistima myrsinites*	.00	.00	.00	.00
% *Pedicularis racemosa*	3.50	4.72	.00	14.00
% *Poa spp*.	.00	.00	.00	.00
% *Populus tremuloides* Reg.	.20	.63	.00	2.00
% *Stellaria jamesiana*	.70	1.25	.00	3.00
% *Symphoricarpos oreophilus*	.10	.32	.00	1.00
% Exposed Soil	.90	.99	.00	3.00
% Litter	53.90	19.12	19.00	73.00
% Moss	.00	.00	.00	.00
% Rock	.10	.32	.00	1.00
% Wood	20.00	8.42	11.00	36.00
Physiognomic Characteristics				
% Shrub	.80	1.03	.00	3.00
% Grass	2.70	3.02	.00	8.00
% Forbs	10.00	7.32	.00	21.00
% Regeneration	11.70	8.87	2.00	26.00
% Basal Vegetation	25.00	12.39	7.00	45.00
Total No. Species	7.80	3.22	4.00	12.00
No. Understory Species	5.90	2.92	2.00	11.00
No. Tree Species	1.90	.88	1.00	3.00
No. Shrub Species	.70	.82	.00	2.00
No. Forb Species	2.80	2.25	.00	6.00
No. Grass Species	1.00	1.05	.00	3.00
No. Regeneration Species	1.40	.52	1.00	2.00

Physical Site Characteristics

Elevation (ft.)	7812.00	435.25	7240.00	8600.00
Slope (percent)	14.00	10.00	.00	30.00
Aspect (normalized radians)	1.35	.77	.28	2.36

Transformed Spectral Values

Brightness	36.78	4.85	29.56	46.29
Greenness	50.19	5.50	42.00	58.08
Wetness	165.82	9.37	150.06	180.79

CLASS 8

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	64.30	12.39	37.00	79.00
% Conifer Cover	60.30	10.02	37.00	72.00
% *Abies lasiocarpa*	18.00	22.49	.00	55.00
% *Picea englemannii*	.00	.00	.00	.00
% *Pinus contorta*	32.50	28.93	.00	72.00
% *Pinus flexilis*	.00	.00	.00	.00
% *Populus tremuloides*	4.00	6.27	.00	18.00
% *Pseudotsuga menziesii*	9.80	22.71	.00	69.00
Basal Area	164.00	39.78	100.00	240.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	17.70	16.30	.00	53.00
% *Arnica spp*.	4.20	5.35	.00	13.00
% *Carex spp*.	3.30	3.80	.00	10.00
% *Osmorhiza spp*.	1.10	2.60	.00	8.00
% *Pachistima myrsinites*	.90	.74	.00	2.00
% *Pedicularis racemosa*	4.20	4.39	.00	11.00
% *Poa spp*.	.10	.32	.00	1.00
% *Populus tremuloides* Reg.	.40	1.26	.00	4.00
% *Stellaria jamesiana*	1.50	2.51	.00	8.00
% *Symphoricarpos oreophilus*	1.80	3.16	.00	10.00
% Exposed Soil	1.80	1.93	.00	6.00
% Litter	36.70	12.70	19.00	55.00
% Moss	.10	.32	.00	1.00
% Rock	.40	.97	.00	3.00
% Wood	15.30	8.43	5.00	35.00
Physiognomic Characteristics				
% Shrub	4.70	6.95	.00	23.00
% Grass	4.70	3.68	.00	10.00
% Forbs	17.90	8.61	5.00	34.00
% Regeneration	18.40	17.00	.00	55.00
% Basal Vegetation	45.70	14.31	26.00	71.00
Total No. Species	10.30	2.36	8.00	16.00
No. Understory Species	8.30	2.06	6.00	13.00
No. Tree Species	2.00	.94	1.00	3.00
No. Shrub Species	1.60	1.51	.00	5.00
No. Forb Species	4.10	1.66	2.00	8.00
No. Grass Species	1.40	.84	.00	3.00
No. Regeneration Species	1.20	.63	.00	2.00

Physical Site Characteristics

Elevation (ft.)	7746.00	259.07	7400.00	8240.00
Slope (percent)	16.00	13.00	5.00	50.00
Aspect (normalized radians)	1.68	.76	.40	2.63

Transformed Spectral Values

Brightness	30.22	1.89	27.00	33.78
Greenness	68.51	3.12	65.26	73.28
Wetness	187.50	5.91	178.44	196.57

CLASS 16

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	78.10	8.72	63.00	92.00
% Conifer Cover	76.30	11.25	55.00	92.00
% *Abies lasiocarpa*	11.40	18.19	.00	55.00
% *Picea englemannii*	1.20	3.79	.00	12.00
% *Pinus contorta*	15.60	30.05	.00	77.00
% *Pinus flexilis*	1.30	3.47	.00	11.00
% *Populus tremuloides*	1.80	3.55	.00	9.00
% *Pseudotsuga menziesii*	46.80	37.60	.00	90.00
Basal Area	210.00	43.46	160.00	280.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	6.30	6.67	.00	19.00
% *Arnica spp*.	3.60	6.92	.00	19.00
% *Carex spp*.	.20	.42	.00	1.00
% *Osmorhiza spp*.	.30	.67	.00	2.00
% *Pachistima myrsinites*	.40	.97	.00	3.00
% *Pedicularis racemosa*	.50	.85	.00	2.00
% *Poa spp*.	.20	.63	.00	2.00
% *Populus tremuloides* Reg.	.20	.63	.00	2.00
% *Stellaria jamesiana*	.40	.97	.00	3.00
% *Symphoricarpos oreophilus*	4.10	6.45	.00	17.00
% Exposed Soil	1.10	1.52	.00	4.00
% Litter	47.30	12.94	35.00	71.00
% Moss	.00	.00	.00	.00
% Rock	1.10	1.45	.00	4.00
% Wood	15.80	11.35	5.00	43.00
Physiognomic Characteristics				
% Shrub	10.20	13.89	.00	43.00
% Grass	1.40	1.65	.00	5.00
% Forbs	12.00	12.65	.00	40.00
% Regeneration	11.00	7.15	1.00	23.00
% Basal Vegetation	34.70	14.60	15.00	51.00
Total No. Species	9.10	3.54	4.00	14.00
No. Understory Species	6.70	3.23	2.00	11.00
No. Tree Species	2.40	1.08	1.00	5.00
No. Shrub Species	1.60	1.43	.00	4.00
No. Forb Species	2.70	1.89	.00	6.00
No. Grass Species	.80	.63	.00	2.00
No. Regeneration Species	1.60	.70	1.00	3.00

Physical Site Characteristics

Elevation (ft.)	7798.00	426.09	7100.00	8300.00
Slope (percent)	40.00	16.00	8.00	6.00
Aspect (normalized radians)	.64	.61	.02	2.13

Transformed Spectral Values

Brightness	13.21	4.62	7.12	20.00
Greenness	71.19	6.71	62.82	88.00
Wetness	214.42	9.64	197.70	227.00

CLASS 17

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	51.00	12.39	26.00	70.00
% Conifer Cover	46.30	16.11	25.00	70.00
% *Abies lasiocarpa*	11.20	8.36	.00	27.00
% *Picea englemannii*	5.70	8.46	.00	24.00
% *Pinus contorta*	23.50	26.90	.00	66.00
% *Pinus flexilis*	.00	.00	.00	.00
% *Populus tremuloides*	4.70	7.94	.00	24.00
% *Pseudotsuga menziesii*	5.90	16.00	.00	51.00
Basal Area	130.00	27.08	80.00	160.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	12.50	7.99	2.00	26.00
% *Arnica spp.*	1.20	1.93	.00	6.00
% *Carex spp.*	1.60	2.37	.00	7.00
% *Osmorhiza spp.*	.70	1.06	.00	3.00
% *Pachistima myrsinites*	2.30	5.95	.00	19.00
% *Pedicularis racemosa*	4.10	6.61	.00	18.00
% *Poa spp.*	.60	.84	.00	2.00
% *Populus tremuloides* Reg.	2.00	2.54	.00	6.00
% *Stellaria jamesiana*	1.90	2.28	.00	6.00
% *Symphoricarpos oreophilus*	2.30	4.40	.00	12.00
% Exposed Soil	4.40	3.69	.00	10.00
% Litter	36.70	18.10	10.00	67.00
% Moss	.00	.00	.00	.00
% Rock	.50	.71	.00	2.00
% Wood	17.30	11.48	6.00	37.00
Physiognomic Characteristics				
% Shrub	5.10	10.37	.00	32.00
% Grass	7.60	10.99	.00	37.00
% Forbs	12.70	8.64	.00	31.00
% Regeneration	15.70	8.34	4.00	29.00
% Basal Vegetation	41.20	18.58	17.00	66.00
Total No. Species	12.00	4.29	6.00	20.00
No. Understory Species	9.30	4.06	2.00	16.00
No. Tree Species	2.70	.95	1.00	4.00
No. Shrub Species	1.10	1.20	.00	3.00
No. Forb Species	3.80	2.10	.00	8.00
No. Grass Species	2.30	1.89	.00	5.00
No. Regeneration Species	2.10	.99	1.00	4.00

Physical Site Characteristics

Elevation (ft.)	8048.00	529.92	7400.00	8700.00
Slope (percent)	22.00	9.00	10.00	35.00
Aspect (normalized radians)	1.50	.73	.09	2.67

Transformed Spectral Values

Brightness	60.69	5.08	51.84	67.43
Greenness	61.24	5.47	52.76	69.63
Wetness	144.20	6.11	136.33	152.70

CLASS 18

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	67.00	8.72	51.00	78.00
% Conifer Cover	66.80	8.97	51.00	78.00
% *Abies lasiocarpa*	14.00	12.61	.00	34.00
% *Picea englemannii*	.20	.63	.00	2.00
% *Pinus contorta*	24.00	31.63	.00	74.00
% *Pinus flexilis*	1.30	2.67	.00	8.00
% *Populus tremuloides*	.20	.63	.00	2.00
% *Pseudotsuga menziesii*	27.30	26.47	.00	70.00
Basal Area	188.00	46.38	120.00	240.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	9.50	13.29	.00	45.00
% *Arnica spp*.	4.50	5.10	.00	13.00
% *Carex spp*.	1.00	2.00	.00	6.00
% *Osmorhiza spp*.	2.80	6.21	.00	20.00
% *Pachistima myrsinites*	2.10	4.28	.00	14.00
% *Pedicularis racemosa*	2.10	4.79	.00	15.00
% *Poa spp*.	.10	.32	.00	1.00
% *Populus tremuloides* Reg.	.00	.00	.00	.00
% *Stellaria jamesiana*	.50	1.27	.00	4.00
% *Symphoricarpos oreophilus*	1.50	2.32	.00	6.00
% Exposed Soil	1.40	2.50	.00	6.00
% Litter	49.90	18.37	21.00	74.00
% Moss	.20	.63	.00	2.00
% Rock	.60	.97	.00	3.00
% Wood	16.90	8.47	3.00	31.00
Physiognomic Characteristics				
% Shrub	6.50	11.77	.00	39.00
% Grass	1.60	2.07	.00	6.00
% Forbs	13.30	13.25	1.00	45.00
% Regeneration	10.00	13.14	1.00	45.00
% Basal Vegetation	30.80	20.82	6.00	63.00
Total No. Species	8.90	2.13	6.00	14.00
No. Understory Species	6.80	2.44	4.00	12.00
No. Tree Species	2.10	.99	1.00	4.00
No. Shrub Species	1.30	1.16	.00	3.00
No. Forb Species	3.40	1.58	1.00	6.00
No. Grass Species	.70	.67	.00	2.00
No. Regeneration Species	1.40	.52	1.00	2.00

Physical Site Characteristics

Elevation (ft.)	7688.00	505.72	7000.00	8600.00
Slope (percent)	35.00	16.00	12.00	65.00
Aspect (normalized radians)	.50	.53	.03	1.76

Transformed Spectral Values

Brightness	16.08	3.44	10.11	20.17
Greenness	48.61	5.43	38.22	57.60
Wetness	195.02	6.33	182.02	205.54

CLASS 19

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	70.80	9.02	60.00	86.00
% Conifer Cover	70.60	9.11	60.00	86.00
% *Abies lasiocarpa*	5.50	5.58	.00	15.00
% *Picea englemannii*	1.80	3.36	.00	10.00
% *Pinus contorta*	18.00	29.13	.00	67.00
% *Pinus flexilis*	1.00	2.21	.00	7.00
% *Populus tremuloides*	.20	.63	.00	2.00
% *Pseudotsuga menziesii*	44.30	30.30	.00	86.00
Basal Area	208.00	31.55	160.00	240.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	14.00	12.99	.00	44.00
% *Arnica spp*.	3.30	4.69	.00	15.00
% *Carex spp*.	.20	.63	.00	2.00
% *Osmorhiza spp*.	.50	.71	.00	2.00
% *Pachistima myrsinites*	1.00	2.16	.00	7.00
% *Pedicularis racemosa*	2.90	7.58	.00	24.00
% *Poa spp*.	.20	.42	.00	1.00
% *Populus tremuloides* Reg.	.00	.00	.00	.00
% *Stellaria jamesiana*	.60	1.26	.00	3.00
% *Symphoricarpos oreophilus*	2.90	4.63	.00	13.00
% Exposed Soil	1.50	2.72	.00	7.00
% Rock	1.00	2.00	.00	6.00
% Litter	51.40	18.52	28.00	93.00
% Wood	11.90	7.25	4.00	26.00
% Moss	.00	.00	.00	.00
Physiognomic Characteristics				
% Shrub	6.30	7.24	.00	19.00
% Grass	2.20	3.46	.00	10.00
% Forbs	10.20	9.50	.00	31.00
% Regeneration	14.60	13.52	.00	46.00
% Basal Vegetation	34.20	16.92	1.00	57.00
Total No. Species	8.50	3.31	2.00	15.00
No. Understory Species	6.00	3.50	1.00	13.00
No. Tree Species	2.50	1.18	1.00	4.00
No. Shrub Species	1.50	1.27	.00	3.00
No. Forb Species	2.50	1.51	.00	5.00
No. Grass Species	.90	1.45	.00	4.00
No. Regeneration Species	1.10	.74	.00	2.00

Physical Site Characteristics

Elevation (ft.)	7954.00	438.49	7100.00	8600.00
Slope (percent)	39.00	16.00	10.00	60.00
Aspect (normalized radians)	.31	.21	.02	.65

Transformed Spectral Values

Brightness	4.54	2.68	1.13	10.13
Greenness	50.54	4.58	39.91	55.55
Wetness	211.43	13.56	182.91	223.93

CLASS 20

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	56.40	12.40	40.00	76.00
% Conifer Cover	39.80	12.73	20.00	58.00
% *Abies lasiocarpa*	18.40	14.00	.00	51.00
% *Picea englemannii*	1.20	3.16	.00	10.00
% *Pinus contorta*	8.30	18.75	.00	58.00
% *Pinus flexilis*	.00	.00	.00	.00
% *Populus tremuloides*	18.10	13.97	.00	40.00
% *Pseudotsuga menziesii*	11.90	16.09	.00	38.00
Basal Area	134.00	31.34	80.00	180.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	13.40	10.06	.00	31.00
% *Arnica spp*.	1.40	2.55	.00	8.00
% *Carex spp*.	2.00	1.89	.00	5.00
% *Osmorhiza spp*.	.70	.95	.00	2.00
% *Pachistima myrsinites*	1.40	4.43	.00	14.00
% *Pedicularis racemosa*	3.30	6.57	.00	18.00
% *Poa spp*.	1.70	2.45	.00	7.00
% *Populus tremuloides* Reg.	5.50	8.14	.00	26.00
% *Stellaria jamesiana*	1.80	2.20	.00	7.00
% *Symphoricarpos oreophilus*	7.60	12.13	.00	33.00
% Exposed Soil	3.70	2.45	1.00	9.00
% Litter	27.40	15.81	11.00	53.00
% Moss	.00	.00	.00	.00
% Rock	.20	.63	.00	2.00
% Wood	15.90	7.72	5.00	33.00
Physiognomic Characteristics				
% Shrub	9.70	12.46	.00	35.00
% Grass	10.00	7.16	1.00	22.00
% Forbs	13.40	7.57	1.00	24.00
% Regeneration	20.00	13.33	1.00	44.00
% Basal Vegetation	52.80	15.53	27.00	77.00
Total No. Species	13.80	2.57	8.00	17.00
No. Understory Species	11.10	2.60	6.00	15.00
No. Tree Species	2.70	.67	2.00	4.00
No. Shrub Species	1.10	1.29	.00	4.00
No. Forb Species	4.90	1.79	1.00	7.00
No. Grass Species	3.10	1.85	1.00	6.00
No. Regeneration Species	2.00	.94	1.00	4.00

Physical Site Characteristics

Elevation (ft.)	8070.00	479.28	7280.00	8600.00
Slope (percent)	18.00	8.00	8.00	30.00
Aspect (normalized radians)	1.73	.93	.16	3.12

Transformed Spectral Values

Brightness	52.23	8.03	39.00	62.07
Greenness	86.97	12.21	64.40	101.06
Wetness	161.63	19.28	124.55	190.06

CLASS 21

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	24.80	21.97	1.00	54.00
% Conifer Cover	20.10	18.52	1.00	50.00
% Abies lasiocarpa	6.90	12.81	.00	40.00
% Picea englemannii	1.00	3.16	.00	10.00
% Pinus contorta	11.10	16.54	.00	45.00
% Pinus flexilis	.10	.32	.00	1.00
% Populus tremuloides	4.70	7.63	.00	22.00
% Pseudotsuga menziesii	1.00	1.63	.00	4.00
Basal Area	69.00	72.18	.00	200.00
Understory Characteristics				
% Abies lasiocarpa Reg.	6.20	7.27	.00	19.00
% Arnica spp.	.90	2.18	.00	7.00
% Carex spp.	1.00	1.15	.00	3.00
% Osmorhiza spp.	.50	.97	.00	3.00
% Pachistima myrsinites	.00	.00	.00	.00
% Pedicularis racemosa	.70	1.25	.00	4.00
% Poa spp.	2.00	3.09	.00	9.00
% Populus tremuloides Reg.	3.30	6.83	.00	22.00
% Stellaria jamesiana	.80	1.48	.00	4.00
% Symphoricarpos oreophilus	8.20	18.32	.00	59.00
% Exposed Soil	10.50	7.18	.00	21.00
% Litter	20.90	18.41	3.00	53.00
% Moss	.00	.00	.00	.00
% Rock	1.60	3.20	.00	9.00
% Wood	11.70	9.26	.00	27.00
Physiognomic Characteristics				
% Shrub	22.30	28.49	.00	68.00
% Grass	13.20	7.89	4.00	28.00
% Forbs	10.70	6.90	4.00	27.00
% Regeneration	10.10	13.41	.00	41.00
% Basal Vegetation	54.60	25.11	12.00	85.00
Total No. Species	12.00	2.79	8.00	17.00
No. Understory Species	10.20	2.44	6.00	14.00
No. Tree Species	1.80	.79	1.00	3.00
No. Shrub Species	2.20	1.93	.00	5.00
No. Forb Species	3.30	1.34	2.00	6.00
No. Grass Species	3.40	1.17	2.00	5.00
No. Regeneration Species	1.30	1.34	.00	3.00

Physical Site Characteristics

Elevation (ft.)	8020.00	507.28	7300.00	8700.00
Slope (percent)	30.00	23.00	5.00	66.00
Aspect (normalized radians)	1.28	.70	.26	2.29

Transformed Spectral Values

Brightness	93.92	13.29	73.42	117.56
Greenness	62.95	10.95	42.08	80.23
Wetness	109.92	13.39	85.53	127.32

CLASS 22

	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Overstory Characteristics				
% Total Cover	73.70	14.65	36.00	88.00
% Conifer Cover	52.90	23.72	21.00	88.00
% *Abies lasiocarpa*	28.20	19.54	.00	68.00
% *Picea englemannii*	1.10	2.42	.00	7.00
% *Pinus contorta*	2.50	6.92	.00	22.00
% *Pinus flexilis*	.50	1.58	.00	5.00
% *Populus tremuloides*	20.80	23.02	.00	56.00
% *Pseudotsuga menziesii*	20.60	25.33	.00	72.00
Basal Area	180.00	55.78	100.00	260.00
Understory Characteristics				
% *Abies lasiocarpa* Reg.	10.70	10.63	.00	31.00
% *Arnica spp.*	2.20	4.69	.00	14.00
% *Carex spp.*	.50	.97	.00	3.00
% *Osmorhiza spp.*	2.50	3.03	.00	9.00
% *Pachistima myrsinites*	.00	.00	.00	.00
% *Pedicularis racemosa*	1.202	.53	.00	8.00
% *Poa spp.*	.30	.48	.00	1.00
% *Populus tremuloides* Reg.	1.30	1.57	.00	4.00
% *Stellaria jamesiana*	.30	.67	.00	2.00
% *Symphoricarpos oreophilus*	2.90	5.57	.00	18.00
% Exposed Soil	1.30	1.57	.00	4.00
% Litter	26.10	18.88	.00	63.00
% Moss	.00	.00	.00	.00
% Rock	.20	.63	.00	2.00
% Wood	10.60	5.70	.00	21.00
Physiognomic Characteristics				
% Shrub	15.40	30.03	.00	99.00
% Grass	8.50	9.29	.00	33.00
% Forbs	25.30	11.31	.00	38.00
% Regeneration	12.50	11.24	1.00	33.00
% Basal Vegetation	61.80	22.25	23.00	100.00
Total No. Species	13.80	3.36	8.00	19.00
No. Understory Species	10.90	2.85	7.00	16.00
No. Tree Species	2.90	1.29	1.00	5.00
No. Shrub Species	2.20	1.81	.00	6.00
No. Forb Species	4.50	2.46	.00	8.00
No. Grass Species	2.30	1.95	.00	7.00
No. Regeneration Species	1.90	.88	1.00	4.00

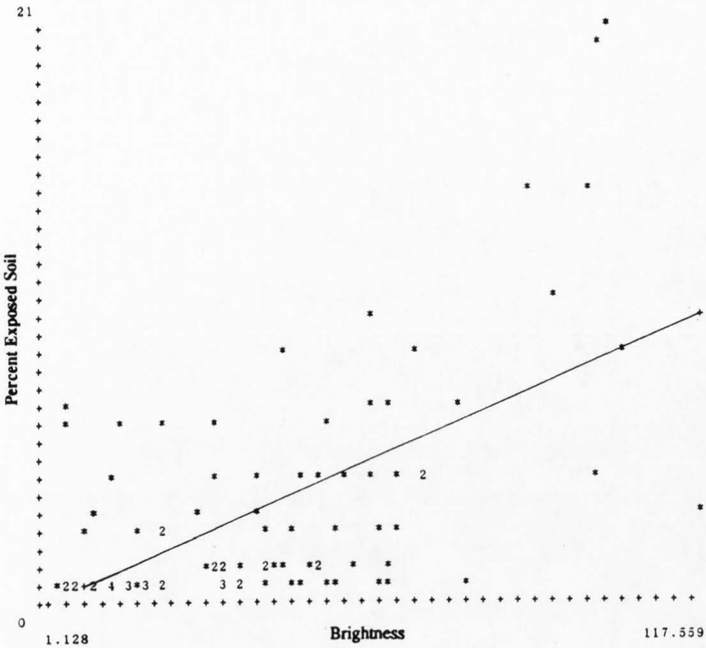
Physical Site Characteristics

Elevation (ft.)	7242.00	854.29	5600.00	8280.00
Slope (percent)	35.00	21.00	.00	65.00
Aspect (normalized radians)	1.09	.70	.14	2.67

Transformed Spectral Values

Brightness	46.65	6.20	37.53	60.75
Greenness	119.14	6.74	105.90	131.45
Wetness	201.01	7.51	190.43	209.84

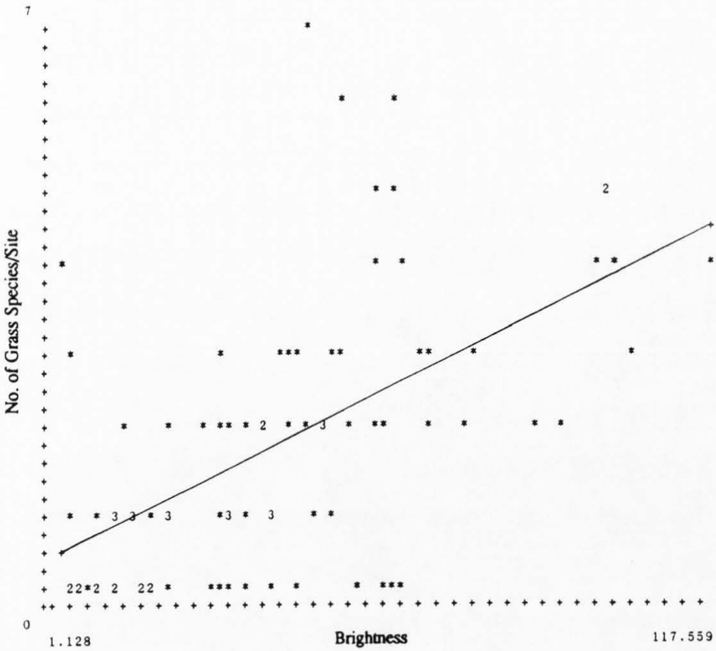
Appendix F. Correlations of Site Characteristics with Brightness, Greenness, and Wetness Values.



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -.6680783279561 SLOPE= 9.2047368856376E-02

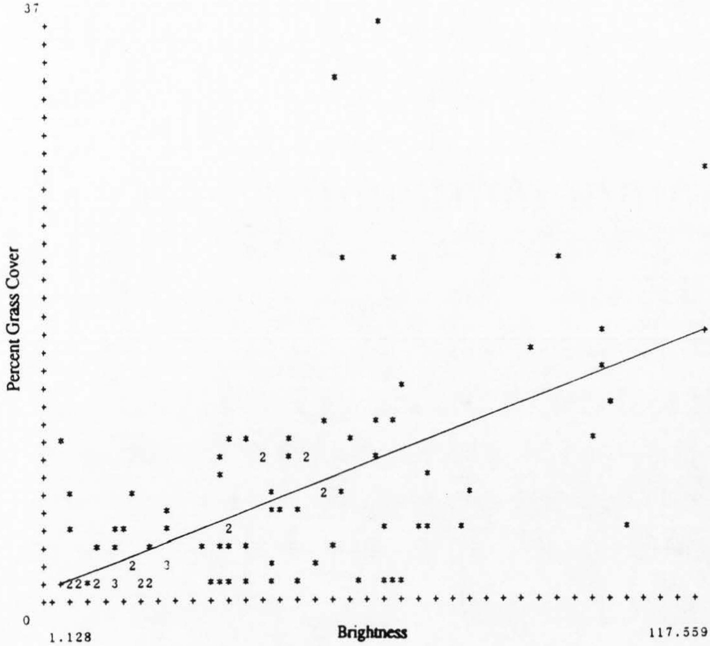
r = .5860 r squared = .3433



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .407597120548 SLOPE= 3.4240773560149E-02

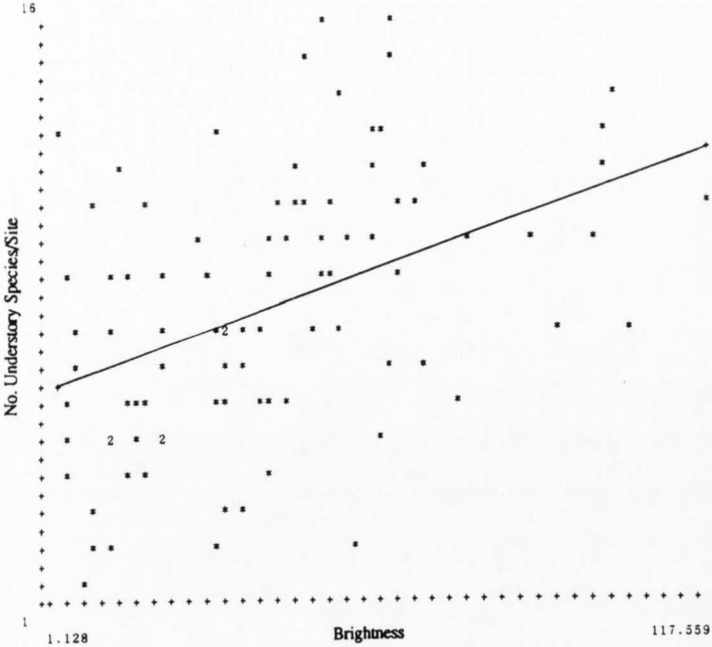
r = .5634 r squared = .3175



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .035215165881 SLOPE= .14559004781796

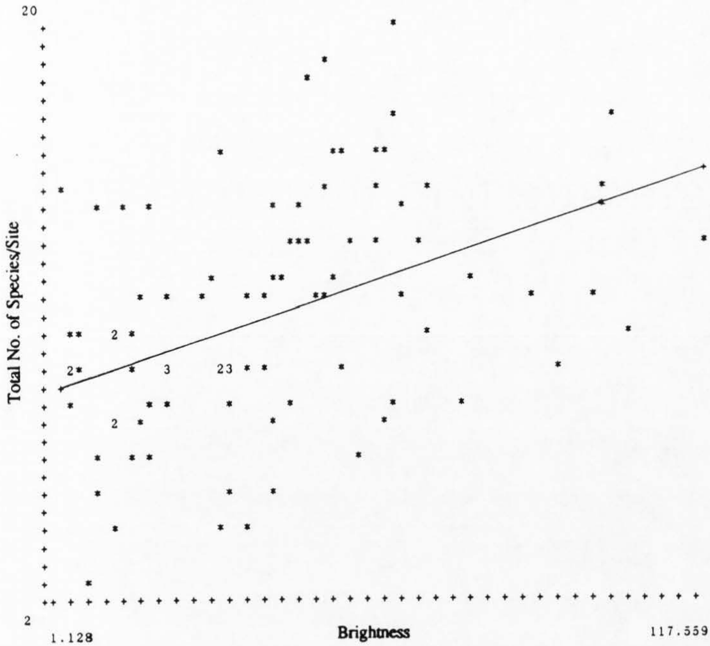
r = .5423 r squared = .2941



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 6.0956160559831   SLOPE= 5.7406871499018E-02

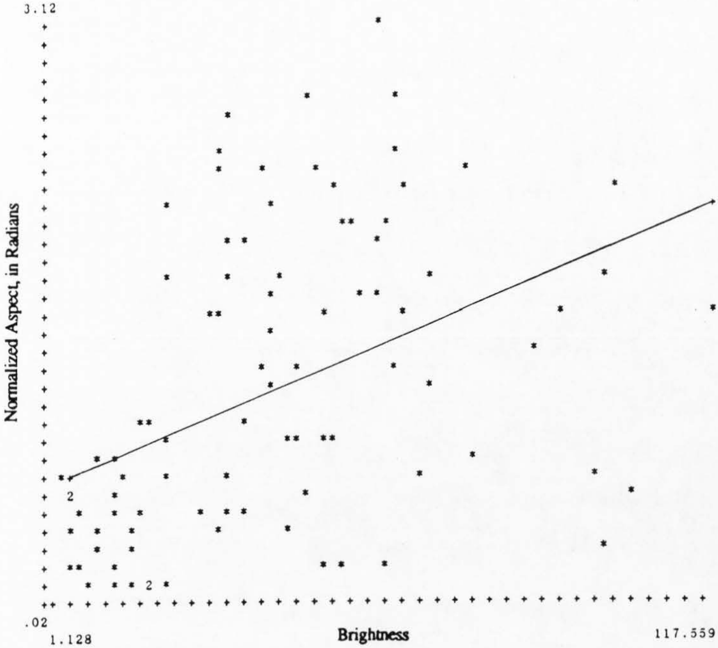
r = .4504   r squared = .2028



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 8.4974996948056   SLOPE= 5.5947803921635E-02

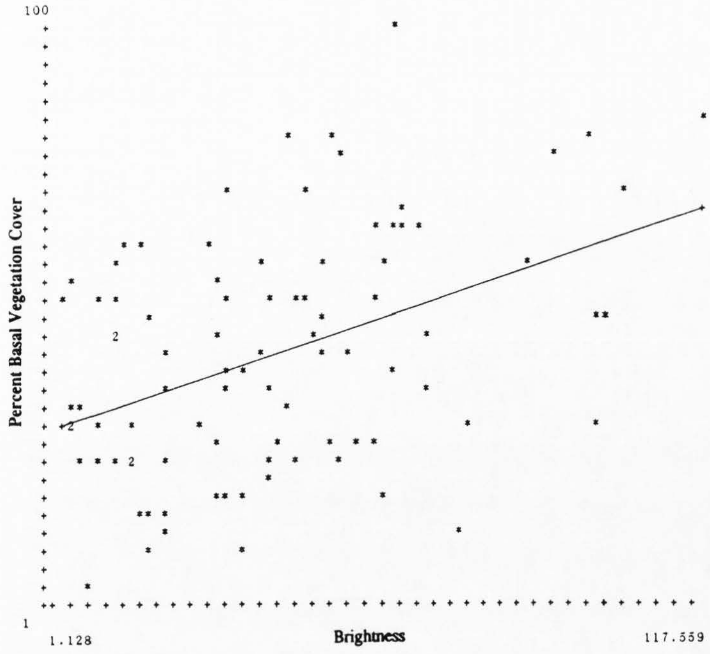
r = .4107   r squared = .1687



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .63026415898137   SLOPE= 1.2313235881575E-02

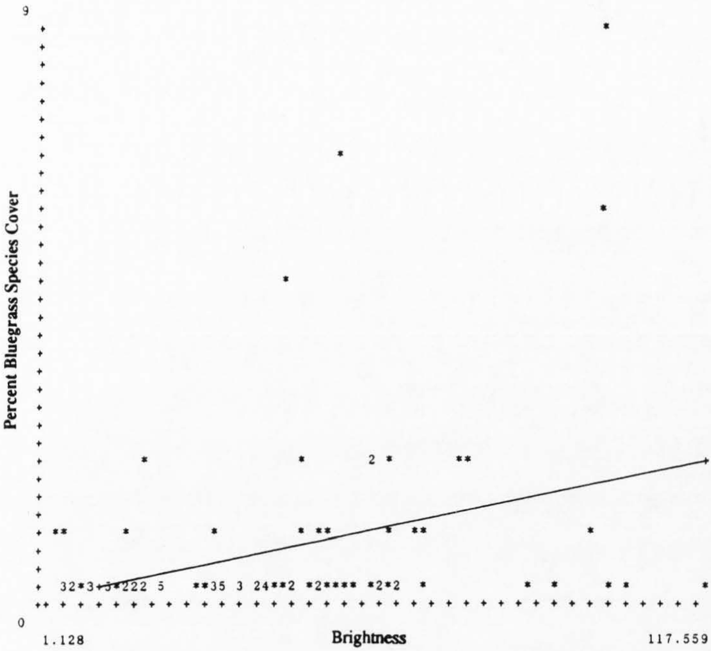
r = .4066   r squared = .1654



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 30.054075401581 SLOPE= .31135261544344

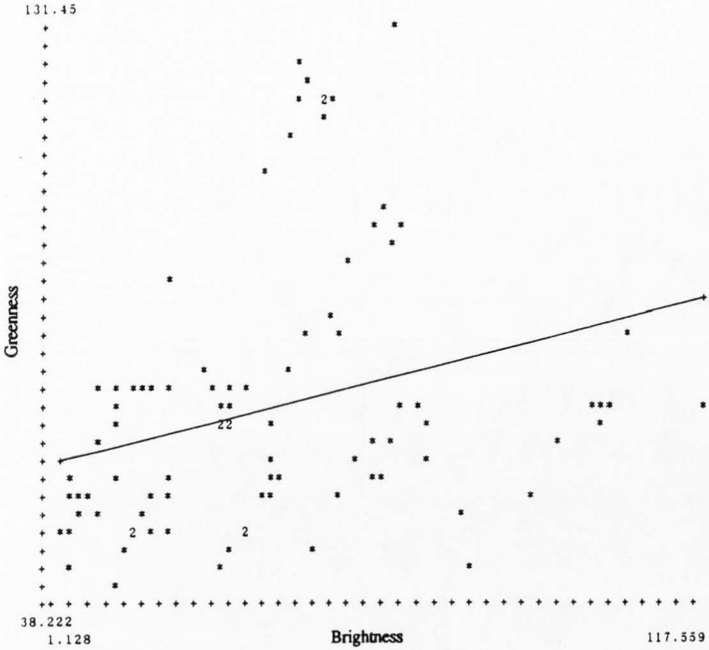
r = .4018 r squared = .1615



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -.18233419984882 SLOPE= 1.93083268966684E-02

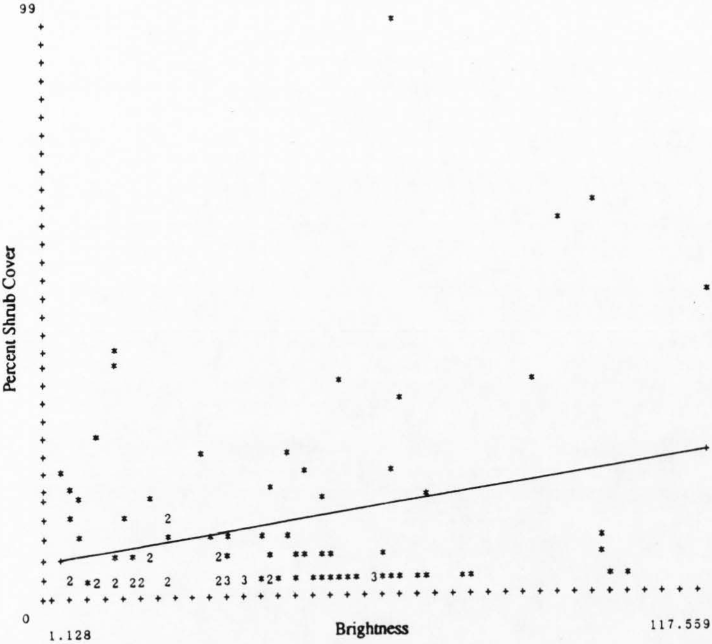
r = .3485 r squared = .1215



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 59.748756903141 SLOPE= .23027372823506

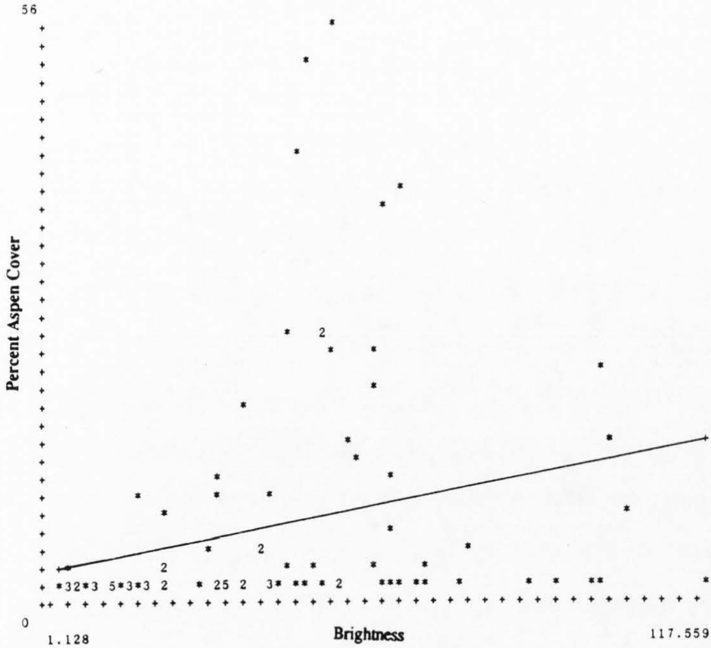
r = .2777 r squared = .0771



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 2.831448134644   SLOPE= .15669324968058

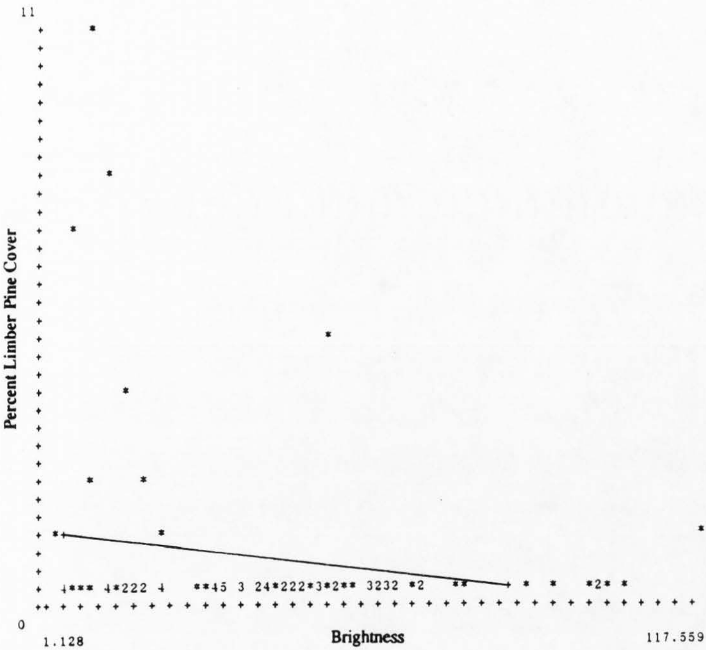
r = .2528   r squared = .0639



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 1.8028831560744 SLOPE= .10943739363379

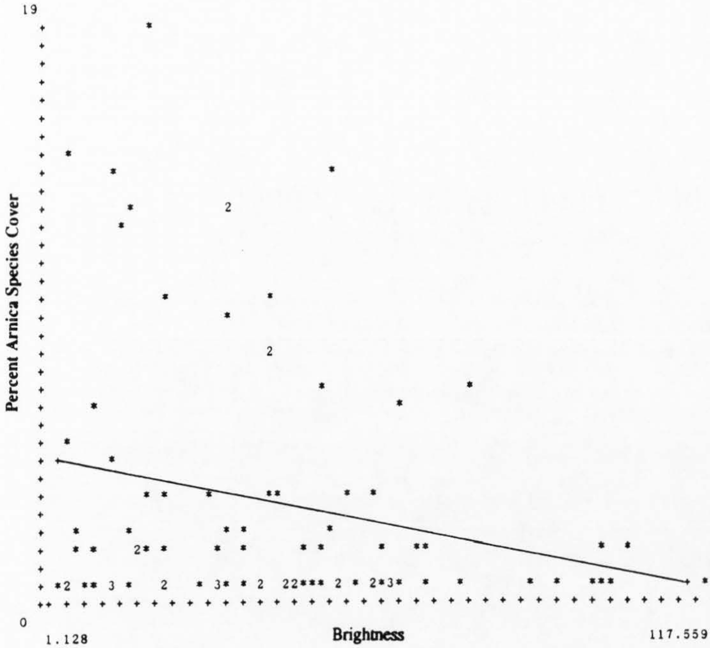
r = .2451 r squared = .0601



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 1.0458428239003 SLOPE= -1.47122041275 43E-02

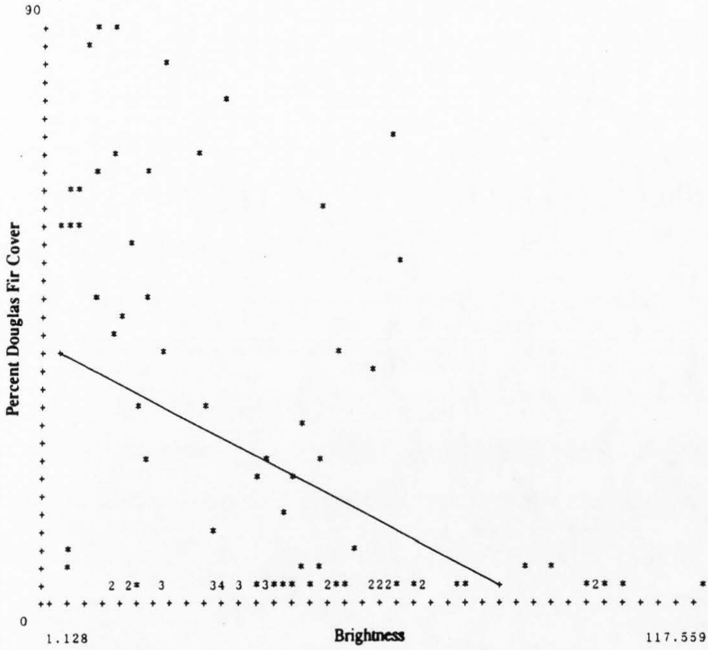
r = -.2301 r squared = .0529



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 4.2060191194051   SLOPE= -3.93847988367l9E-02

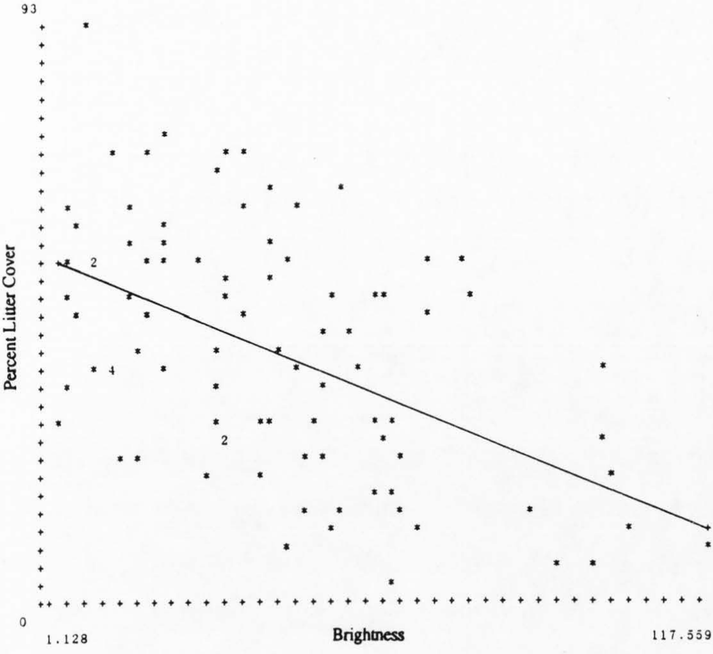
r = -.2429   r squared = .0590



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 38.672875115392   SLOPE= -.484770475l3932

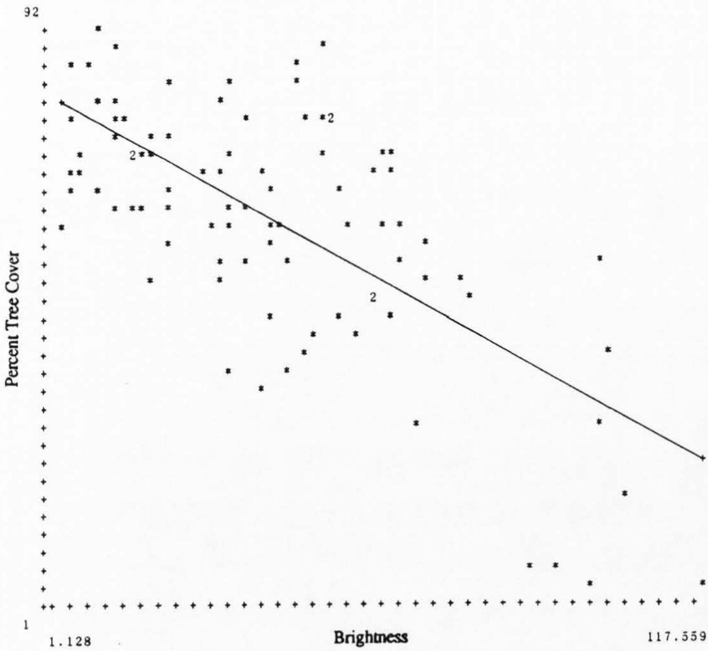
r = -.4679   r squared = .2189



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 53.88776458807 SLOPE= -.38015396769331

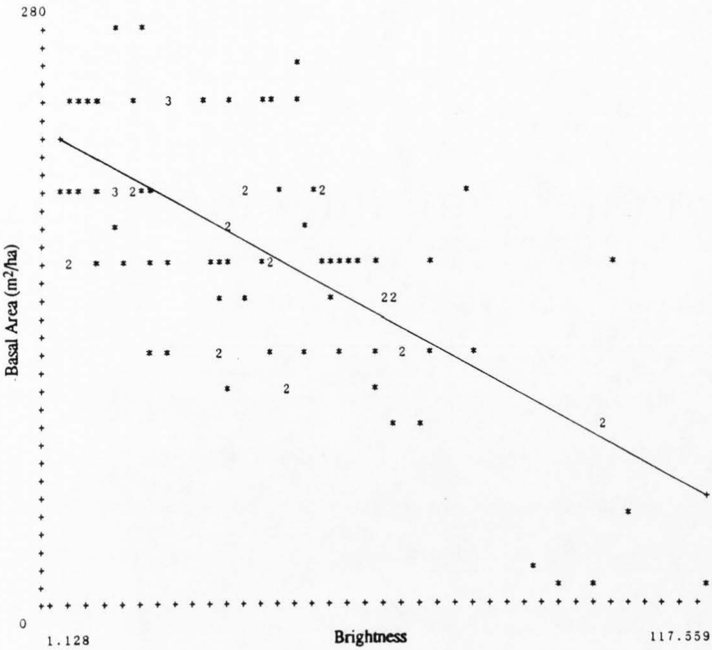
r = -.5125 r squared = .2626



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 79.907287721027   SLOPE= -.49213623204186

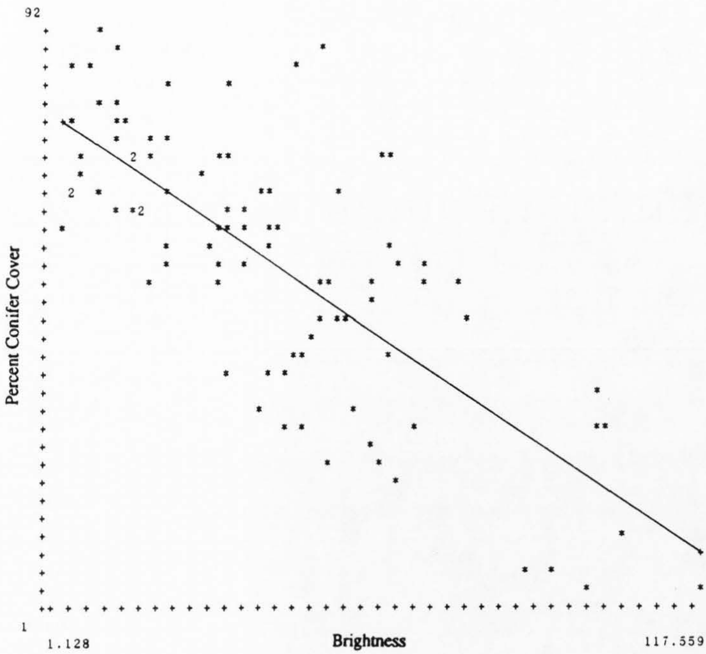
r = -.6791   r squared = .4611



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 223.60653901845   SLOPE= -1.5451691873381

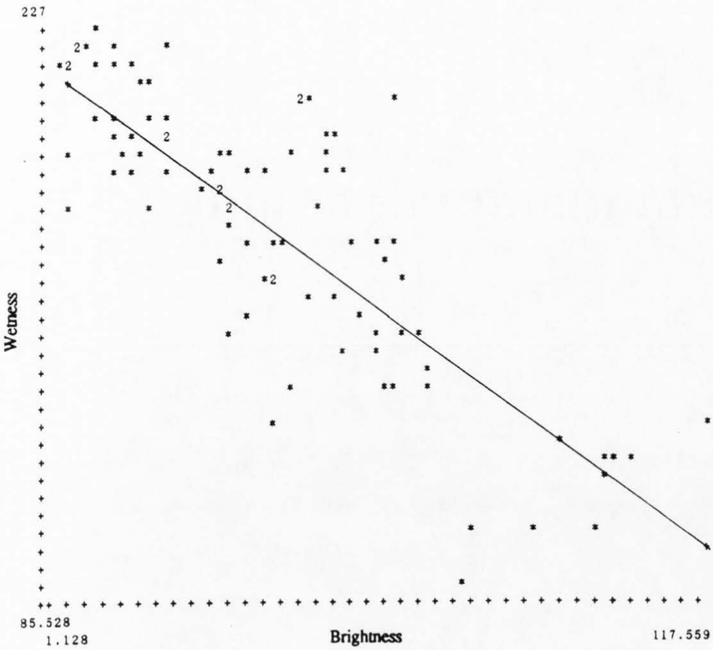
r = -.6893   r squared = .4751



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 78.104404564953 SLOPE= -.60157362567566

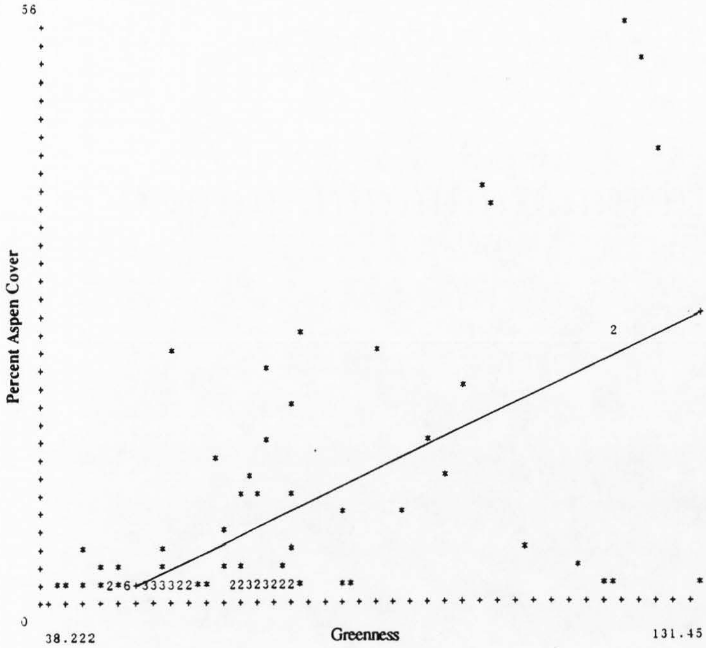
r = -.7568 r squared = .5727



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 217.75200312924 SLOPE= -1.0409361695923

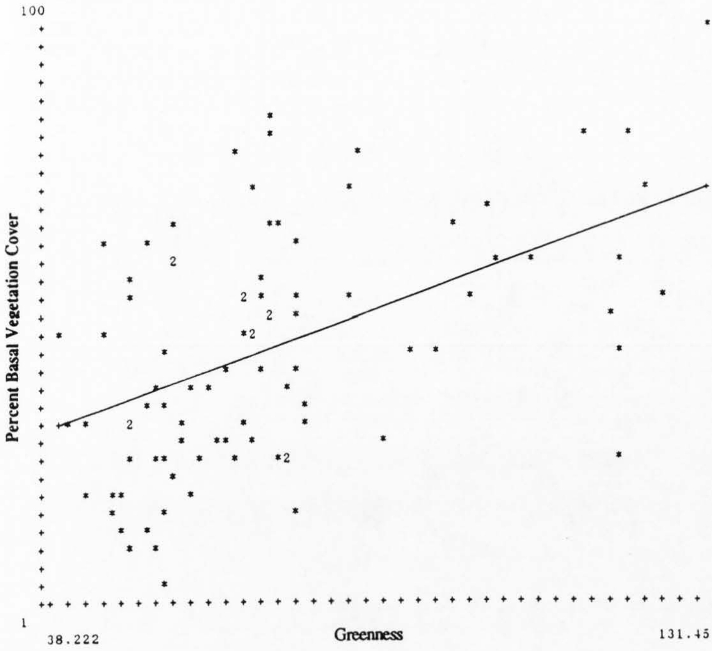
r = -.8196 r squared = .6717



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -16.121605376787 SLOPE= .32308441374146

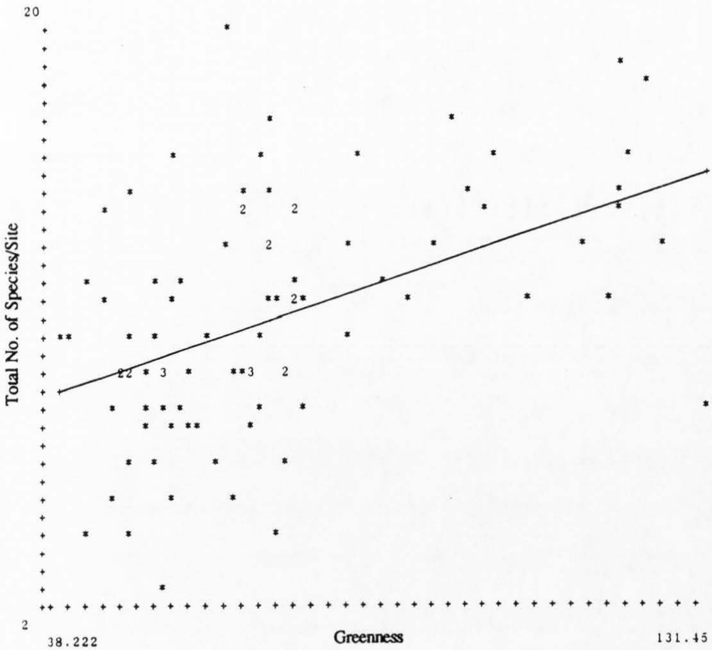
r = .6002 r squared = .3602



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 10.739724108017 SLOPE= .45879337625934

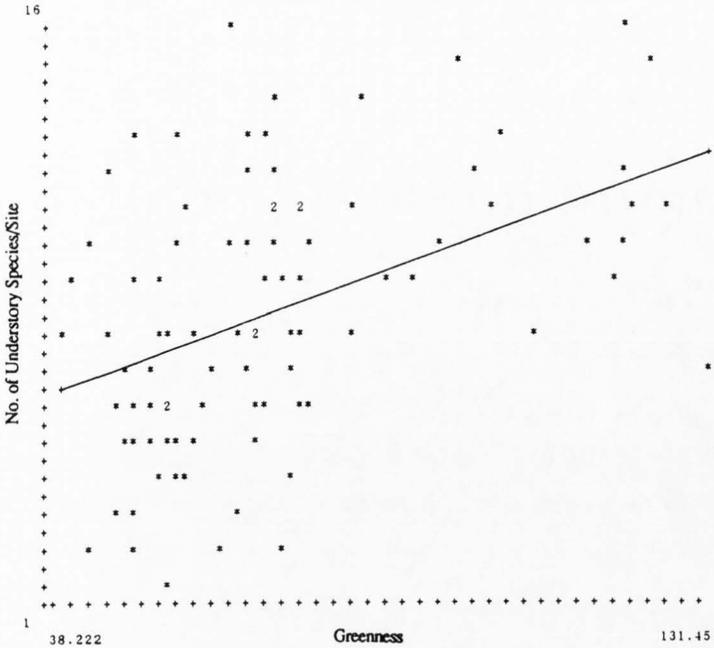
r = .4911 r squared = .2411



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 5.3404229245051 SLOPE= 7.7885031200799E-02

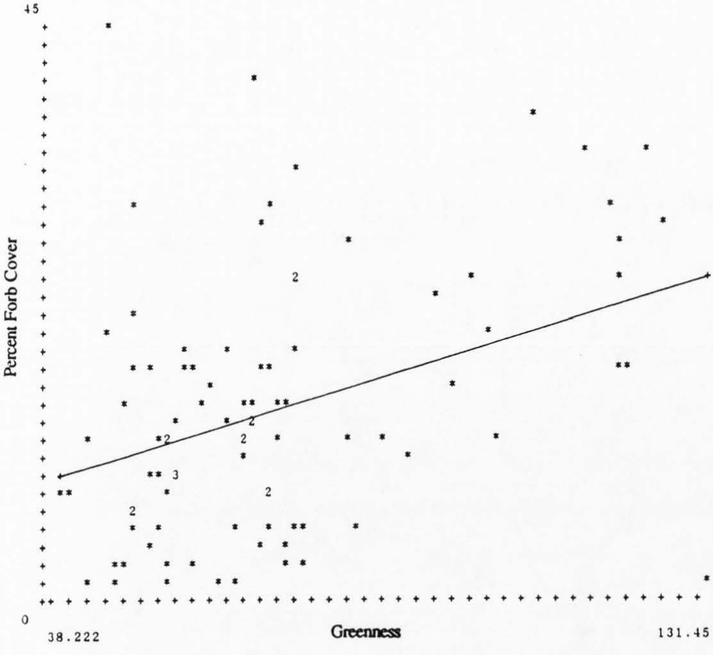
r = .4742 r squared = .2249



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 3.6445695909625   SLOPE= 6.84597466685 34E-02

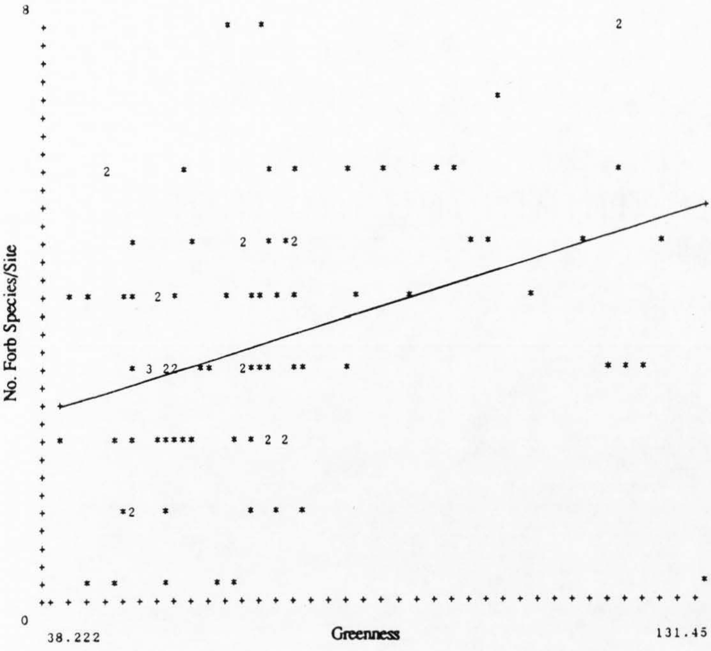
r = .4454   r squared = .1984



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 1.792142330434   SLOPE= .17659647691956

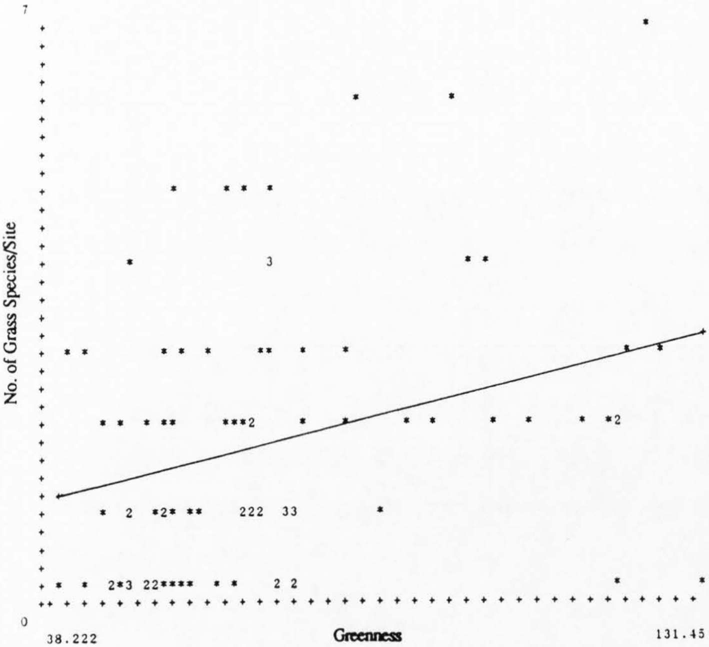
r = .3804   r squared = .1447



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 1.502364074875 SLOPE= 2.9352449383853E-02

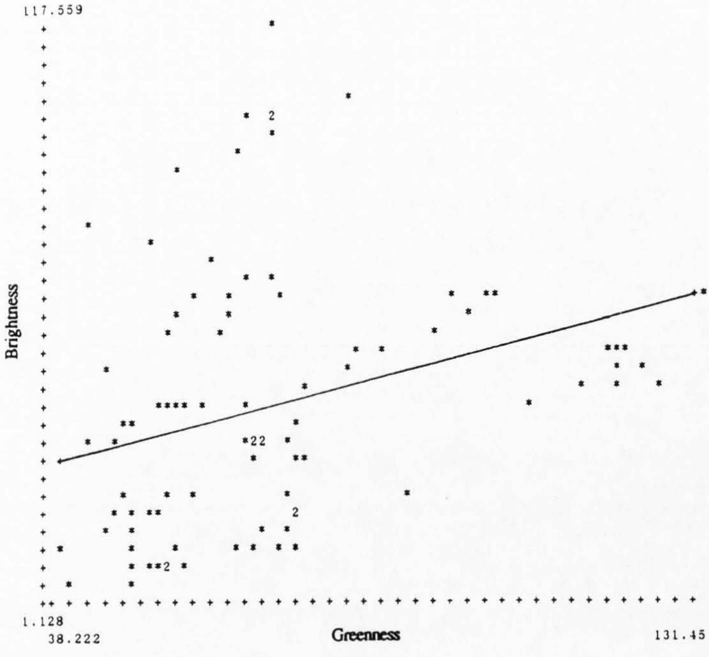
r = .3368 r squared = .1134



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .2350003840756 SLOPE= 2.20966104797 21E-02

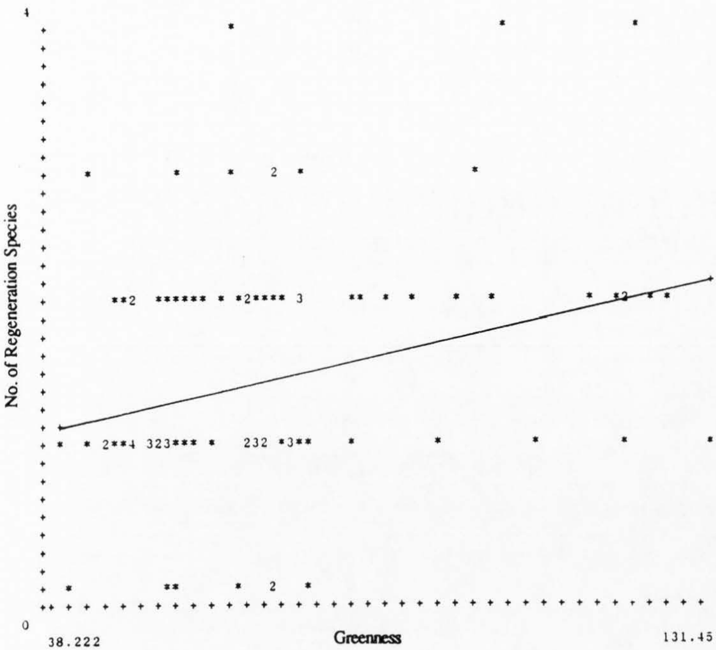
r = .3016 r squared = .0909



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 16.328425279034   SLOPE= .33479590136222

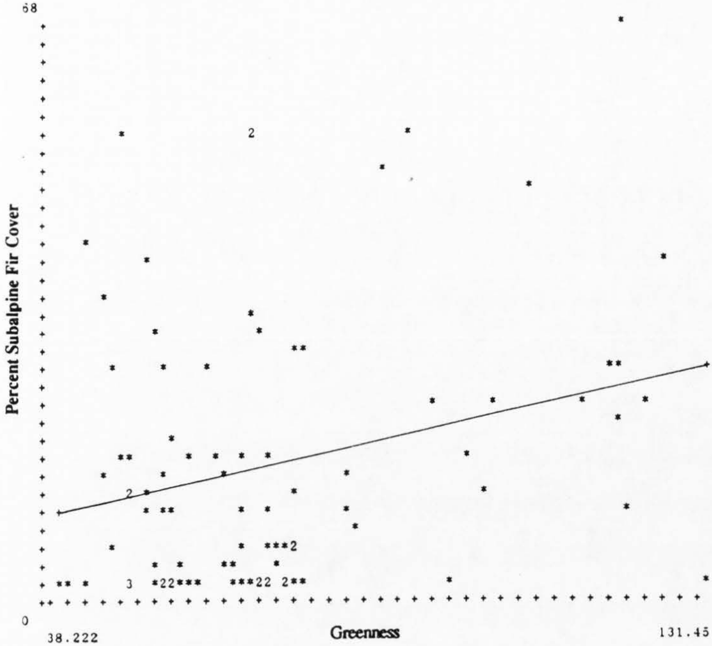
r = .2777   r squared = .0771



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .7847831322401 SLOPE= 1.1039349592264E-02

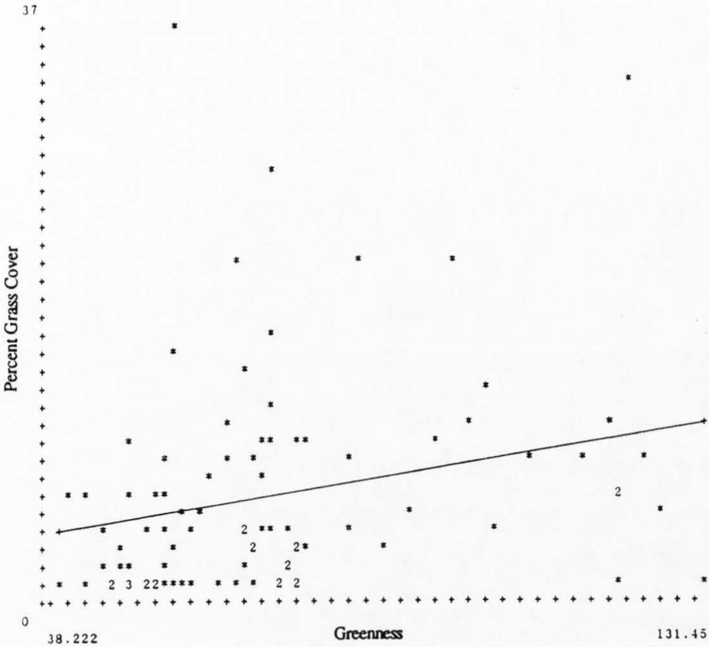
r = .2827 r squared = .0799



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .542056124588 SLOPE= .19847636667806

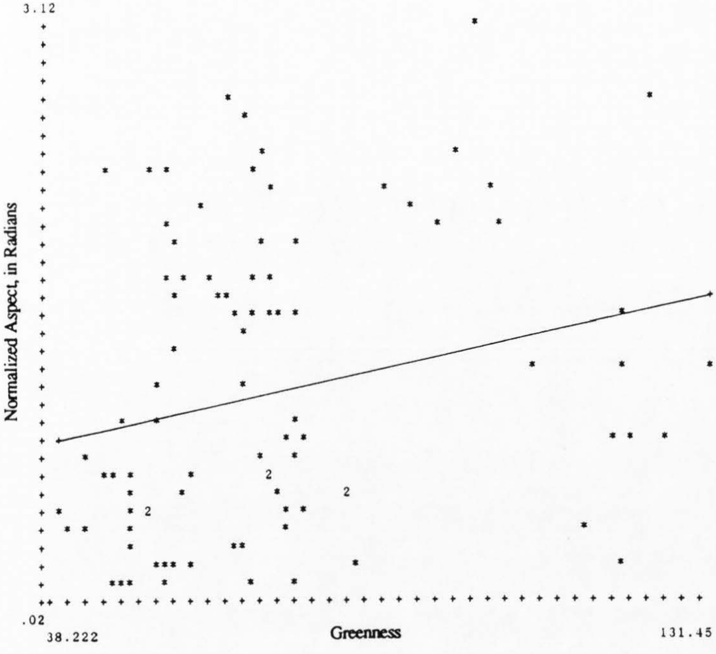
r = .2721 r squared = .0740



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .0840999145649   SLOPE= .08257869651911

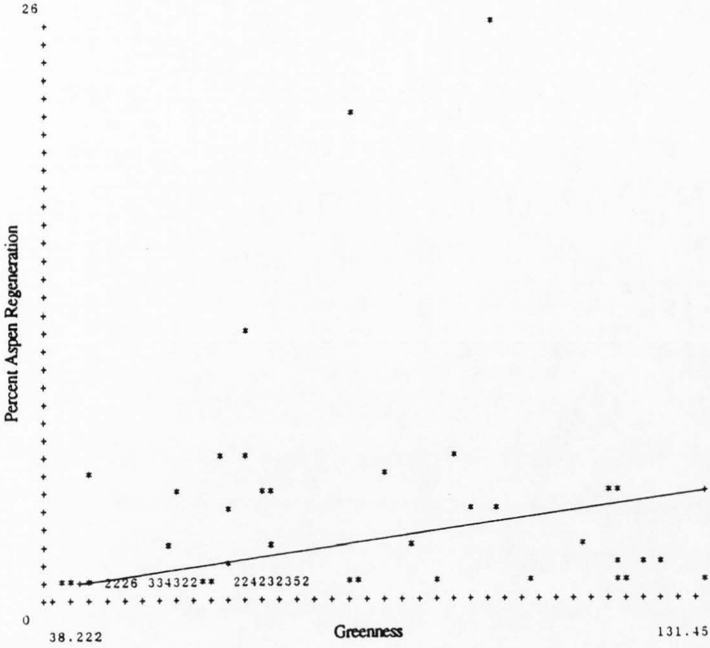
r = .2551   r squared = .0651



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .53791059457788   SLOPE= 8.3862263223077E-03

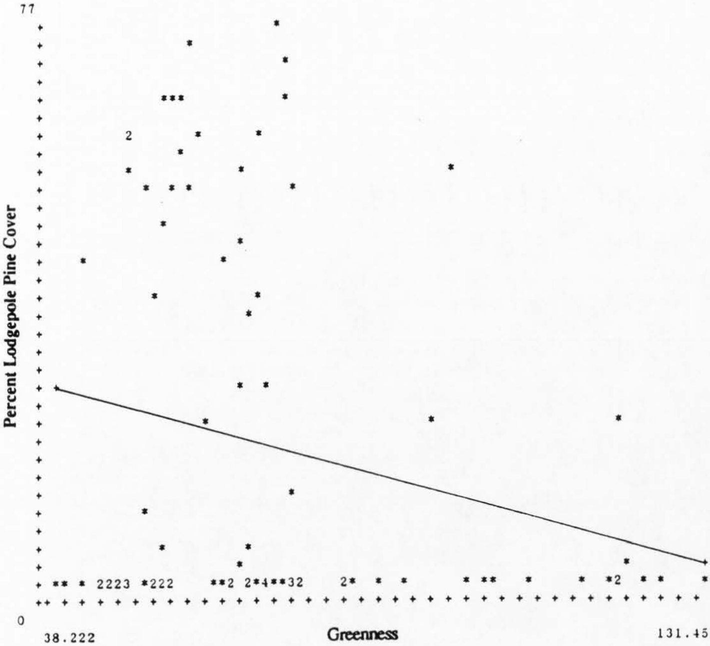
r = .2297   r squared = .0528



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -1.286599231813 SLOPE= 3.9525886038486E-02

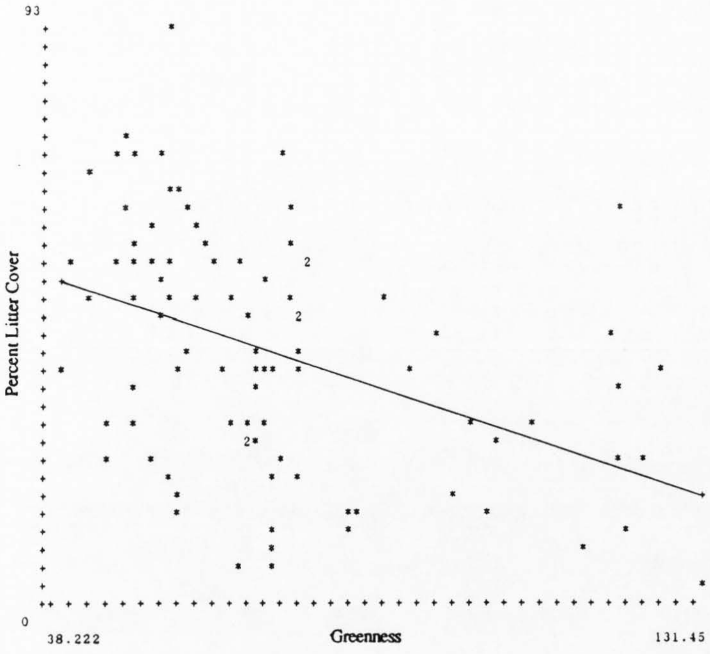
r = .2233 r squared = .0499



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 35.979510435861 SLOPE= -.25659458275703

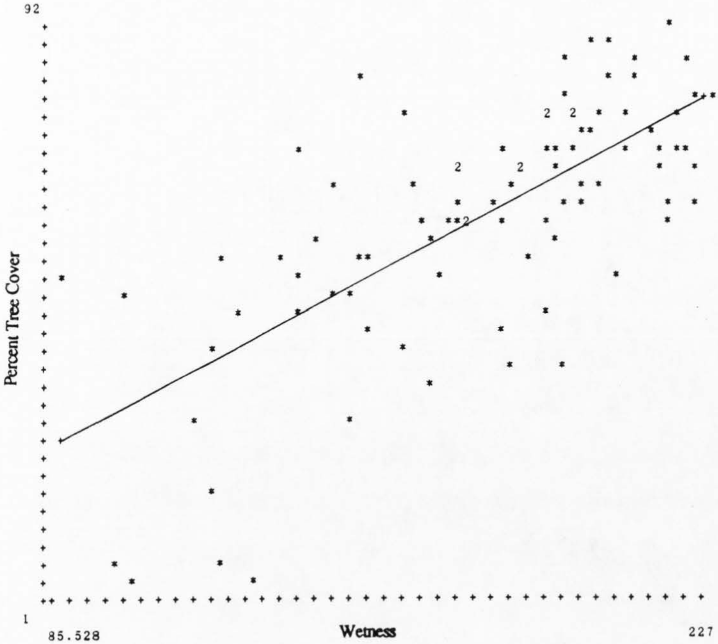
r = -.2192 r squared = .0480



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 64.200223982107   SLOPE= -.36733830450245

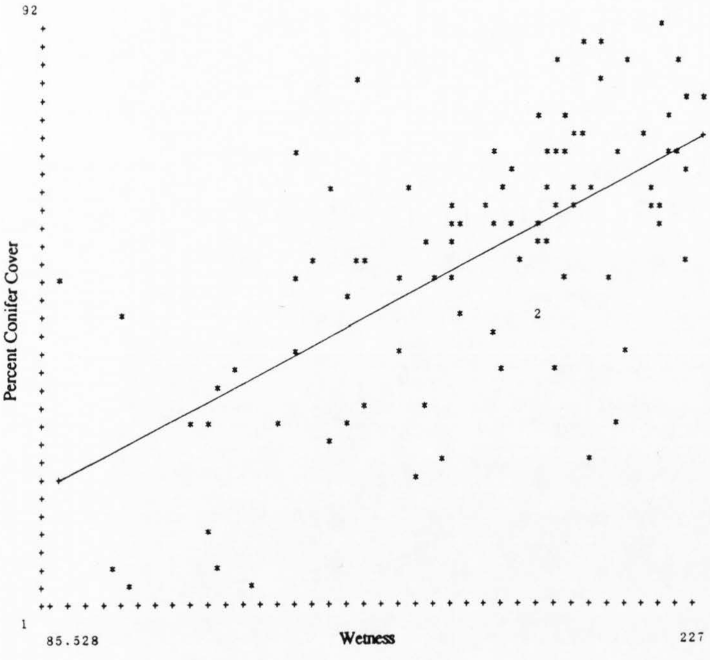
r = -.4107   r squared = .1687



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -10.405906640493 SLOPE= .40130039652421

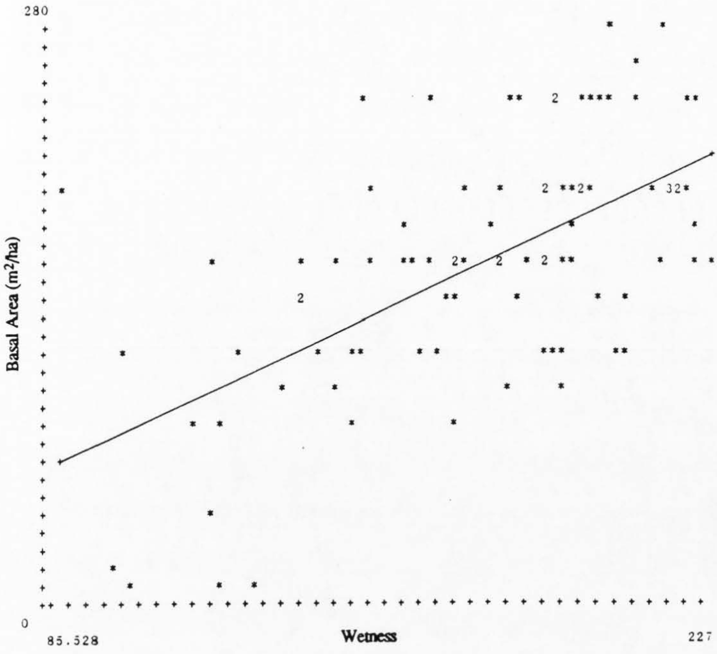
r = .7033 r squared = .4946



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -17.418306595258   SLOPE= .40639895087121

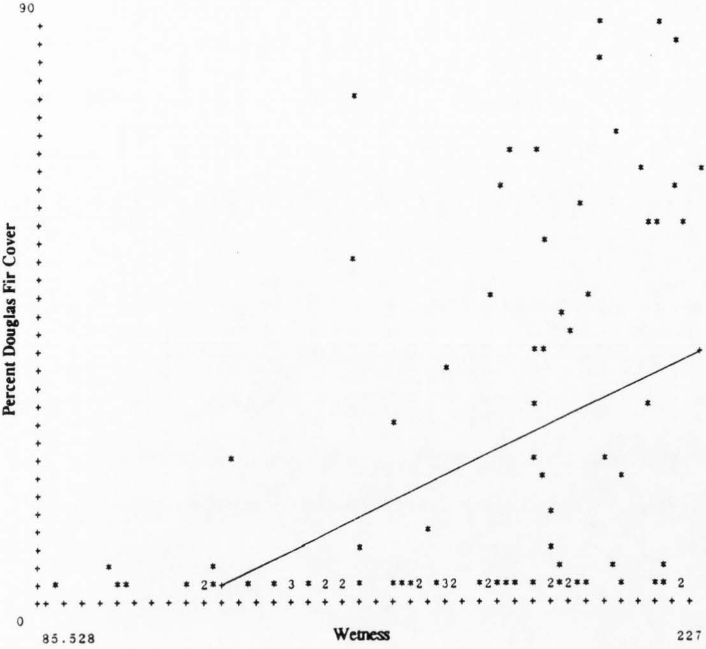
r = .6494   r squared = .4217



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -25.78262977559 SLOPE= 1.066678559678

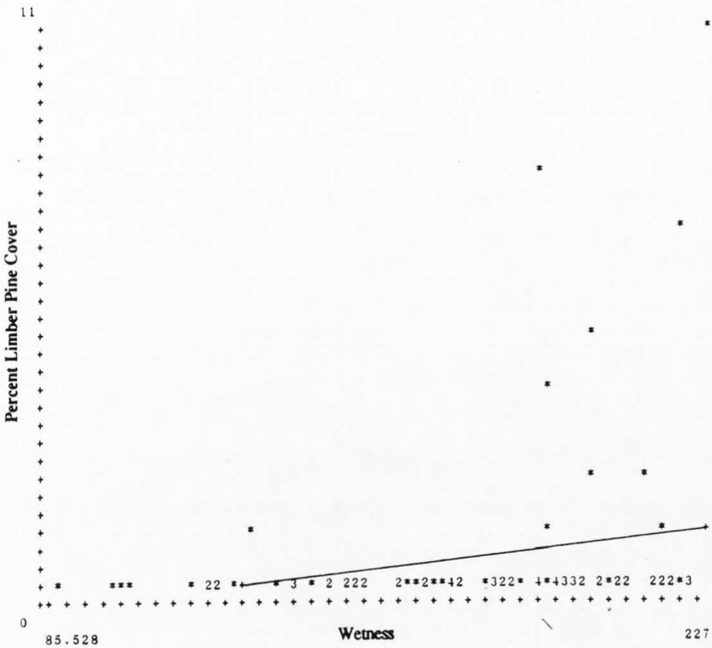
r = .6044 r squared = .3653



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -42.287201564927   SLOPE= .3500305281484

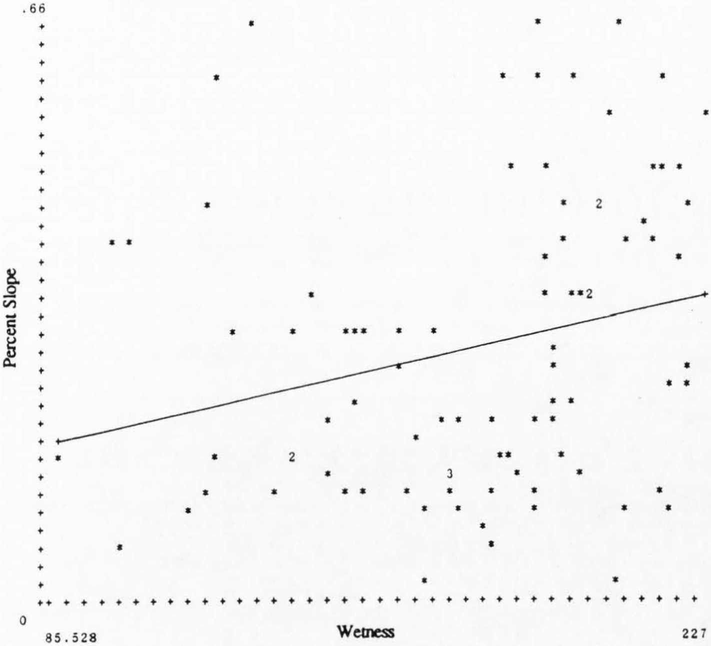
r = .4291   r squared = .1841



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= -1.7158442628934 SLOPE= 1.2346375599373E-02

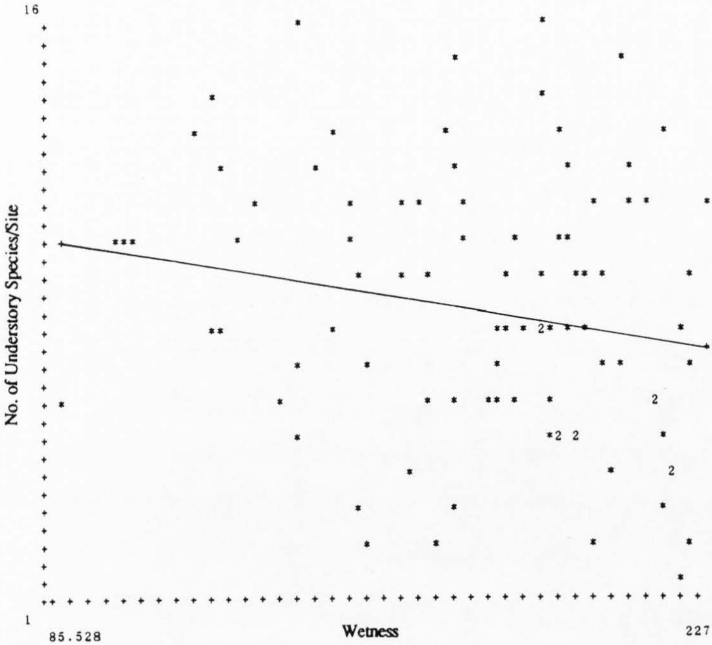
r = .2452 r squared = .0601



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= .06392937015566 SLOPE= 1.2091031969546E-03

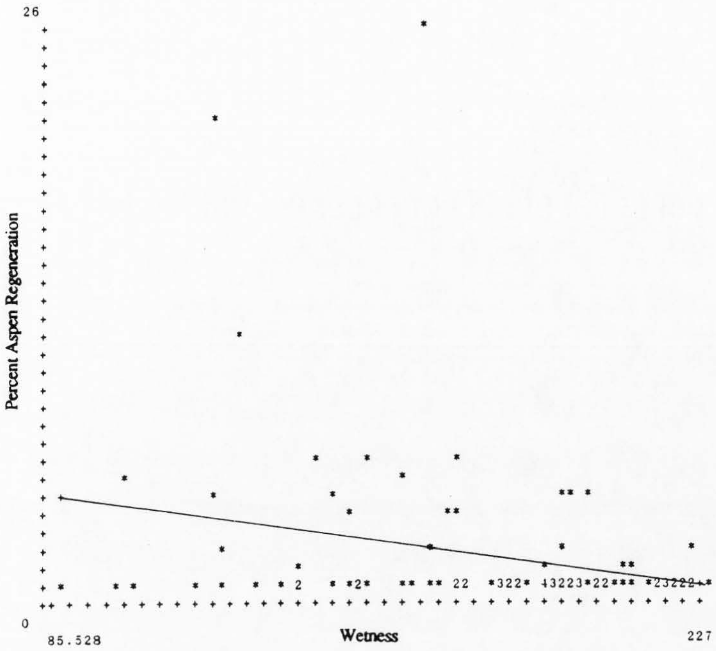
r = .2357 r squared = .0555



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 12.182077257078   SLOPE= -2.1646477699734E-02

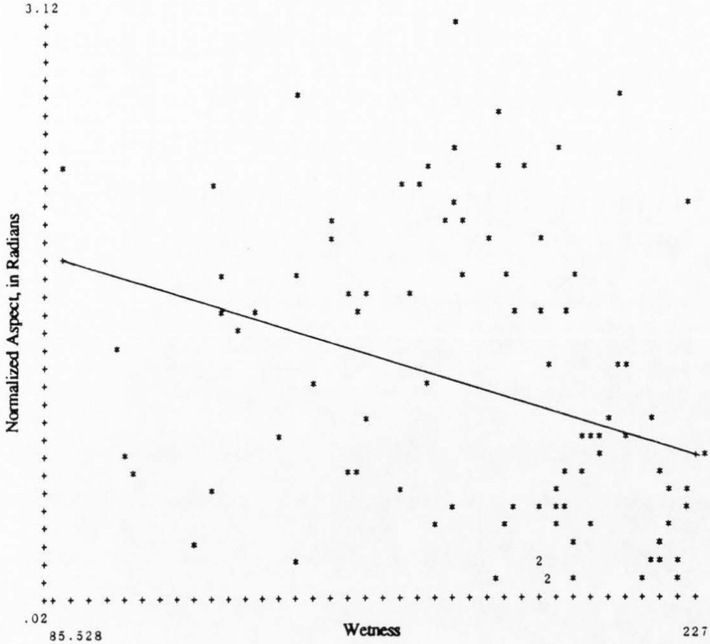
r = -.2157   r squared = .0465



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 7.1118237898933   SLOPE= -3.2122989655898E-02

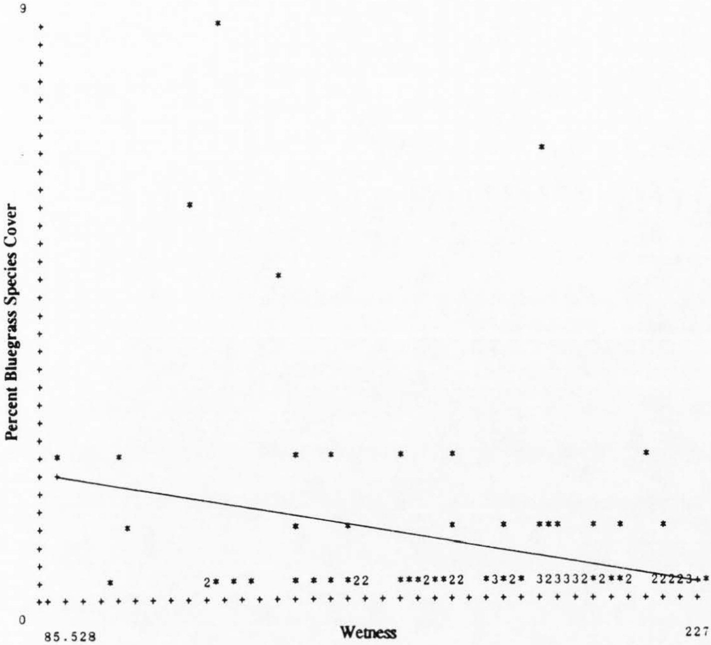
r = -.2779   r squared = .0772



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 2.4200339033371 SLOPE= -7.3825237355228E-03

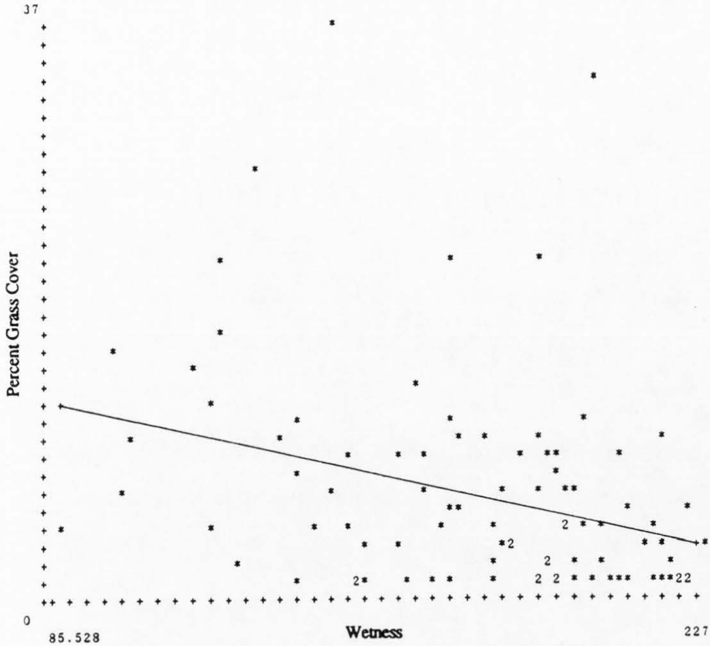
r = -.3097 r squared = .0959



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 3.049991218283   SLOPE= -1.3985210926044E-02

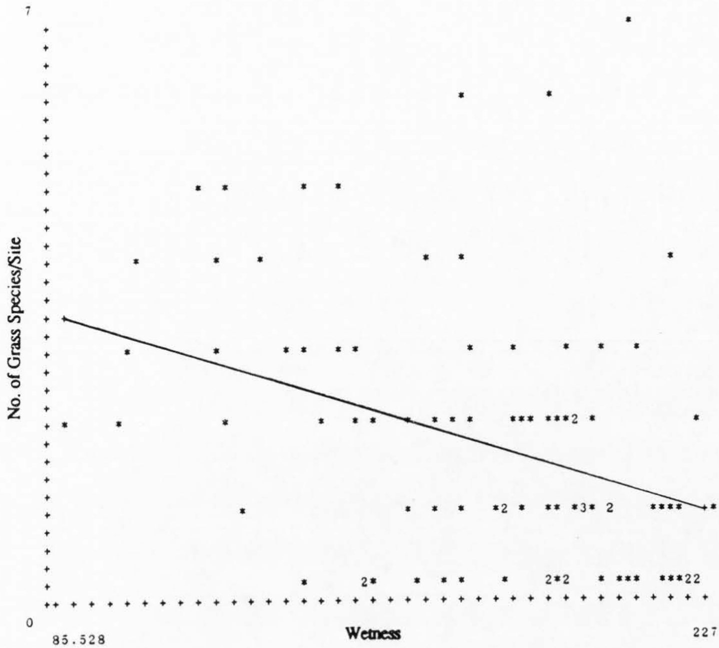
r = -.3206   r squared = .1028



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 18.797508078132   SLOPE= -7.3714940100776E-02

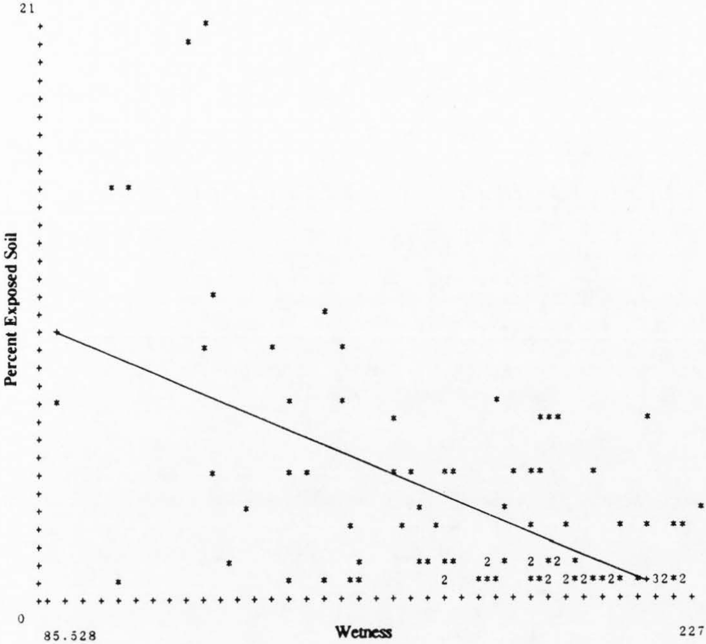
r = -.3487   r squared = .1216



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 5.0763267722047   SLOPE= -1.8785467767898E-02

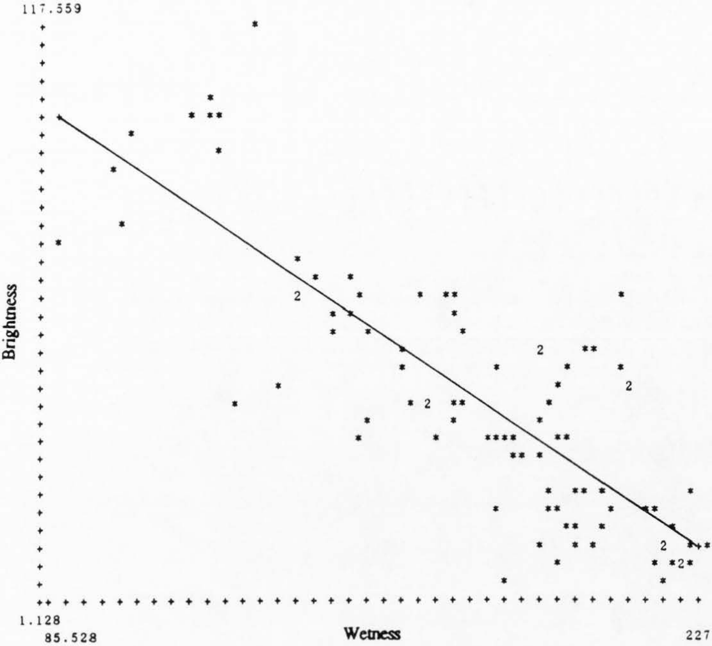
r = -.3926   r squared = .1541



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 15.831600462174   SLOPE= -7.2839262566046E-02

r = -.5889   r squared = .3468



REGRESSION EQUATION (Shown by +'s on scatterplot):

INTERCEPT= 153.43457602286   SLOPE= -.64527532591202

r = -.8196   r squared = .6717