COMPARISON OF METHODS TO DETECT CONIFER ENCROACHMENT INTO ASPEN STANDS USING LANDSAT 7 ETM+ SATELLITE IMAGERY

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Rangeland Ecology and Management

in the

College of Graduate Studies

University of Idaho

by

Sarah Crocker Heide

May 2002

Major Professor: Dr. Stephen C. Bunting, Ph.D.

AUTHORIZATION TO SUBMIT

THESIS

This thesis of Sarah Crocker Heide, submitted for the degree of Master of Science with a major in Rangeland Ecology and Management and titled "Comparison of Methods to Detect Conifer Encroachment Into Aspen Stands Using Landsat 7 ETM+ Satellite Imagery," has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor ______________________________ Date______________
Stephen C. Bunting

Committee
Members ______________________________ Date______________
Karen L. Launchbaugh

______________________________ Date______________
Karen Humes

Department
Administrator ______________________________ Date______________
Kendall L. Johnson

Natural Resources
College Dean ______________________________ Date______________
Leonard R. Johnson

Final Approval and Acceptance by the College of Graduate Studies

______________________________ Date______________
Charles R. Hatch

ABSTRACT: Aspen (*Populus tremuloides*) stands found in the western United States today are often even-aged and decadent, being encroached upon by adjacent coniferous tree species, and lack the level of reproduction necessary to maintain themselves into the future. In the past, methods for mapping aspen community extent and/or decline across landscapes have been both costly and time consuming (e.g. aerial photograph interpretation). Recent advances in satellite imagery and geographical information systems (GIS) offer potential alternatives to previous methods. In this paper, we compare three data processing techniques for mapping increasing levels of conifer encroachment into aspen stands using Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite imagery. Vegetation maps including three stages of conifer encroachment into aspen were produced using both unsupervised and supervised classification techniques. Both parametric and non-parametric discriminant analysis were employed in the supervised classification procedures. Supervised classification using non-parametric discriminant analysis outperformed the other two techniques with an overall map accuracy of 77%. By combining the three conifer encroachment classes into one aspen/conifer mixed class the overall accuracy was increased to 79%. We found that conifer encroachment into aspen stands can be detected and mapped using Landsat 7 ETM+ imagery. However, lower producer's accuracy was attained for the three classes of conifer encroachment (63%, 17%, and 8%) than for the landscape as a whole with the described techniques.

ACKNOWLEDGEMENTS: As with most projects there are numerous people and organizations who deserve recognition for their help and support. First and foremost I would like to thank my major professor Dr. Stephen C. Bunting who took me on without funding and continued to believe in me throughout the process. Thank you for all of the knowledge gained and laughs along the way! Thanks go to my committee members Dr. Karen Launchbaugh and Dr. Karen Humes for their support and suggestions over the last three years. A huge thanks to Ms. Eva Strand for sharing her invaluable expertise in GIS and remote sensing. Without her help I'm not sure I would have made it to graduation day! Thanks to Dr. Chris Williams for his assistance with the statistics used in this project. Another huge thanks to Michelle Williams who assisted me in the collection of field data over two summers and kept me organized through it all. Thanks for keeping my spirits high! Thank you Ray Brainard and James Kumm for showing me around the Pleasantview Hills, taking an interest in my endeavors, and lending me your time, expertise, and equipment. Thank you Krista Gollnick-Waid, Patricia Roller, and Rick Belger for making it possible to seamlessly transition from work to school and then back to work again. The confidence you have shown in me is much appreciated. Thank you Cleve Davis for helping me identify all of those forbs found in the aspen /Douglas-fir cover type. In addition, I would like to thank the BLM Upper Snake River District Fuels Crews over the 2000-2001 field seasons, Nancy Fetterman, Joel Sauder, the Department of Rangeland Ecology and Management at the University of Idaho (especially Kathy Mallory), Geneva Pym, Joeseph and Genevieve Pechanec, and all of the fellow students who helped and/or influenced me in some way.

DEDICATION: I dedicate this thesis to my family who have supported me and motivated me to do my best in this endeavor and throughout my educational career. I could not have made it this far without you. In addition, I dedicate this thesis to my late dog, Unique, who patiently waited for me to come home many a time over the last years of her life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Quaking aspen (*Populus tremuloides*) communities are known to depend on periodic disturbances (e.g. wildfire) to reduce competition from late seral conifer trees and stimulate asexual reproduction. Disturbance contributes to the diversity of aspen stand age and structure across a landscape. The effects of land management practices through the twentieth century (e.g. fire suppression and livestock grazing) on many vegetation assemblages in the United States have been profound. These effects include an increased number of landscapes characterized by homogeneous vegetation cover, a reduction in biodiversity, and major shifts away from historical disturbance regimes (Renkin and Despain 1991, Covington et al. 1994, Fule' et al. 1997, Caprio and Graber 2000). Changes in forest structure and composition have caused a decline in the ecological health of many aspen communities in the western United States. Data collected on the historical and current abundance of aspen in the west indicate that, at a minimum, there has been a 50% decline in aspen dominated sites since European arrival (Bartos and Campbell 1998, Club 20 Research Foundation 1998). Individual aspen stands found today are often even-aged and decadent, being encroached upon by adjacent coniferous tree species, and lack the level of reproduction necessary to maintain themselves into the future (Jones and DeByle 1985, Bartos et al. 1991, Bartos and Campbell 1998).

The Bureau of Land Management (BLM) would like to use prescribed fire and/or mechanical treatments in the Pleasantview Mountains of southeastern Idaho to rejuvenate aspen communities and maintain existing aspen stands on the landscape. The number and location of aspen stands in this area, their current condition, the degree of conifer tree encroachment, and how readily they might burn is not well known. Acquiring this knowledge in a cost effective and timely manner is key to accomplishing this goal.

We compare and discuss 3 techniques with the use of remotely sensed data for mapping aspen stands that are at risk of being lost, perhaps permanently, due to lack of periodic disturbance in the form of fire and resulting conifer tree encroachment. This paper begins with a background on the unique ecology of aspen and its importance, followed by a discussion of different data types and techniques that have been used to inventory and map forest cover types and various forest attributes. Three remotely sensed data processing techniques for mapping increasing levels of Douglas-fir (*Pseudotsuga menziesii*) encroachment into aspen stands are compared and contrasted with each other to help provide a better understanding of the advantages, disadvantages, and limitations of each. In addition, quantitative data on species composition, age-class distribution, and aspen sucker production are presented for 4 aspen/Douglas-fir encroachment classes. These field data were collected over the 2000-2001 summer seasons. The paper concludes with suggestions on how the methods described could be improved upon for future application.

BACKGROUND

Aspen Ecology and Importance

Scattered throughout many coniferous forests of the western United States is the quaking aspen, a colorful tree with leaves that turn brilliant shades of yellow, orange, and red in the fall season. Quaking aspen has a broad geographic and environmental range and is considered North America's most widely distributed native tree species. It can be found from the east coast to the west coast on the northern portion of the continent and from Mexico all the way up through the western United States to Alaska at elevations from sea level to 3700 m (Little 1971, Jones 1985). As a member of the willow family *(Salicaceae)*, quaking aspen is closely related to cottonwoods as well as other poplar species.

Aspen communities typically only account for 1–5% of the forested areas on western landscapes (Baker 1925) but are considered one of the most biologically diverse (Kay 1997). They are important because they support a multitude of both plant and animal species, provide wood products and livestock/wildlife forage, improve the water quality and holding capacity of watersheds, and are considered esthetically pleasing (DeByle 1985a, DeByle 1985b, Johnson et al. 1985, Jones et al. 1985, Mueggler 1985, Turchi et al. 1995, Chong et al. 2001). Aspen stands can provide quality habitat for both mammal and bird species because they often contain a variety of forage, water, and cover.

One of the unusual features of quaking aspen is its large underground system of lateral roots (Kemperman and Barnes 1976). Under the right conditions (usually after a disturbance of some kind) this root system will send up new erect stems (suckers). This collection of multiple stems all form one single genetic individual sometimes called a clone. An aspen stand is a collection of aspen stems that include mature aspen "trees". This method of vegetative asexual reproduction is much more commonly employed by the species than sexual reproduction from seed. Aspen are rarely established from seed largely because of stringent seedbed requirements. (McDonough 1985, Jelinski and Cheliak 1992, Mitton and Grant 1996). Factors negatively affecting aspen seed germination and seedling survival include rapid loss of germinability with age (2-4 weeks), presence of inhibitors in soil or litter, dry soils at or near the surface, and high soil surface temperatures (Maini 1968). Some scientists believe that sexual reproduction of aspen has not been widespread since at least the end of the last glaciation period ten thousand years ago (Barnes 1975, McDonough 1985).

Aspen clones depend on periodic disturbance, such as fire, to stimulate vegetative reproduction and to reduce competition from conifers (Bartos and Mueggler 1981, Jones and DeByle 1985, DeByle et al. 1987). Mature aspen stems (trees) release a growth inhibiting hormone known as auxin that suppresses sucker initiation. When mature stems are damaged or killed by a disturbance, auxin levels sent to the root systems decline and a flush of new suckers begin to grow. Fires at intervals anywhere from 20 to 130 years are necessary to assure successful reproduction of aspen clones (Jones and DeByle 1985). Many aspen community types are classified as early seral to coniferous forest types (Mueggler 1988). Periodic disturbance sets back succession assuring a niche for these aspen community types by reducing conifer tree cover.

Scientists and land managers are concerned about the declining number and vigor of aspen communities in many places throughout western North America (Krebill 1972, Loope and Gruell 1973, Schier 1975, Olmsted 1979, Kay 1990, Bartos et al. 1991, Lachowski et al. 1996, Baker et al. 1997, White et al. 1998). Fire suppression in western forests and rangelands over the last 100 years has been reported as one of the reasons for this decline (Gruell 1983, Jones 1985, DeByle et al. 1987, Muggler 1989). As natural succession has occurred in the absence of disturbance, aspen clones have been slowly replaced by conifer tree species that are more tolerant of shade (Kay 1997). Bartos and Campbell (1998) rate the progressive invasion of conifer species into aspen stands as one of the top 5 risk factors associated with the loss of aspen communities from the landscape. Lack of vegetative regeneration is also considered a risk factor and has created even-aged stands with little to no younger age classes of aspen present. Lacking periodic fire or some other disturbance, the root systems of aspen clones have died back or have been completely lost (Schier 1975, Mueggler 1989). The use of aspen suckers as food for both livestock and wildlife has exacerbated this problem in many areas (Bartos et al. 1994, Romme et al. 1995, White et al.

1998, Kay 2001, Kay et al. 2001). As aspen dominated communities shrink in size or disappear from western landscapes, so does the diversity of vascular and nonvascular plants, vertebrate animals and invertebrate organisms that depend on them (Stohlgren et al. 1997a,b, Bartos and Amacher 1998, Bartos and Campbell 1998).

Prescribed fire has been recommended by scientists and land managers to rejuvenate forest types that historically have evolved with fire (Covington and Sackett 1984, Parsons et al. 1986, Caprio and Graber 2000). Fire used as a treatment to rejuvenate aspen communities has had mixed results. From 3,000 to 150,000 suckers/ha following fire have been reported (Patton and Avant 1970, Brown and DeByle 1987, Bartos et al. 1991). In a study done by Bartos and Mueggler (1981), there was a doubling of aspen suckers 2 years after burning aspen stands in the Gros Ventre Mountains of Wyoming. By the end of the third year post-fire, however, the number of suckers had returned to near pre-burn levels. They recommended prescribed fire treatments of moderate severity for optimum suckering response.

The Use of Remotely Sensed Data

Scientists and land managers have used aerial photography as a tool to inventory, manage, and monitor land resources (Befort 1988, Greer et al. 1990, Tueller 1994, Hart and Laycock 1996, Quilter and Anderson 2000). Since the launch of NASA's first Earth Resources Technology Satellite (Landsat 1) in 1972, there has been an immense interest in the potential uses of remotely sensed data for forest and rangeland inventory, mapping, modeling, and analysis (Warren and Hutchinson 1984, Franklin et al. 1986, Smith et al. 1990, Ringrose and Matheson 1991, Chavez and MacKinnon 1994, Keane et al. 1996, Jensen et al. 2001). Remotely sensed images have been used to map numerous characteristics of both forests and rangelands including stand age (Congalton et al. 1993, Fiorella and Ripple 1993), successional stage (Hall et al. 1991, Jabubauskas 1996), vegetation density (Cohen and Spies 1992, Knick et al. 1997), and leaf area index (Clevers 1988, Spanner et al. 1990).

Two key components to estimating many biophysical characteristics of forests and rangelands with remotely sensed imagery is the precision and the accuracy to which different vegetation cover types can be consistently and reliably mapped. Different sensors [e.g. Landsat Multi-Spectral Scanner (MSS), Landsat Thematic Mapper (TM), Systeme Probatoire d'Observation de la Tere (SPOT)] as well as advanced data processing techniques have been used to map general vegetation cover types [i.e. Anderson Level II precision - Anderson et al. (1976)]. Early efforts to classify Landsat MSS images into discrete vegetation cover types did not always achieved satisfactory results. Moore and Bauer (1990) concluded that a detailed vegetation classification could not be reliably generated from Landsat MSS imagery due to suboptimal spectral and radiometric resolution of the sensor. With the onset of the Landsat TM sensor generation in 1982 came improved classification accuracy due to additional spectral bands and finer spatial and radiometric resolution (Moore and Bauer 1990). For example, Homer et al. (1997) mapped a state-wide Landsat TM mosaic for the state of Utah into 36 vegetation cover types with an overall accuracy of 75%. Additional improvements made to the Landsat 7 Enhanced Thematic

Mapper plus (ETM+) sensor (launched in 1999) will likely have significant effects on the quality of satellite imagery outputs (Masek et al. 2001).

There is hope among scientists and land managers that more ecologically meaningful, landscape-scale map products can be produced from medium spatial resolution satellite imagery (i.e. Landsat, SPOT). The most commonly employed method for mapping forests and rangelands at the individual species level (i.e. Anderson Level III precision) is through aerial photograph interpretation (Avery 1968, Paine and McCadden 1988, Everitt et al. 1992, Magnussen 1997). Classification of digital data to date has failed to duplicate the level of detail accomplished with aerial photos (Pitt et al. 1997). Nonetheless, some satellite image classification efforts to the species level have had promising results. Wolter et al. (1995) used multi-temporal Landsat MSS and TM images of a forest in the northern Lake States region to generate a map of 22 forest species with an overall accuracy of 83%. The accuracy of the forest species classes combined (excluding the nonforested classes) was 80%. Mickelson et al. (1998) used multi-temporal Landsat TM data to map 33 forest species in New England with an 80% overall accuracy. Mapping sub-classes within a general vegetation cover type has also been of interest (Luther et al. 1994). For example, Joria and Ahearn (1991) used Landsat TM imagery to map 2 levels of defoliation (moderate and severe) of hardwood trees by the gypsy moth (*Porthetria dispar*) in Michigan. They reported an overall accuracy of 82%. Knick et al. (1997) used non-parametric discriminant analysis in a supervised classification of Landsat TM data to separate 8 density classes of a shrubland cover type in the Snake River Plains of southwestern Idaho. The classification accuracy of shrubland density classes was only 50%.

Discriminant analysis (DA) is a multivariate statistical technique that can be used to identify a set of quantitative variables that best discriminate subjects of 2 or more classes (groups) from one another. A subset of the original quantitative variables often contribute maximally to class separation and therefore DA can be used as a data reduction technique. Discriminant analysis also permits an analyst to predict class membership of a subject whose status is unknown. It can be performed both parametrically and non-parametrically. The most commonly used parametric DA technique is Fisher's Discriminant Analysis. With this technique, determination of group membership is based on differences between class means in multivariate space (Legendre and Legendre 1983, Duarte Silva and Stam 1995). Parametric DA develops a classification criterion by finding linear combinations of quantitative variables that maximize the difference between classes while minimizing the variance within each class. Underlying assumptions about the data to be classified when using parametric DA include multivariate normality and equal within class covariance matrices. On the other hand, non-parametric DA seeks to classify an unknown subject by calculating either Mahalanobis or Euclidean distances in multidimensional space between the unknown subject and a set of subjects whose classes are known (training set). The unknown subject is assigned to a class based on the majority class of the nearest subjects in the training set (Rosenblatt 1956, Parzen 1962). An advantage to non-parametric DA is that there are no underlying assumptions about the data to be analyzed.

Discriminant Analysis has been applied across a broad array of disciplines. For example, the textile industry has used DA to distinguish between new and recycled cashmere (Langley 2000) and the wine industry have classified wines according to their geographical origin (Day 1995). Jensen et al. (2001) used DA to develop a potential vegetation map of the Little Missouri National Grasslands in North Dakota with Landsat satellite imagery, terrain indices, and interpolated climate information. It has been suggested by Lillesand and Kiefer (2000) that the canonical components derived from parametric discriminant analysis can not only improve satellite image classification efficiency but also improve classification accuracy due to increased spectral separability of classes. Peddle (1993) conducted a comparison of algorithms including evidential reasoning, maximum likelihood, and parametric discriminant analysis for alpine land cover classification. Evidential reasoning had the highest overall classification accuracies for 9 of the 12 variable combinations compared, however, the overall classification accuracy using parametric DA improved from 63% (six SPOT image variables and three texture variables used) to 84% when additional elevation, slope, and solar incidence variables were included. Lobo (1997) used a technique for classifying remotely sensed data that first involved image segmentation and then application of parametric DA to classify the segments. He found that partitioning images into segments based on texture analysis and then classifying these segments using DA and maximum likelihood algorithms yielded much better results than classifications done on a per pixel basis. Using this methodology Lobo classified a Landsat TM subscene of the Chimanes Forest in the Bolivian Amazon into 6 classes with an overall accuracy of 94%.

The use of multi-spectral satellite imagery for aspen inventory and management has been limited. Hall et al. (1983) used Landsat MSS color composites to map the distribution of aspen defoliation by the tent caterpillar (*Malacosoma disstria*) in northwestern Alberta, Canada. The visual analysis of satellite images more accurately delineated the affected areas compared to an aerial survey map of the same area. However, damage intensity classes could not be resolved.

Lachowski et al. (1996) used Landsat TM imagery and GIS layers to detect the loss of aspen habitat found in the Gravelly Mountains of Montana. They report an approximate 47% decrease in the aspen cover type from 1947 to 1992 due mostly to conifer invasion. Since some scientists have recommended “taking action now and often” to counteract the loss of aspen in some areas of the western United States (Bartos and Campbell 1998), the development of a cost effective yet accurate method for mapping aspen distribution and stand deterioration due to conifer encroachment over broad areas would be useful.

OBJECTIVES

The principal objectives of our research were:

1) To determine if Landsat 7 ETM+ satellite imagery can be used to accurately classify aspen stands according to degree of Douglas-fir encroachment.
2) To compare the performance of 3 data processing techniques for classifying increasing levels of Douglas-fir encroachment into aspen stands. An unsupervised classification technique was included because it is often used by both scientists and land managers due to it's relatively low cost, ease of application, and low prior knowledge of the land area to be classified. Two supervised classification techniques using parametric discriminant analysis and non-parametric discriminant analysis were used in hopes of improving aspen/Douglas-fir encroachment class separation.
3) To describe 4 levels (classes) of Douglas-fir encroachment into aspen stands with respect to age-class structure, composition of the understory, and amount of aspen vegetative reproduction.

METHODS

Study Site Description

The Pleasantview Hills are located in Oneida county Idaho between Malad Valley and Arbon Valley at Lat. 42°07'30" through 42°22'20" and Long. 112°22'30" through 112°32'30". The Pleasantview Hills can be characterized as a small mountain range dissected by deep canyons with slopes varying from 0-70% and elevations ranging from 1524-2216 m. Average annual precipitation ranges from 43-61 cm and falls predominantly in the form of winter snow. Paleozoic age limestone and dolomite rock outcrops dominate the underlying geology with shale deposits also present. Due to the karst topography, there are numerous springs in most drainages but very few perennial streams. Soils are loamy-skeletal, well drained and predominately frigid calcic Haploxerolls underneath sagebrush, grassland, and mountain shrub vegetation cover types and carbonatic lithic Cryrendolls underneath Douglas-fir and quaking aspen cover types.

All plant taxonomy used in this paper follows that used by the United States Department of Agriculture Natural Resources Conservation Service PLANTS Database (USDA, NRCS 2001). Common tree species in the Pleasantview Hills include Douglas-fir and aspen on north, northeast, and northwest aspects and bigtooth maple (*Acer grandenditatum*) on south, southeast, and southwest aspects. Common mountain shrub species include: common chokecherry (*Prunus virginiana*), Saskatoon serviceberry (*Amelanchier alnifolia*), mountain snowberry (*Symphoricarpos oreophilius*), and mallow ninebark (*Physocarpus malvaceus*). Common sagebrush steppe species include: mountain big sagebrush (*Artemesia tridentata* subsp. *vaseyena*), basin big sagebrush (*Artemesia tridentata* subsp. *tridentata*), yellow rabbitbrush (*Chrysothamnus nauseosus*), broom snakeweed (*Gutierrezia sarothrae*), and gray horsebrush (*Tetradymia canescens*). Common forbs species include common yarrow (*Achillea millefolium*), heart-leaf arnica (*Arnica cordifolia*), twolobe speedwell (*Veronica biloba*), American vetch (*Vicia americana*), arrowleaf balsamroot (*Balsamorhiza sagittata*), tapertip hawksbeard (*Crepis acuminata*), small-flowered nemophila (*Nemophila parviflora*), and early blue violet (*Viola adunca*).

Common grass and grass-like species include Geyer's sedge (*Carex geyeri*), pinegrass (*Calamagrostis rubescens*), orchard-grass (*Dactylis glomerata*), mountain brome (*Bromus carinatus*), intermediate wheatgrass (*Agropyron intermedium*), oniongrass (*Melica* bulbosa), and Kentucky bluegrass (*Poa pratensis*).

The vast majority of land in the Pleasantview Hills is managed by the BLM. Other land owners include the State of Idaho and private entities. Current resource uses include livestock grazing, timber harvesting, wildlife habitat, and recreation. A Federal Aviation Administration (FAA) site and other communication towers are located on some of the highest knolls in the area. Small mining operations have been operational in the past. Cattle grazing occurs during the summer and fall months (May through Sept.) and is managed with a rest-rotation system where each pasture is rested 1 out of every 3 years. Timber harvesting to salvage beetle infested Douglas-fir has been administered by both the BLM and the State of Idaho. Hunting occurs in the summer and fall months. A partial list of wildlife species found in the Pleasantview Hills includes mule deer (*Odocoileus virginianus*), moose (*Alces alces*), elk (*Cervus elaphus*), mountain lion (*Felis concolor*), western spotted skunk (*Spilogale gracilis*), western rattlesnake (*Crotalus viridus*), gopher snake (*Pituophis melanole*), sagebrush lizard (*Sceloporus graciosus*), sage grouse (*Centrocercus urophasianus*), ruffed grouse (*Bonasa umbellus*), blue grouse (*Dendragapus obscurus*), northern goshawk (*Accipiter gentilis*), red-tailed hawk (*Buteo jamaicensis*), and other birds of prey. A concurrent study conducted in the Pleasantview Hills and surrounding areas on habitat types used by neotropical and passerine birds recorded 29 different species using aspen communities over a 3 year period in the early to mid-summer months (Joel Sauder, personal communication 2002).

The study area for this research covers the southern portion of the Pleasantview Hills and is approximately 21,310 ha in size. Intensive aspen plots were established within four drainages including John Evans Canyon, Sheep Creek Canyon, Wood Canyon, and West Elkhorn Canyon. Training sites were located within all of the above mentioned drainages as well as North Canyon, Mansfield Canyon, Stump Canyon, Morgan Jones Canyon, Point Canyon, and Sublette Canyon.

Intensive Aspen Plots

Early in the 2000 summer field season a visual reconnaissance of the study area was conducted and the majority of aspen stands occurring there were classified and mapped (digitized onto 7.5 minute topographic maps) according to the estimated amount of Douglas-fir present in the overstory canopy. These Douglas-fir "encroachment" classes were refined as quantitative data over the 2000 and 2001 fields seasons were collected and include pure aspen stands with less than 1% Douglas-fir canopy cover, aspen stands with 1-15% Douglas-fir canopy cover, aspen stands with 16-30% Douglas-fir canopy cover, and aspen stands with greater than 30% Douglas-fir canopy cover. We felt that mapping conifer encroachment into aspen at these levels was ecologically justified. By mapping conifer encroachment in its early stages, the threshold at which an aspen stand becomes more flammable can be assessed and stands at risk can be identified early on.

Potential aspen plot locations were generated throughout each of the aspen/Douglas-fir encroachment cover classes using an ArcView Geographical Information System (GIS) script that placed random points on digital topographic maps. Plot locations for each aspen/Douglas-fir strata were selected from these maps using a random number table and were navigated to on the ground using 7.5 minute topographic maps and aerial photographs. The center or origin of each aspen plot was located by walking a random distance towards a random azimuth from the position on the ground estimated to be the computer generated random point and then recorded with a Trimble ProXRS Global Positioning System (GPS) unit. Twenty permanent aspen plots were established within 4 drainages. Seven of these plots were established in John Evans Canyon, 6 in Wood Canyon drainage, 4 in Sheep Creek Canyon drainage, and 3 in West Elkhorn Canyon. See Appendix #1 for Universal Transverse Mercator (UTM) coordinates and legal location descriptions of permanent aspen plots.

Plot dimensions from the National Park Service's Fire Management Handbook (USDI 1992) were adopted as the standard for permanent aspen plot layout and dimensions (Fig. 1). All permanent aspen plots consist of three 50 m parallel transects spaced 10 m apart from each other. Due to steep and rough terrain and associated safety concerns, all transects were oriented parallel to the terrain contour.

Digital photographs of the plot were taken from the origin in all 4 cardinal directions. Understory shrubs, forbs, and grasses were recorded in these photographs. Percent canopy cover of aspen, Douglas-fir, and maple within each plot was estimated using a spherical densiometer. Readings were taken from each corner of the plot in all 4 cardinal directions and averaged. Percent canopy cover from all corners were averaged to estimate overall percent canopy cover for all 3 tree species. Twenty by fifty cm quadrats were used to estimate species composition and percent canopy coverage of grasses and forbs within a plot (Daubenmire 1959). The quadrat was placed along each of the 3 established transects at 1 m intervals along the uphill side of each transect for a total of 30 quadrats per plot. Canfield's (1941) line-intercept method was used to estimate percent shrub coverage within a plot. Twenty-five meters of each established transect were read totaling 75 m per plot. To estimate aspen sucker density, a 1 m wide belt along the uphill side of each established transect was read for a total area of 150 m^2 per plot. All aspen suckers 1 m or less in height and growing within the belt were counted. The number of suckers within each belt were totaled and the 3 belt transect totals were added together for an estimation of aspen sucker density within the plot. Four or 5 of the largest diameter aspen ramets (trees) within each plot were cored with an increment borer. The largest diameter Douglas-fir tree within each plot was also cored. All cores were stored and air dried in paper straws. All cores were mounted on core boards with wood glue and hand sanded 4 times with increasingly fine grit sandpaper (300, 400, 800, 1500 grit) (Asherin and Mata 2001). Fehling's solution (USDA Forest Service 1962) was applied to the aspen cores to make the growth rings more visible. Growth rings for each aspen core were counted under a dissecting microscope and averaged with the other aspen cores from the plot for an estimation of aspen stand age. Douglas-fir cores were sanded with 400 grit sandpaper and growth rings were counted with the naked eye. Age of Douglas-fir trees were recorded separately and not included in the average aspen stand age calculation.

Training Sites

Training sites were located across all of the general vegetation cover types present in the southern portion of the Pleasantview Hills. If a vegetation cover type occurred on more than one aspect, additional training sites were established for that category, so that all combinations of cover type/aspect were represented. There were a total of 12 general vegetation cover types (including three aspen/Douglas-fir encroachment classes) documented in the field (Table 1). Training sites were not located randomly. Instead, easily and moderately accessible areas with homogeneous vegetation cover spanning across at least 100 m^2 were strategically chosen throughout the study area. Over the 2000 and 2001 summer field seasons, 138 training sites were sampled. In addition, another 57 training sites in the sagebrush, grassland, and mountain shrub vegetation types were obtained from a satellite image classification project funded by both the BLM and Idaho Department of Fish and Game in 1997-98 (James Kumm, personal communication 2001). All 20 of the permanent aspen plot center stakes were also used as training sites bringing the total number of sites to 215. Each training site consisted of a point location collected with the Trimble ProXRS GPS unit. The major plant species present within a 100 m^2 area of the point location as well as the canopy cover of trees, shrubs, grasses, and forbs were visually estimated and recorded. Slope and aspect were recorded with the use of a Suunto Tandem clinometer/ compass. A photograph of the vegetation was taken at each site. Each GPS file was differentially corrected in Pathfinder Office (version 2.80) with base station files from the Idaho State University GIS Center Base Station to assure a high level of location accuracy. All GPS files were exported into ArcView GIS (version 3.2) as shapefiles.

Satellite Image Processing

The Landsat 7 ETM+ satellite images were acquired through the Utah State University Landscape Ecology and Modeling Center. Both images are indexed as Path 31 Row 39 in the Worldwide Reference System (WRS). The summer image was taken on July 4, 1999, the winter image was taken on October 24, 1999. Both images were georeferenced by the EROS Data Center (EDC) to the UTM coordinate system, zone 12 North, spheroid Geodetic Reference System (GRS) 1980, North American Datum 1983 (NAD83) and resampled to 28.5 m^2 pixels using cubic convolution. Six bands of data from each image were used in the classification procedures including bands 1-5 and 7 (visible, near-infrared, and mid-infrared regions of the electromagnetic spectrum). Bands 6 (thermal) and 8 (panchromatic) were not used in the classification efforts. The Data Preparation Module in ERDAS Imagine (version 8.5) was used to subset both images making the study area the only portion of the images included in the classification procedures. The Modeler Module in ERDAS Imagine was used to convert the pixel data in both images to radiance values and then exo-atmospheric reflectance values.

A USGS 3 arc-second digital elevation model (DEM) with 30 m^2 pixels was resampled to 28.5 m^2 in ArcInfo (version 8.1) and used with the Solar Analyst (version 1.0) ArcView GIS extension (HEMI 2000) to create a solar insolation layer. The amount of incoming solar radiation over the span of a year was estimated for each pixel location with this extention. Two Normalized Difference Vegetation Index (NDVI) layers (one for each image) were created in the ERDAS Imagine Image Interpreter Module using the red and near-infrared bands. See Equation 1 for the NDVI computation.

The magnitude or range of values for the layers described above were not all approximately equal. In order to more easily interpret the coefficients developed in the classification of pixels into vegetation classes, all layers were normalized in the Modeler Module of ERDAS Imagine. See Equation 2 for the normalization computation. The ERDAS Imagine Image Interpreter Module was used to stack all layers into one multi-layered image for use in the classification procedures described below.

Equation 1

$$\text{NDVI} = \frac{\text{Near Infrared Band} - \text{Red Band}}{\text{Red Band} - \text{Near Infrared Band}}$$

Equation 2

$$Z = \frac{X - \mu}{\sigma}$$

where:

Z = Normalized pixel value

X = Pixel value

μ = Mean of pixels values in a given band

σ = standard deviation of pixel values in a given band

Unsupervised Classification

An unsupervised classification of satellite imagery can be defined as the identification, labeling, and mapping of natural groups, or structures, within multi-spectral data (Campbell 1996). The multi-layered image described above was classified using the Interative Self-Organizing Data Analysis (ISODATA) algorithm in the Classifier Module of ERDAS Imagine (Jensen 1996). This algorithm uses the minimum spectral distance formula to form clusters of pixels with similar spectral values throughout all layers of data. See Equation #3 for the minimum spectral distance calculation. The software starts by clustering pixels of the image using the minimum spectral distance formula. The ISODATA algorithm iteratively clusters the pixels of an image (shifting the mean of pixel values in a cluster as pixels are either added or removed) until either a maximum number of iterations has been performed or a maximum percentage of unchanged pixel assignments has been reached between two iterations (i.e. convergence threshold) (Jensen 1996). The number of final clusters, the number of iterations, and the convergence threshold is set by the image analyst. For the classification of the multi-layered image described above, the number of clusters was set to 35, maximum iterations to 30, and convergence threshold to 0.950. The iteration process was stopped when 5% or fewer of the pixels changed clusters between iterations (Jensen 1996).

Equation 3

$$D_{ab} = \sqrt{\sum_{i=1}^{n} (a_i - b_i)^2}$$

where:

a_i = pixel value in one of *n* spectral bands

b_i = pixel value in one of *n* spectral bands

D_{ab} = distance between pixel *a* and *b* through *n* spectral bands

Sixteen 1 m^2 resolution digital orthophoto quarter-quadrangles as well as training site locations described above were used to identify what each class generated by the ISODATA algorithm represented on the ground. The thematic map created with the unsupervised classification procedure as well as the orthophoto quads were loaded into 2side by side viewers in ERDAS Imagine and geometrically linked. A cross-hair visible on both the map and the orthophotos could be moved to different classes/vegetation cover types for identification purposes. Each class of the map was labeled according to the dominant vegetation cover type visible in the orthophotos. The class labels used generally follow Anderson's (1976) Level II precision classification scheme with the exception of the aspen/Douglas-fir encroachment classes. The encroachment classes are more accurately described as Anderson precision level III labels (e.g. dominant tree species, forest successional stages, or insect damage levels). Finally, the thematic map was recoded (pixel clusters with the same class label were combined) resulting in 1 label for each vegetation cover type.

Supervised Classifications

A supervised classification of satellite imagery can be described as the process of using pixels of known identity to classify pixels of unknown identity. As a general rule, 100 pixels/class are needed to classify the remaining unknown pixels of an image into a defined number of target classes (Campbell 1996, Jensen 1996). The number of classes used in a supervised classification should correspond to the number of categories (i.e. vegetation type, urban, water, etc.) found on the ground. A minimum of 50 additional pixels/class have been recommended for assessing the accuracy of a classification raising the needed number of known identity pixels to 150/class (Campbell 1996).

Samples of known pixel identity for this project (i.e. known vegetation cover type and location in the image) were created from the training sites collected in the field with GPS technology over the 2000 and 2001 summer field seasons. The vegetation cover types sampled in the field were grouped into 12 classes. The region growing tool in the Viewer Module of ERDAS Imagine was used to increase the sample size (number of pixels) per class. Each training site was displayed over the image and used as a seed pixel (model pixel) against which contiguous pixels were compared spectrally. The parameters used to decide whether a contiguous pixel was accepted or not into a "training field" was set and included a maximum spectral Euclidean Distance of 1 and a maximum number of 20 to 30 surrounding pixels examined. Region growing was an iterative process with the mean of an accepted training field used for further comparison of adjacent pixels. Training fields were further refined with the digital orthophoto quarter quadrangles. Two viewers in ERDAS Imagine were geometrically linked so that a training field created with the region growing tool on the satellite image was also defined on the orthophoto quarter quadrangle in the second viewer. The vertices of each training field could be moved and the boundaries refined in either viewer to assure that only 1 vegetation class was included in a training field. All training fields were recorded in separate files with labels indicating which class they belonged to. Training field files included UTM map coordinates for all included pixels and associated values for each of the 15 image layers. The files were exported in ASCII format for use in Excel (Microsoft 2000) and Statistical Analysis Software (SAS 1999) packages. The total number of known identity pixels used in the supervised classification procedures was 2,807. Seventy-five % of these pixels were designated for training and the remaining 25% were used for accuracy assessment.

A worksheet for each vegetation class was created in Excel and corresponding training field files were imported into the appropriate worksheet. Random numbers were generated with Excel and assigned to each pixel throughout all of the worksheets. Pixels were sorted by random number. Twenty-five % of the pixels from each class were removed from the top of each worksheet and became the validation data set used for accuracy assessment. The remaining pixels for each class were merged and became the training data set used to perform both parametric and non-parametric discriminant analysis.

Parametric Discriminant Analysis

The procedure DISCRIM was used in SAS to develop linear equations with discriminant function coefficients for all 12 classes (Table 2). These equations formed a classification rule that could be used to predict membership of unknown pixels into 1 of 12 classes. Cross-validation was applied to the training data set to estimate how the classification rule might perform on an independent set of data. Automated Machine Language (AML) containing linear equations for each vegetation class was used in conjunction with ArcInfo to classify the satellite image.

Non-Parametric Discriminant Analysis

The DISCRIM procedure was also used to perform *k*-nearest neighbor non-parametric discriminant analysis. The training data set was imported into SAS as well as an ASCII file of the entire study area. Mahalanobis distance in multi-dimensional space was calculated for every pixel in the study area against all pixels in the training data set. Seven nearest neighbor (the 7 training pixels closest in multidimensional space to an unknown pixel in the study area) was chosen over 5 nearest neighbor because it produced the lowest error rate when cross-validation was applied to the training data set. A SAS file containing class labels for every study area pixel was produced. This file was exported into ArcView as a table and used to reconstruct a thematic map that included all 12 vegetation classes.

Equation 4

$$\mathrm{K}_{hat} = \frac{\mathrm{N}\sum_{i=1}^{r} x_{ii} \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}{\mathrm{N}^2 - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}$$

where:

$\mathrm{K}_{hat} =$ Kappa statistic

$r =$ the number of rows in the error matrix

$x_{ii} =$ the number of observations in row i and column i

$x_{i+} =$ marginal total for row i

$x_{+i} =$ marginal total for column i

N = total number of observations

Accuracy Assessment

Accuracy of all three classifications was assessed with the validation data set described above. Errors of omission and commission were calculated as well as overall accuracy in the Classifier Module of ERDAS Imagine. In addition, Kappa statistics were generated measuring the degree to which each classification was better than pure chance (Hudson and Ramm 1987). See Equation 4 for the Kappa statistic calculation. Error matrices were developed in Excel to display errors of omission and commission between classes and overall accuracy for all 3 classifications (Story and Congalton 1986).

RESULTS

Intensive Aspen Plots

The elevation of all twenty intensive aspen plots were very similar with only 374 m separating the highest plot from the lowest. The 1-15% Douglas-fir encroachment class includes both the highest and the lowest elevational plot at 2130 m and 1756 m respectively. The steepness of slope varied more than elevation with the steepest plot occurring in the +30% Douglas-fir encroachment class at 62% and the flattest plot occurring in the pure aspen class at 15%.

Overstory canopy cover for all plots was comprised of aspen, Douglas-fir, and an occasional big-tooth maple. The total overstory canopy cover per plot ranged widely from 17 to 79%. The +30% Douglas-fir encroachment class had the highest average total overstory canopy cover with 78% and the pure aspen and 1-15% Douglas-fir encroachment class had the lowest averages with 45 and 43% respectively. The average amount of Douglas-fir canopy cover component varied from less than 1% in the pure aspen class to 56% in the +30% Douglas-fir encroachment class. The 16-30% Douglas-fir encroachment class included 1 plot with 31% Douglas-fir overstory canopy cover making the total number of plots per class even at 5. This plot's Douglas-fir canopy cover score more closely resembled the 16-30% encroachment class scores while the +30% Douglas-fir encroachment class ranged from a low score of 48% to a high score of 73%. Logically, the average aspen canopy cover component was highest in the pure aspen class (highest plot 68%) and lowest in the +30% Douglas-fir encroachment class (lowest plot 1%).

The understory vegetation of all intensive aspen plots consisted of grass, grass-like, forb, sub-shrub, and shrub life forms. In addition, all Douglas-fir trees less than 2 m in height were included in the line intercept canopy cover scores. Average grass canopy cover was highest in the pure aspen class (20.0%) and lowest in the aspen +30% Douglas-fir encroachment class (12.0%). Pinegrass, orchardgrass, alpine timothy (*Phleum pratense*), bulbous bluegrass (*Poa bulbosa*), and Kentucky bluegrass all had more than 5.0% canopy cover in at least 1 of the 20 intensive aspen plots. Kentucky bluegrass had the highest average canopy cover in 3 of the 4 aspen/Douglas-fir encroachment classes including pure aspen (9.9%), 1-15% Douglas-fir encroachment class (11.5%), and aspen +30% Douglas-fir encroachment class (6.6%). Pinegrass had the highest average canopy cover in the 16-30% Douglas-fir encroachment class (4.8%) (Table 3).

Average forb/sub-shrub canopy cover was highest in the 16-30% Douglas-fir encroachment class (29.9%) and lowest in the 1-15% Douglas-fir encroachment class (23.4%). The forb and sub-shrub species heartleaf arnica, creeping barberry, small-flowered nemophila, western sweetroot (*Osmorhiza occidentalis*), mountain lover (*Paxistima myrsinites*), twolobe speedwell, and American vetch all had more than 5.0% canopy cover in at least 1 of the 20 intensive aspen plots. Creeping barberry had the highest average canopy cover in both the pure aspen and 1-15% Douglas-fir encroachment classes with 4.4% and 4.5% cover respectively. Western sweetroot had the second highest average canopy cover score for the pure aspen class (2.6%) and small-flowered nemophila had the second highest canopy cover score for the 1-15% Douglas-fir encroachment class (2.1%). Heartleaf arnica had the highest average canopy coverages for the 16-30% and +30% Douglas-fir encroachment classes with 8.5 and 8.0% respectively. Western sweetroot had the second highest cover values for both of these classes with 4.1 and 4.4% respectively (Table 3).

The highest average shrub canopy cover occurred in the pure aspen class (43.4%) and the lowest in the +30% Douglas-fir encroachment class (35.7%). The shrub species Rocky Mountain maple, Saskatoon serviceberry, mallow ninebark, common chokecherry, sticky current (*Ribes viscosissimum*), Wood's rose (*Rosa woodsii*), Scouler's willow (*Salix scouleriana*), and mountain snowberry had greater than 5.0% canopy cover in at least 1 of the 20 intensive aspen plots. In the pure aspen class, Saskatoon serviceberry and mountain snowberry had the highest average shrub canopy cover with 11.6% and 9.6%, respectively. In the 1-15% Douglas-fir encroachment class mallow ninebark and western snowberry had the highest average shrub canopy cover with 11.0% and 10.5%, respectively. In the 16-30% Douglas-fir encroachment class mallow ninebark and Saskatoon serviceberry had the highest average canopy cover with 14.4% and 11.6%, respectively. In the +30% Douglas-fir encroachment class western snowberry and mallow ninebark had the highest average canopy cover scores with 8.7% and 8.4%, respectively (Table 3).

Several plant species displayed high fidelity to one of the aspen/Douglas-fir encroachment classes. Nodding onion (*Allium cernuum*), mule-ears (*Wyethia amplexicaulis*), and yellow rabbitbrush were only recorded in the pure aspen class. Thurber's needlegrass (*Achnatherum thurberianum*), wild oat (*Avena fatua*), western wheatgrass (*Pascopyrum smithii*), narrowleaf blue-eyed Mary (*Collinsia linearis*), Crytantha (*Cryptantha spp.*), ballhead waterleaf (*Hydrophyllum capitatum*), and snowbrush ceanothus (*Ceanothus velutinus*) were only recorded in the 1-15% Douglas-fir encroachment class. Littleleaf pussytoes (*Antennaria microphylla*), roughfruit fairybells (*Disporum trachycarpum*), and western rattlesnake plantain (*Goodyera oblongifolia*) were only recorded in the 16-30% Douglas-fir encroachment class. Canada wildrye (*Elymus canadensis*), miner's lettuce (*Claytonia perfoliata*), brittle bladderfern (*Cystopterus fragilis*), and field pennycress (*Thlaspi arvense*) were only recorded in the +30% Douglas-fir encroachment class.

The aspen encroachment classes with the highest average number of vascular plant species recorded (species richness) were the pure aspen and 1-15% Douglas-fir encroachment classes, tied at 33 species. The lowest average number of plant species was 28 in the 16-30% Douglas-fir encroachment class. Wood Canyon plot #25 had the highest number of plant species recorded (45 species) and John Evans Canyon plot #5 had the lowest number of plant species recorded (19 species);(Table 4).

The oldest aspen trees sampled were at both ends of the spectrum in the pure aspen and +30% Douglas-fir encroachment classes. Pure aspen plots had the highest average aspen age at 94 years followed by the +30% Douglas-fir encroachment class with an average of 88 years. Sheep Creek plot #13 had the highest individual plot average aspen age of 114 years. The 1-15% and 16-30% Douglas-fir encroachment classes had lower average aspen ages at 61 and 72 years, respectively (Fig. 2). The aspen tree diameter at breast height (dbh) corresponded with the results of age. The pure aspen class had the highest dbh with 25.9 cm followed by the +30% Douglas-fir encroachment class with 22.9

cm. The 1-15% and 16-30% Douglas-fir encroachment classes had an average dbh of 19.8 and 15.7 cm respectively. The oldest Douglas-fir sampled throughout all of the intensive aspen plots was approximately 106 years of age. This tree was found in a plot belonging to the 16-30% Douglas-fir encroachment class. The +30% Douglas-fir encroachment class had the highest average Douglas-fir age at 80 years while the pure aspen and 1-15% Douglas-fir encroachment classes had lower average ages at 61 and 62 years respectively (Table 4).

Average aspen sucker density appears to be negatively related to increasing aspen age (Fig. 2 and 3). In the pure aspen class where average aspen age was the highest (94 years), sucker density was the lowest with an average of only 17 suckers/plot. In the 1-15% Douglas-fir encroachment class where average aspen age was the lowest (61 years), sucker density was the highest with an average of 67 suckers/plot. Plot #1 in John Evans Canyon had the highest number of aspen suckers recorded (102) and belonged to the 1-15% Douglas-fir encroachment class. Plot #6 in John Evans Canyon had the fewest aspen suckers recorded (4) and belonged to the +30% Douglas-fir encroachment class (Table 4).

Classification Accuracy of Satellite Imagery

The overall accuracy of a satellite image classification can be defined as the total number of correctly classified pixels divided by the total number of reference pixels used to evaluate accuracy (Jensen 1996). The relationship between a satellite image classification and reference information is summarized in an error matrix. An error matrix is a square array of numbers laid out in rows and columns that expresses the number of sample units (i.e., pixels, clusters of pixels, or polygons) assigned to a particular category relative to the actual category as verified in the field (Jensen 1996). Error matrices include measures of both omission and commission errors. Errors of omission indicate the proportion of reference pixels that have been correctly classified and is derived by dividing the total number of correctly classified pixels in a class by the total number of reference pixels for that class. Subtracting percent omission error from 100 yields producer's accuracy (the producer or analyst is interested in how well a particular scene can be classified). Errors of commission indicate the proportion of pixels classified on the map that actually represent the appropriate class on the ground. It is derived by dividing the total number of correctly classified reference pixels in a class by the total number of pixels labeled as that class on the map. Subtracting the percent commission error from 100 yields user's accuracy (which represents how reliable a final map product will be on the ground).

Another measure of classification overall accuracy is the Kappa statistic (Congalton and Mead 1983). Computation of this statistic incorporates the off diagonal elements in an error matrix as a product of the row and column marginals for each class. In this way the Kappa statistic includes the overall accuracy as well as both omission and commission errors. The range of values for a kappa statistic vary from –1 to +1 and indicate whether the results presented in an error matrix are better than random chance alone (i.e., a null hypothesis of $K_{hat} = 0$) (Jensen 1996).

Accuracy of the Unsupervised Classification

The Douglas-fir, pure aspen, and Douglas-fir encroachment classes were of primary interest in this study and will be discussed throughout this section. Errors of omission and commission for the classes agriculture active, agriculture fallow, maple, mountain shrub, grassland, sagebrush, and juniper are not discussed here but are summarized in Tables 5-8.

The overall accuracy of the unsupervised classification was low at 50%. The Kappa statistic indicates the classification was 40% better than if done by chance alone but only moderately so with a value of 0.399.

The Douglas-fir, 16-30%, and +30% Douglas-fir encroachment classes were consistently confused with one another (Table 5). Only 11% of the +30% Douglas-fir encroachment class reference pixels were classified correctly, the misclassified pixels labeled as either Douglas-fir, 16-30% Douglas-fir encroachment, or mountain shrub. User's accuracy indicates that only 29% of those pixels labeled as +30% Douglas-fir encroachment on the map would represent +30% Douglas-fir encroachment occurrence on the ground. Seventy-two percent of the Douglas-fir reference pixels were classified correctly, the majority of misclassified pixels labeled as either 16-30% or +30% Douglas-fir encroachment. User's accuracy was 54%. The 16-30% Douglas-fir encroachment class had relatively low omission error with 86% of the reference pixels being correctly classified, but again, user's accuracy indicates only 38% percent of those pixels labeled as 16-30% Douglas-fir encroachment on the map would be of this class on the ground.

The pure aspen class was often confused with the 16-30% Douglas-fir encroachment class as well as with the agriculture active, maple, and mountain shrub classes. Forty-nine percent of the pure aspen reference pixels were classified correctly, the misclassified pixels labeled as either 16-30% Douglas-fir encroachment or mountain shrub. User's accuracy indicates that only 39% of those pixels labeled as pure aspen on the map would correctly represent pure aspen occurrence on the ground. None of the 1-15% Douglas-fir encroachment class reference pixels were classified correctly and none of the pixels labeled as such would be of this class on the ground (Table 5 and Fig. 4).

Accuracy of the Parametric Supervised Classification

The overall accuracy of the supervised classification using Fisher's DA was 13% higher than the unsupervised classification at 63%, however, this procedure did not improve the accuracy levels of the aspen/Douglas-fir encroachment classes (Table 6). In fact, the number of omission and/or commission errors for the aspen/Douglas-fir encroachment classes were very similar for both classifications, the difference being where the misclassifications were made. It is worth noting that this data processing technique improved producer's and user's accuracy for 6 of the 7 "other" classes not of primary interest in this study. The Kappa statistic indicates the supervised classification was 54% better than if the classification had been done by chance alone.

As was seen in the unsupervised classification, the algorithm used in this technique had difficulty separating the 16-30% Douglas-fir and +30% Douglas-fir encroachment classes. Sixty-six % of the Douglas-fir reference pixels were classified correctly, the majority of misclassified pixels labeled as either 1-15% or +30% Douglas-fir encroachment. User's accuracy indicates that 56% of the pixels labeled Douglas-fir on the map would correctly represent Douglas-fir occurrence on the ground. Only 8% of the +30% Douglas-fir encroachment class reference pixels were correctly classified, the majority of misclassified pixels labeled as either Douglas-fir or 1-15% Douglas-fir encroachment. User's accuracy was only 15%. Nine percent of the 16-30% Douglas-fir encroachment class reference pixels were correctly classified, the majority of misclassified pixels labeled as either 1-15% or +30% Douglas-fir encroachment. User's accuracy was 26%.

Eighty-one percent of the pure aspen reference pixels were correctly classified, the majority of misclassified pixels labeled as either 1-15% Douglas-fir encroachment or mountain shrub. User's accuracy indicates, however, that only 52% of the pixels labeled pure aspen on the map would truly represent pure aspen on the ground. Thirty-three % of the 1-15% Douglas-fir encroachment reference pixels were classified correctly, the majority of misclassified pixels labeled as pure aspen and the others labeled as either 16-30% or +30% Douglas-fir encroachment. User's accuracy was only 16% (Table 6 and Fig. 5).

Accuracy of the Non-Parametric Supervised Classification

At 77%, the supervised classification using non-parametric discriminant analysis had the highest overall accuracy out performing the unsupervised classification by 27% and the parametric supervised classification by 14%. The Kappa statistic was 0.709 indicating that this classification was 71% better than if done by chance alone (Table 7). Producer's accuracy was improved over the parametric supervised classification for 8 of the 12 classes including Douglas-fir, 1-15%, and 16-30% Douglas-fir encroachment. Three out of the 4 remaining classes' classification accuracy was not greatly different from the previous classification technique, including the +30% Douglas-fir encroachment class. User's accuracy was also improved for 9 out of the 12 classes including Douglas-fir, pure aspen, and all of the Douglas-fir encroachment classes (Fig. 7).

Ninty-two % of the Douglas-fir reference pixels were correctly classified, the misclassified pixels labeled +30% Douglas-fir encroachment. User's accuracy indicates that 58% of the pixels labeled Douglas-fir on the map would represent Douglas-fir occurrence on the ground. Of all classes, the +30% Douglas-fir encroachment class has the lowest producer's accuracy with only 8% of the reference pixels correctly classified. The misclassified pixels were labeled as either Douglas-fir, pure aspen, or one of the other Douglas-fir encroachment classes. User's accuracy for this class was also the lowest at 36%. Only 17% of the 16-30% Douglas-fir encroachment reference pixels were correctly classified, the majority of misclassified pixels labeled as 1-15% Douglas-fir encroachment and the remaining pixels labeled as either Douglas-fir or +30% Douglas-fir encroachment. User's accuracy was 45%.

Pure aspen was the only class with a producer's accuracy lower than that of the parametric supervised classification technique dropping from 81% to 77%. However, user's accuracy was slightly improved from 52 to 53%. Sixty-three % of the 1-15% Douglas-fir encroachment class reference pixels were correctly classified, the majority of misclassified pixels labeled as pure aspen and the remaining pixels labeled as either 16-30% or +30% Douglas-fir encroachment. User's accuracy for this class was only 32% (Table 7 and Fig. 6).

Supervised Classification with Douglas-fir Encroachment Classes Combined

With all three classification procedures failing to accurately discriminate between Douglas-fir, aspen, and the intermediate encroachment classes, the precision to which we could map the aspen Douglas-fir continuum was in need of reevaluation. The spectral signatures of the three Douglas-fir encroachment classes greatly overlapped in multi-dimensional space and so a discrete classification that included all three was difficult. By combining the 3 intermediate Douglas-fir encroachment classes into 1 aspen/Douglas-fir mix class, the overall accuracy of the supervised classification using both parametric and nonparametric DA as well as the individual class accuracies were improved (Table 8).

The overall accuracy of this classification was 79% with a kappa statistic of 0.732. One hundred % of the Douglas-fir reference pixels were classified correctly. User's accuracy was only 51% however, indicating that only half of the pixels labeled as Douglas-fir on the map represent Douglas-fir occurrence on the ground. Ninety-four % of the pure aspen reference pixels were classified correctly. User's accuracy was 52%. Forty % of the aspen/Douglas-fir mix reference pixels were classified correctly with the majority of misclassified pixels labeled as either Douglas-fir or pure aspen. User's accuracy for this class was higher than previous classifications at 90% (Table 8 and Fig. 8).

DISCUSSION

Intensive Aspen Plots

There were 75 vascular plant species recorded throughout all of the intensive aspen plots. The average number of plants found for any single conifer encroachment class was approximately 30. A count of species occurring in any plot within a given encroachment class reflects species richness of the encroachment class as a whole. Number of species found in at least one of the pure aspen plots was 49, for the 1-15% Douglas-fir encroachment plots 56, for the 16-30% Douglas-fir encroachment plots 52, and for the +30% Douglas-fir encroachment plots 51. These data support the goal of managing for a balanced mix of all aspen and Douglas-fir cover types across the landscape. In the southern portion of the Pleasantview Hills, approximately 75% of those areas currently supporting aspen clones are being encroached upon by Douglas-fir trees. Over time, in the absence of periodic disturbance, these aspen woodlands will convert to coniferous forest (Fig. 9).

As forested areas dominated by aspen change through time into mixed aspen/conifer stands and eventually into pure stands of conifer, understory plant species composition also varies. In the Pleasantview Hills, several understory plant species were found in greater abundance towards one end of the aspen/Douglas-fir continuum with little to no cover at the opposite end. For example, bluebunch wheatgrass (*Pseudoroegneria spicata*), creeping barberry (*Mahonia repens*), and twolobe speedwell had higher cover values in the pure aspen class but tended to fade out or disappear as the Douglas-fir component increased. Heartleaf arnica (*Arnica cordifolia*), gooseberryleaf alumroot (*Heuchera grossularifolia*), northern green orchid (*Platanthera hyperborea*), and Pennsylvanica cinquefoil (*Potentilla pennsylvanica*) had higher cover values in the +30% Douglas-fir encroachment class but had very little to zero cover in the pure aspen class. Pinegrass and sticky current had high cover values in the 1-15% and 16-30% Douglas-fir encroachment classes but tended to drop out in both the pure aspen and +30% Douglas-fir encroachment classes (Fig. 10 and 11). Some understory plants showed fidelity to only one of the aspen/conifer encroachment classes. For example, yellow rabbitbrush, nodding onion (*Allium cernuum*), and mules ears (*Wyethia amplexicaulis*) were only recorded in the pure aspen class. Miner's lettuce, smallwing sedge (*Carex microptera*), brittle bladderfern (*Cystopterus fragilis*), and Canada wildrye were only recorded in the +30% Douglas-fir encroachment class. Some of these species could be diagnostic of a given level of overstory species dominance, however, differences in environmental variables across intensive aspen plot locations (i.e. slope, aspect, elevation) could also explain plant preferences. With only 5 intensive plots per encroachment class, it is quite possible that some species distributions were wider than they appeared. With a larger sample size, those species showing fidelity to one encroachment class might prove to be more wide spread than the data for this research indicate.

Variable Selection

Stepwise discriminant analysis using backwards selection showed that all layers of the image significantly helped to explain variance in the data. None of the 15 layers were removed from the analysis. Biophysical characteristics of both the vegetation to be classified and the topographic setting drove the choice of layers. Discriminant functions were developed in the parametric discriminant analysis procedure and used as coefficients in linear equations (one equation for every vegetation class). Unknown pixel values (one value for every layer of the image) were entered into the twelve linear equations and solved. Each unknown pixel was labeled according to which linear equation had the highest score. The range or spread between the highest and lowest coefficient values for a given layer across all vegetation classes gave an indication of the weight of that layer or how useful it was for separating unknown pixels into the twelve classes (Fig. 12). In parametric DA the summer NDVI (layer 13) was the most heavily weighted with a range of 35 followed by winter red (layer 9) with a range of 27, winter near-infrared (layer 10) with a range of 26, and summer red (layer 3) with a range of 22. Layers with the lowest range of coefficient values and therefore least helpful in separating unknown pixels into vegetation classes included solar insolation (layer 15) with a range of 3, summer mid-infrared (layer 6) with a range of 4, winter blue (layer 7) with a range of 4, and winter green (layer 8) with a range of 6. All other layers had intermediate coefficient ranges.

The use of data from multi-temporal images has been shown to improve the accuracy of classifications where both coniferous and deciduous tree species were present (Shen et al. 1985, Wolter et al. 1995, Mickelson et al. 1998). By including layers from a satellite image of the study area where deciduous leaves were still on the trees and actively photosynthesizing (July) and from an image of the same area where those leaves had senesced and fallen off (October), we were attempting to accentuate the difference in reflectance between the coniferous and deciduous trees. Specific bands from both images were important for separating the data into twelve vegetation classes. This is can be seen in the weights of the layers used with July NDVI, July red, October red, and October near-infrared having the largest coefficient value ranges (Fig. 12).

NDVI layers created from the red and near-infrared bands of the July and October images were included because they are considered to be a good measure of both vegetation biomass and vigor on the ground. The inverse relationship between vegetation brightness in the red and near-infrared region of the electromagnetic spectrum make NDVI an effective way of representing the importance of vegetative reflectance within a given pixel (Campbell 1996).

Solar radiation is the primary driver of Earth's physical and biological processes. Vegetation pattern in the Pleasantview Hills is strongly influenced by incoming solar radiation as it is affected by topographic slope and aspect. The insolation layer used in the classification process was a measure of the incoming solar radiation over the period of a year for any given pixel. This layer was advantageous because it combined the interaction of slope and aspect on incoming solar radiation into a single variable. Big tooth maple and aspen had similar brightness values throughout the spectral layers of the July image. In the study area, big tooth maple was primarily found on south-facing slopes and aspen was found primarily on slopes with northerly aspects. We felt that the total amount of incoming solar radiation for any given pixel would help to separate the maple and aspen cover classes. The spread between the highest and lowest coefficient values for the solar insolation layer was the lowest of all variables but was still significant at the 0.01 level for separating the data into vegetation classes.

Sources of Error

One of the possible sources of error introduced while classifying the satellite imagery was how training sites were defined on the ground. At each training site the amount of Douglas-fir in the forest canopy was visually estimated and not quantified with a densiometer. The encroachment classes used were fairly broad and most training sites probably had the appropriate label but the potential for confusion between classes did exist. This was especially true for those training sites on the successional boundary between two encroachment classes. Another possible source of error was the number of Douglas-fir saplings and small trees found in the understory of training site locations. These small trees would have been visible to the remote sensor in the winter scene when the aspen tree leaves had fallen off. The small Douglas-fir trees were not taken into account when determining which encroachment class a given training site belonged to on the ground, therefore, an underestimation of the amount of Douglas-fir recorded by the sensor probably occurred at some training site locations.

Mapping the continuum from pure aspen to pure Douglas-fir was difficult for all 3 of the data processing techniques described in this paper because the spectral values throughout all fifteen bands of data for these vegetation classes were very similar. Ellipse plots in two-dimensional feature space were created for several of the image band combinations to visualize how extensively the “spectral signatures” of the Douglas-fir/aspen encroachment classes overlap in multi-dimensional space. The center of an ellipse represents the mean for a particular vegetation class on both the x and y axis and the ellipse boundaries represent the range of data values (2 standard deviations). Ellipse plots of the red band versus the near-infrared band for both the July and October images are displayed in Figures 13 and 14. The relatively arbitrary selection of cut-off points between conifer encroachment classes more than likely impacted classification accuracies. A cluster analysis could have been performed on the training site data in order to develop boundaries between classes, however, the ecological significance of the resulting map product would have been compromised.

Deviations from underlying assumptions likely diminished the effectiveness of the classification rule developed with Fisher's discriminant analysis. A multivariate normality plot constructed in SAS indicated that the data through the 15 layers of the image were not normally distributed and a Chi-squared test indicated the covariance matrices between classes were not equal. These are not unusual features of remotely sensed data (Jensen 1996). Non-parametric discriminant analysis was well suited for this research because no prior assumptions about the data needed to be met. With the onset of powerful computers and robust software this type of analysis has become more common (Knick et al. 1997, Lobo 1997).

Thematic Accuracy versus Classification Accuracy

Cartographers and GIS specialists are continually faced with making decisions concerning map utility. Is it better to have an accurate map with coarse-scale thematic resolution or a less accurate map where all of the biological or physical characteristics of interest are displayed? The right choice is usually a balancing act between reliability and meaningfulness. Several levels of conifer encroachment into aspen stands displayed on a map would be useful for monitoring aspen community extent through time. However, mapping conifer encroachment into aspen with high precision may not be necessary if the goal is to use this product as a "first cut" in the search for areas needing silvilcultural and/or prescribed fire treatments. A map with one aspen/conifer mixed class could adequately indicate where further investigation and field studies are warranted.

CONCLUSIONS

Many of the aspen stands studied in the southern portion of the Pleasantview Hills are in need of rejuvenation. In those stands where intensive plots were located, aspen trees were often towards the end of their lifespan (average aspen age was 79 years) and infected with cystospora and/or sooty bark cankers. Aspen sucker initiation and survival was very low for all sampled locations (plot average was 36 suckers/150 m^2). We believe this to be a function of two things; older aspen trees producing enough auxin to suppress sucker initiation from the root system (Schier 1975) and the utilization of suckers as forage by livestock and wildlife (Walker 1993, White et al. 1998, Kay and Bartos 2000). Without younger age classes present to presume dominance after older trees die, aspen stands and their root systems are in danger of permanent extirpation.

In the absence of disturbance, the Pleasantview Hills have experienced a conversion of aspen stands to forests dominated by Douglas-fir. Finding potential intensive plot locations in the +30% Douglas-fir encroachment class was substantially easier than for any of the other encroachment classes in three out of the four drainages sampled. The production of merchantable Douglas-fir on BLM lands in the Pleasantview Hills has provided higher economic gain than the production of aspen. However, maintaining aspen communities across the landscape offers it's own benefits including increased biodiversity. Species richness was the highest in the pure aspen and 1-15% Douglas-fir encroachment classes. These aspen communities have attracted a higher number of neotropical and passerine birds in the summer than other surrounding vegetation assemblages (Joel Sauder, personal communication 2002).

Landsat 7 ETM+ satellite imagery can be used to accurately detect and map conifer encroachment into aspen stands, however, the thematic precision we had hoped to achieve was not attainable with the three techniques utilized in this study. Despite not being able to accurately resolve all three Douglas-fir encroachment levels, the combination of the three classes into one aspen/Douglas-fir mixed class produced a vegetation map that will be both ecologically meaningful and dependable. This map will be especially useful in identifying areas where further investigation and ground-based studies are warranted. The change from aspen dominance to Douglas-fir dominance in the Pleasantview Hills could be more precisely monitored over time with data processing techniques and remotely sensed data that allowed for the discrimination of several Douglas-fir encroachment levels.

Using multi-temporal images to accentuate the difference between deciduous and coniferous forest types appeared to be useful. ETM+ bands 1-5, 7, and NDVI layers from both the summer and winter images as well as the solar insolation layer significantly helped to separate the data into vegetation classes. However, until the three classification methods used in this study are replicated using either the summer image or the winter image, but not both, it is unclear as to whether one or more bands from both of the images combined were indispensable in separating the data into vegetation classes.

Unsupervised classification of the image yielded much lower accuracies throughout all of the classes when compared with either of the supervised classification techniques (50% overall accuracy). The supervised classification procedure using non-parametric discriminant analysis performed the best with an overall accuracy level of 77%. Producer's accuracy was improved for 8 out of 12 vegetation classes including Douglas-fir (from 66 to 92%), 1-15% Douglas-fir encroachment (from 33 to 63%), and 16-30% Douglas-fir encroachment (from 9 to 17%) when compared to the supervised classification technique using parametric discriminant analysis. The accuracy of three out of the four remaining classes remained static including the +30% Douglas-fir encroachment class (8%). Pure aspen was the only class with a lower producer's accuracy dropping from 81 to 77%. The training data used in this study did not have multivariate normal distributions or equal within-class covariance matrices, so consequently, non-parametric discriminant analysis proved to be a better technique for the classification of image pixels into vegetation classes. Supervised classification techniques are somewhat more labor intensive, time consuming, and costly when compared to unsupervised classification techniques due to the field work required for training site collection. However, if an unsupervised classification is properly assessed for accuracy with field visited locations the difference in costs between the two methods should be minimal. Scientists and land managers in conjunction with GIS/remote sensing analysts must weight the costs of using a less accurate and perhaps less precise vegetation map against the inputs needed to perform a more intensive analysis when making decisions about which data processing technique to use for the classification of Landsat satellite imagery.

LITERATURE CITED

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geol. Surv. Prof. Paper 964. Washington, D.C. 28 p.

Asherin, L.A., and S.A. Mata. 2001. Basic tree-ring sample preparation techniques for aging aspen. p. 347-351. *In* W.D. Shepperd, D. Binkley, D.L. Bartos, T.J. Stohlgren, and L.G. Eskew, (eds.), Sustaining Aspen in Western Landscapes: Symposium Proceedings. Jun. 13-15, 2000, Grand Junction, Colo.RMRS-P-18. USDA For. Sev., Rocky Mountain Res. Sta., Fort Collins, Colo.

Avery, T.E. 1968. Interpretation of aerial photographs. 2nd Ed., Burgess Publishing Co., Minneapolis, Minn., 324 p.

Baker, F.S. 1925. Aspen in the central Rocky Mountain region. USDA Bull. 1291. Washington, D.C., 47 p.

Baker, W.L., J.A. Monroe, and A.E. Hessl. 1997. The effects of elk on aspen in the winter range in Rocky Mountain National Park. Ecography 20:155-165.

Barnes, B.V. 1975. Phenotypic variation of trembling aspen in western North America. For. Sci. 21:319-328.

Bartos, D.L., and M.C. Amacher. 1998. Soil properties associated with aspen to conifer succession. Rangelands 20:25-28.

Bartos, D.L., and R.B. Campbell Jr. 1998. Decline of quaking aspen in the Interior West – examples from Utah. Rangelands 20:17-24

Bartos, D.L., W.F. Mueggler, and R.B. Campbell Jr. 1994. Twelve years biomass response in aspen commnities following fire. J. Range Manage. 47:79-83.

Bartos, D.L., W.F. Mueggler, and R.J. Campbell. 1991. Regeneration of aspen by suckering on burned sites in western Wyoming. For. Res. Paper INT-448, USDA For. Serv., Intermountain Res. Sta., Ogden, Ut., 10 p.

Bartos, D.L., and W.F. Mueggler. 1981. Early succession in aspen communities following fires in western Wyoming. J. Range Manage. 34:315-318.

Befort, W. 1988. Controlled-scale aerial sampling photography: development and implications for multiresource inventory. J. For. 86:21-28.

Brown, J.K., and N.V. DeByle. 1987. Fire damage, mortality, and suckering in aspen. Can. J. For. Resources 17:1100-1109.

Campbell, J.B. 1996. Introduction to remote sensing. 2nd Ed., The Guilford Press, New York, N.Y. 622 p.

Canfield, R. 1941. Application of the line interception method in sampling range vegetation. J. For. 39:388-394.

Caprio, A.C., and D.M. Graber. 2000. Returning fire to the mountains: can we successfully restore the ecological role of pre-European fire regimes to the Sierra Nevada? p. 233-241. *In* D.N. Cole, S.F. McCool, W.T. Borrie and J. O'Loughlin, (eds.), Wilderness Science in a Time of Change conference, Volume 5: Wilderness Ecosystems, Threats, and Management. May 23-29, 1999, Missoula, Mont. RMRS-P-15-Vol-5. USDA For. Serv., Intermountain Res. Sta., Ogden, Ut.

Chavez, P.S. Jr., and D.J. MacKinnon. 1994. Automatic detection of vegetation changes in the southwestern United States using remotely sensed images. Photogramm. Eng. Remote Sensing 60:571-583.

Chong, G.W., S.E. Simonson, T.J. Stohlgren, and M.A. Kalkhan. 2001. Biodiversity: Aspen stands have the lead, but will nonnative species take over? p. 261-271 I*n* W.D. Shepperd, D. Binkley, D.L. Bartos, T.J. Stohlgren, and L.G. Eskew, (eds.), Sustaining Aspen in Western Landscapes: Symposium Proceedings. June 13-15, 2000, Grand Junction, Colo. RMRS-P-18. USDA For. Serv., Rocky Mountain Res. Sta., Fort Collins, Colo.

Clevers, J.G.P.W. 1988. The derivation of a simplified reflectance model for the estimation of leaf area index. Remote Sensing Environ. 25:52-69.

Club 20 Research Foundation. 1998. Decline of the aspen: special report on the health of national forests in western Colorado. Grand Junction, Colo. 39 p.

Cohen, W.B., and T.A. Spies. 1992. Estimating structural attributres of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery. Remote Sensing Environ. 41:1-17.

Congalton, R.G., K. Green, and J.Teply. 1993. Mapping old-growth forests on national forest and park lands in the Pacific Northwest from remotely sensed data. Photogramm. Eng. Remote Sensing 59:529-535.

Congalton, R.G., and R.A. Mead. 1983. A quantitative method to test for consistency and correctness in photointerpretation. Photogramm. Eng. Remote Sensing 49:6-74.

Covington, W.W., R.L. Everett, R. Steele, L.L. Irwin, T.A. Daer, and A.N.D. Auclair. 1994. Historical and anticipated changes in forest ecosystems of the inland west of the United States. p. 13-63. *In* R.L. Sampson, and D.L. Adams (eds.), Assessing forest system health in the inland west. Proc. of the American forests scientific workshop. The Haworth Press, Inc., New York, N.Y.

Covington, W.W., and S.S. Sackett. 1984. The effect of a prescribed burn in southwestern ponderosa pine on organic matter and nutrients in wood debris and forest floor. For. Sci. 30:183-192.

Daubenmire, R.F. 1959. Canopy coverage method of vegetation analysis. Northwest Sci. 33:43-64.

Day, M.P. 1995. Determination of the geographical origin of wine using joint analysis of elemental and isotopic composition. II. Differentiation of the principle production zones in France for the 1990 vintage. J. Sci. Food Agr. 67:113-123.

DeByle, N.V. 1985a. Wildlife. p. 135-152. *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

DeByle, N.V. 1985b. Water and watershed. p. 153-160. *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

DeByle, N.V., C.D. Bevins, and W.C. Fischer. 1987. Wildfire occurrence in aspen in the interior western United States. West. J. Applied For. 2:73-76.

Duarte Silva, A.P., and A. Stam. 1995. Discriminant analysis, p. 277-318. *In* L.G., and P.R. Yarnold (eds.), Reading and understanding multivariate statistics. American Psychological Association, Washington D.C..

Everitt, J.H., M.A. Alaniz, D.E. Escobar, and M.R. Davis. 1992. Using remote sensing to distinguish common (*Isocoma coronopifolia*) and Drummond goldenweed (*Isocoma drummondii*). Weed Sci. 40:621-628.

Fiorella, M., and W.J. Ripple. 1993. Determining the successional stage of temperate coniferous forest with Landsat satellite data. Photogramm. Eng. Remote Sensing 59:239-246.

Franklin, J., T. Logan, C.E. Woodcock, and A.H. Stahler. 1986. Coniferous forest classification and inventory using Landsat and digital terrain data. IEEE Trans. On Geosci. Remote Sensing GE-24:139-149.

Fule', P.Z., W.W. Covington, and M.M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecol. Appl. 7:895-908.

Greer, J.D., M.L. Hoppus, and H.M. Lachowski. 1990. Color infrared photography for resource management. J. For. 88:12-17.

Gruell, G.E. 1984. Fire and vegetative trends in the northern Rockies: interpretations from 1971-1982 photographs. GTR-INT-158. USDA For. Serv., Intermountain Res. Sta., Ogden, Ut. 117 p.

Hall, F.G., D.B. Botkin, D.E. Strebel, K.D. Woods, and S.J. Goetz. 1991. Large-scale patterns of forest succession as determined by remote sensing. Ecology 72:628-640.

Hall, R.J., G.N. Still, and P.H. Crown. 1983. Mapping the distribution of aspen defoliation using Landsat color composites. Can. J. Remote Sensing 9:86-91.

Hart, R.H., and W.A. Laycock. 1996. Repeat photography on range and forest lands in the western United States. J. Range Mange. 49:60-67.

Helios Environmental Modeling Institute (HEMI). 2000. The Solar Analyst 1.0 User Manual.

Hudson, W., and C. Ramm. 1987. Correct formulation of the Kappa coefficient of agreement. Photogramm. Eng. Remote Sensing 53:421-422.

Jakubauskas, M.E. 1996. Thematic Mapper characterization of lodgepole pine seral stages in Yellowstone National Park, USA. Remote Sens. Environ. 56:118-132.

Jelinski, D.E., and W.M. Cheliak. 1992. Genetic diversity and spatial subdivision of *Populus tremuloides* (Salicaceae) in a heterogeneous landscape. Amer. J. Bot. 79:728-736.

Jensen, J.R. 1996. Introductory digital image processing: a remote sensing perspective. 2nd Ed., Printice-Hall, Inc. Upper Saddle River, N.J. 318 p.

Jensen, M.E., J.P. Dibenedetto, J.A. Barber, C. Montagne, and P.S. Bourgeron. 2001. Spatial modeling of rangeland potential vegetation environments. J. Range Manage. 54:528-536.

Johnson, C.W., T.C. Brown, and M.L. Timmons. 1985. Esthetics and Landscaping. p. 185-188. *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

Jones, J.R. 1985. Distribution. p. 9-10 *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

Jones, J.R., and N.V. DeByle. 1985. Fire. p. 77-81. *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

Jones, J.R., N.V. DeByle, and R.P. Winokur. 1985. Wood Resource. p. 161-167. *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western

United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

Joria, P.E., and S.C. Ahearn. 1991. A comparison of the SPOT and Landsat Thematic Mapper satellite systems for detecting gypsy moth defoliation in Michigan. Photogramm. Eng. Remote Sensing 57:1605-1612.

Kay, C.E. 2001. Long-term aspen exclosures in the Yellowstone ecosystem. p. 225-240 *In* W.D. Shepperd, D. Binkley, D.L. Bartos, T.J. Stohlgren, and L.G. Eskew, (eds.), Sustaining Aspen in Western Landscapes: Symposium Proceedings. June 13-15, 2000, Grand Junction, Colo. RMRS-P-18. USDA For. Serv., Rocky Mountain Res. Sta., Fort Collins, Colo.

Kay, C.E. 1997. Is aspen doomed? J. For. 95:4-11.

Kay, C.E. 1990. Yellowstone's northern elk herd: A critical evaluation of the "natural regulation" paradigm. PhD dissertation, Utah State University, Logan, Ut. 490 p.

Kay, C.E., and D.L. Bartos. 2000. Ungulate herbivory on Utah aspen: assessment of longterm exclosures. J. Range Manage. 53:145-153.

Kaye, M.W., K. Suzuki, D. Binkley, and T.J. Stohlgren. 2001. Landscape-scale dynamics of aspen in Rocky Mountain National Park, Colorado. p. 39-49 *In* W.D. Shepperd, D. Binkley, D.L. Bartos, T.J. Stohlgren, and L.G. Eskew, (eds.), Sustaining Aspen in Western Landscapes: Symposium Proceedings. June 13-15, 2000, Grand Junction, Colo. RMRS-P-18. USDA For. Serv., Rocky Mountain Res. Sta., Fort Collins, Colo.

Kean, R.E., D.G. Long, J.P. Menakis, W.J. Hann, and C.D. Bevins. 1996. Simulating coarse-scale vegetation dynamics using the Columbia River Basin successional model – CRBSUM. GTR-INT-340, USDA For. Serv., Intermountain Research Station, Ogden, Ut.

Kemperman, J.A., and B.V. Barnes. 1976. Clone size in American aspen. Can. J. Bot. 54:2603-2607.

Knick, S.T., J.T. Rotenberry, and T.J. Zarriello. 1997. Supervised classification of Landsat Thematic Mapper imagery in a semi-arid rangeland by nonparametric discriminant analysis. Photogramm. Eng. Remote Sensing 63:79-86.

Krebil, R.G. 1972. Mortality of aspen on the Gros Ventre elk winter range. Res. Paper INT-129. USDA For. Serv., Intermountain For. Range Exp. Sta., Ogden, Ut. 16 p.

Lachowski, H., J. Powell, T. Wirth, P. Maus, K. Suzuhi, J. McNamera, P. Riordan, and R. Brohman. 1996. Monitoring aspen decline using remote sensing and GIS: Gravelly Mountain, landscape, soutwestern Montana. p. 174-183. *In* J.D. Greer (ed.), Proc. 6th For. Serv. Remote Sensing Applications Conf., Amer. Soc. Photogramm. and Remote Sensing. Denver, Colo.Beaverhead National Forest, Dillion, MT.

Langley, K.D. 2000. Distinguishing between new and recycled cashmere with Fisher's Discriminant analysis. Textile Res. J. 70:181-184.

Legendre, L., and P. Legendre. 1983. Numerical Ecology. Elsevier Scientific Publishing Co., New York, N.Y. 419 p.

Lillesand, T.M., and W. Kiefer. 2000. Remote sensing and image interpretation. John Wiley & Sons, Inc., New York, N.Y. 724 p.

Little, E.L., Jr. 1971. Atlas of United States trees: Vol. 1. Conifers and important hardwoods. USDA Misc. Pub. 1146. Washington, D.C. 9 p. + 202 maps.

Lobo, A. 1997. Image segmentation and discriminant analysis for the identification of land cover units in ecology. IEEE Trans. on Geosci. and Remote Sensing GE-35:1136-1145.

Loope, L.L., and G.E. Gruell. 1973. The ecological role of fire in the Jackson Hole area, northwestern Wyoming. Quaternary Res. 3:425-443.

Luther, J.E., S.E. Franklin, J. Hudak, and J.P. Meades. 1994. Forcasting balsam fir forest defoliation by insects using satellite remote sensing. p. 504. *In* J.M. Power, M. Strome, and T.C. Daniel, (eds.), 17th Annual Geographic Information Seminar, Volume 1: Decision Support – 2001. Sept. 1994, Toronto, Can.

Magnussen, S. 1997. A method for enhancing tree species proportions from aerial photos. For. Chron. 73:479-487.

Maini, J.S. 1968. Silvics and ecology of Populus in Canada. p. 20-69. J.S. Maini, and J.H. Crayford, (eds.), Growth and utilization of poplars in Canada, Canada Department of Forestry and Rural Development, Forestry Branch. Dep. Pub. 1205, Ottawa, Can.

Masek, J.G., M. Honzak, S.N. Goward, P. Liu, and E. Pak. 2001. Landsat 7 ETM+ as an observatory for land cover: initial radiometric and geometric comparisons with Landsat 5 Thematic Mapper. Remote Sensing Environ. 78:118-130.

McDonough, W.T. 1985. Sexual reproduction, seeds and seedlings. p. 25-28. *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

Mickelson, J.G., Jr., D.L. Civco, and J.A. Silander, Jr. 1998. Delineating forest canopy species in the northeastern United States using multi-temporal Thematic Mapper imagery. Photogramm. Eng. Remote Sensing 64:891-904.

Mitton, B.J., and M.C. Grant. 1996. Genetic variation and the natural history of quaking aspen. Bioscience 46:25-31.

Moore, M.M., and M.E. Bauer. 1990. Classification of forest vegetation in north-central Minnesota using Landsat Multispectral Scanner and Thematic Mapper data. For. Sci. 36:330-342.

Mueggler, W.F. 1989. Age distribution and reproduction of intermountain aspen stands. Western J. Applied Forest. 4:41-45.

Mueggler, W.F. 1988. Aspen community types of the Intermountain Region. GTR-INT-250. USDA For. Serv., Intermountain Res. Sta., Ogden, Ut. 135 p.

Mueggler, W.F. 1985. Forage. p. 129-134. *In* N.V. DeByle, and R.P. Winokur, (eds.), Aspen: ecology and management in the western United States. GTR-RM-119. USDA For. Sev., Rocky Mtn. For. Range Exp. Sta., Fort Collins, Colo.

Olmsted, C.E. 1979. The ecology of aspen with reference to utilization by large herbivores in Rocky Mountain National Park. p. 89-97. *In* M.S. Boyce, and L.D. Hayden-Wing, (eds.), North American elk: ecology, behavior, and management. University of Wyoming, Laramie, Wyo.

Parsons, D.J., D.M. Graber, J.K. Agee and J.W. Van Wagtendonk. 1986. Natural fire management in national parks. Environ. Manage. 10: 21-24.

Parzen, E. 1962. On estimation of a probability density function and mode. Annals Math Stat. 33:1065-1076.

Patton, D.R., and H.D. Avant. 1970. Fire stimulated aspen sprouting in a spruce-fir forest in New Mexico. Res. Note 159. USDA For. Serv., Rocky Mtn. For. and Range Exp. Sta., Fort Collins, Colo.

Peddle, D.R. 1993. An empirical comparison of evidential reasoning, linear discriminant analysis, and maximum likelihood algorithms for alpine land cover classification. Can. J. Remote Sensing 19:31-44.

Pitt, D.G., R.G. Wagner, R.J. Hall, D.J. King, D.G. Leckie, and U. Runesson. 1997. Use of remote sensing for forest vegetation management: a problem analysis. For Chronicle 73:459-477.

Quilter, M.C., and V.J. Anderson. 2000. Low altitude/large scale aerial photographs: a tool for range and resource managers. Rangelands 22:13-17.

Renkin, R., and D. Despain. 1991. Preburn root biomass/basal area influences on the response of aspen to fire and herbivory. p. 95-103. *In* D. Despain (ed.), Plants and their environment: proceedings of the 1st biennial scientific conference on the Greater Yellowstone National Park, Mammoth, Wyo.

Ringrose, S., and W. Matheson. 1991. A Landsat analysis of range conditions in the Botswana Kalahari drought. Int. J. Remote Sensing 12:1023-1051.

Romme, W.H., M.G. Turner, L.L. Wallace, and J.S. Walker. 1995. Aspen, elk, and fire in northern Yellowstone National Park. Ecology 76:2097-2106.

Rosenblatt, M. 1956. Remarks on some nonparametric estimates of a density function. Annals Math. Stat. 27:832-837.

SAS. 1999. Version 8 of the SAS System for Windows NT. SAS Institute Inc., Cary, N.C.

Schier, G.A. 1975. Deterioration of aspen clones in the middle Rocky Mountains. Res. Paper INT-170. USDA For. Serv., Intermountain For. and Range Exp. Sta., Ogden, Ut. 14 p.

Shen, S.S., G.D. Badhwar, and J.G. Carnes. 1985. Separability of boreal forest species in the Lake Jennette area, Minnesota. Photogramm. Eng. Remote Sensing 51:1775-1783.

Smith, M.O., S.L. Ustin, J.B. Adams, and A.R. Gillespie. 1990. Vegetation in deserts: regional measure of abundance from multi-spectral images. Remote Sensing Environ. 31:1-26.

Spanner, M.A., L.L. Pierce, S.W. Running, and D.L. Peterson. 1990. Remote sensing temperate coniferous forest leaf area index: the influence of canopy closure, understory vegetation, and background spectral response. Int. J. Remote Sens. 11:95-111.

Stohlgren, T.J., G.W. Chong, M.A. Kalkhan, and L.D. Schell. 1997a. Multi-scale sampling of plant diversity: effects of minimum mapping unit size. Ecol. Appl. 7:1064-1074.

Stohlgren, T.J., G.W. Chong, M.A. Kalkhan, and L.D. Schell. 1997b. Rapid assessment of plant diversity patterns: a methodology for landscapes. Environ. Monitoring and Assess. 48:25-43.

Story, M., and R. Congalton. 1986. Accuracy assessment: a user’s perspective. Photogramm. Eng. Remote Sensing 52:397-399.

Tueller, P.T. 1994. Great Basin annual vegetation patterns assessed by remote sensing. Gen. Tech. Rep. INT-313. USDA For. Serv., Intermountain Res. Sta., Ogden, Ut.

Turchi, G.M., P.L. Kennedy, D. Urban, and D. Hein. 1995. Bird species richness in relation to isolation of aspen habitats. Wilson Bulletin 107: 463-474.

USDA Forest Service. 1962. Color test for differentiating heartwood and sapwood in certain softwood tree species. Rep. No. 1962, USDA For. Serv., Madison, Wis.

USDI, National Park Service. 1992. Western region fire monitoring handbook. USDI National Park Service, Western Region, San Francisco, Calif., 297 p.

USDA, Natural Resources Conservation Service. 2001. The PLANTS Database, Version 3.1 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

Walker, S.C. 1993. Effects of cattle and big game on the secondary succession of aspen-conifer understory following fire. Master's Thesis, Brigham Young University, Provo, UT.

Warren, P.L., and C.F. Hutchinson. 1984. Indicators of rangeland change and their potential for remote sensing. J. Arid Environ. 7:107-126.

White, C.A., C.E. Olmsted, and C.E. Kay. 1998. Aspen, elk, and fire in the rocky mountain parks of North America. Wildl. Society Bull. 26:449-462.

Wolter, P.T., D.J. Mladenoff, G.E. Host, and T.R. Crow. 1995. Improved forest classification in the northern lake states using multi-temporal Landsat imagery. Photogramm. Eng. Remote Sensing 61:1129-1143.

APPENDIX 1

Permanent aspen plot Universal Transverse Mercator (UTM) coordinates (GRS 1980, NAD83, Zone 12 North) and legal descriptions.

Plot ID	UTM Coordinates		Legal Location
	Northing	Easting	
John Evans Canyon #1	4,674,787.67	378,954.44	T.14S R.34E S.10 NWSE
John Evans Canyon #2	4,676,355.95	381,232.37	T.14S R. 34E S.1 NWSW
John Evans Canyon #3	4,675,980.86	380,808.93	T.14S R.34E S.2 SESE
John Evans Canyon #4	4,674,571.73	378,165.69	T.14S R.34E S.10 SWSW
John Evans Canyon #5	4,674,939.10	379,697.73	T.14S R.34E S.11 NWSW
John Evans Canyon #6	4,675,413.91	380,155.76	T.14S R.34E S.11 SENW
John Evans Canyon #7	4,674,499.71	378,320.34	T.14S R.34E S.10 SWSW
Sheep Creek Canyon #11	4,676,511.09	373,000.60	T.14S R.33E S.1 SENE
Sheep Creek Canyon #12	4,676,022.80	374,049.20	T.14S R.34E S.6 SWSE
Sheep Creek Canyon #13	4,676,191.92	373,936.31	T.14S R.34S S.6 NESW
Sheep Creek Canyon #14	4,675,863.87	373,561.67	T.14S R.34S S.6 SWSW
Wood Creek Canyon #21	4,672,847.23	378,220.67	T.14S R.34E S.15 SWSW
Wood Creek Canyon #22	4,675,656.32	374,843.80	T.14S R.34E S.8 NWNW
Wood Creek Canyon #23	4,675,598.01	374,789.23	T.14S R34E S.8 NWNW
Wood Creek Canyon #24	4,674,275.42	377,061.11	T.14S R.34E S.9 SESW
Wood Creek Canyon #25	4,672,881.22	377,947.32	T.14S R.34E S.15 SWSW
Wood Creek Canyon #26	4,672,914.51	377,336.06	T.14S R.34E S.16 SWSE
West Elkhorn Canyon #31	4,677,401.69	375,085.93	T.14S R.34E S.5 NWNW
West Elkhorn Canyon #32	4,678,00.80	376,007.08	T.13S R.34E S.32 SESE
West Elkhorn Canyon #33	4,677,837.24	374,209.45	T.13S R.34E S.31 SWSE

APPENDIX 2

Average canopy cover of vascular plant species by conifer encroachment class. Numbers within parenthesis indicate range of canopy cover values. Plant taxonomy follows that used by the United States Department of Agriculture Natural Resources Conservation Service PLANTS Database (USDA, NRCS 2001).

Vascular Plants	Conifer Encroachment Classes			
	Pure Aspen	Aspen 1-15% Df	Aspen 16-30% Df	Aspen >30% Df
Achnatherum thurberianum Thurber's needlegrass	0.00	0.006 (0.00-0.03)	0.00	0.00
Avena fatua wild oat	0.00	0.004 (0.00-0.02)	0.00	0.00
Bromus marginatus mountain brome	1.162 (0.00-4.53)	0.174 (0.00-0.52)	0.004 (0.00-0.02)	0.278 (0.00-0.77)
Calamagrostis rubescens pinegrass	1.288 (0.00-4.58)	2.542 (0.00-8.53)	4.798 (0.67-12.11)	1.932 (0.00-6.93)
Carex geyeri Geyer's sedge	0.56 (0.00-2.68)	1.62 (0.00-4.73)	1.146 (0.00-3.02)	0.67 (0.00-1.88)
Carex microptera smallwing sedge	0.00	0.00	0.00	0.004 (0.00-0.02)
Dactylis glomerata orchardgrass	2.632 (0.08-4.43)	0.004 (0.00-0.02)	3.39 (0.00-14.92)	2.286 (0.00-11.43)
Elymus canadensis Canada wildrye	0.00	0.00	0.00	0.366 (0.00-1.83)
Pascopyrum smithii western wheatgrass	0.00	0.044 (0.00-0.12)	0.00	0.00
Phleum pratense timothy	1.694 (0.00-8.00)	0.016 (0.00-0.08)	0.284 (0.00-1.42)	0.00
Poa bulbosa bulbous bluegrass	0.704 (0.00-3.52)	1.6 (0.00-7.92)	0.00	0.004 (0.00-0.02)
Poa pratensis Kentucky bluegrass	9.916 (5.12-16.93)	11.544 (0.00-22.85)	3.3 (0.00-8.98)	6.644 (0.00-26.60)
Pseudoroegneria spicata bluebunch wheatgrass	0.616 (0.00-2.75)	0.29 (0.00-1.42)	0.024 (0.00-0.12)	0.00
Thinopyrum intermedium intermediate wheatgrass	1.426 (0.00-3.43)	0.00	0.00	0.008 (0.00-0.02)
Achillea millefolium common yarrow	1.086 (0.00-3.08)	0.214 (0.00-0.58)	0.478 (0.00-2.12)	0.352 (0.00-0.90)
Agastache urticifolia nettleleaf giant hyssop	0.624 (0.00-1.60)	0.066 (0.00-0.33)	0.666 (0.00-3.33)	0.304 (0.00-1.52)
Allium cernuum nodding onion	0.016 (0.00-0.08)	0.00	0.00	0.00
Antennaria microphylla littleleaf pussytoes	0.00	0.00	0.00 (0.00-0.02)	0.00
Arabis holboellii Holboell's rockcress	0.054 (0.00-0.27)	0.256 (0.00-1.25)	0.00	0.00

Vascular Plants	Conifer Encroachment Classes			
	Pure Aspen	Aspen 1-15% Df	Aspen 16-30% Df	Aspen >30% Df
Arnica cordifolia **heartleaf arnica**	1.872 (0.00-7.83)	1.07 (0.00-4.92)	8.548 (0.00-33.75)	8.014 (0.00-25.52)
Castelleja linariifolia **Wyoming Indian paintbrush**	0.02 (0.00-0.08)	0.02 (0.00-0.08)	0.00	0.00
Chimaphila umbellata **pipsissewa**	0.00	0.00	0.82 (0.00-4.10)	0.05 (0.00-0.25)
Cirsium arvense **Canada thistle**	0.182 (0.00-0.83)	0.00	0.124 (0.00-0.62)	0.08 (0.00-0.25)
Claytonia perfoliata **miner's lettuce**	0.00	0.00	0.00	0.696 (0.00-3.48)
Collinsia linearis **narrowleaf blue eyed Mary**	0.00	0.058 (0.00-0.22)	0.00	0.00
Collinsia parviflora **maiden blue eyed Mary**	0.952 (0.00-2.27)	0.878 (0.00-1.98)	0.726 (0.00-2.00)	0.75 (0.10-1.05)
***Cryptantha* spp.**	0.00	0.004 (0.00-0.02)	0.00	0.00
Cynoglossum officinale **houndstongue**	1.328 (0.00-4.77)	0.026 (0.00-0.10)	0.09 (0.00-0.37)	0.36 (0.00-0.85)
Cystopterus fragilis **brittle bladderfern**	0.00	0.00	0.00	0.04 (0.00-0.12)
Disporum trachycarpum **roughfruit fairybells**	0.00	0.00	0.056 (0.00-0.28)	0.00
Erigeron speciousus **aspen fleabane**	0.12 (0.00-0.58)	0.796 (0.00-2.43)	0.00	0.202 (0.00-0.93)
Fragaria vesca **woodland strawberry**	0.00	0.00	0.576 (0.00-2.08)	1.918 (0.00-4.65)
Galium bifolium **twinleaf bedstraw**	1.082 (0.05-3.75)	0.434 (0.00-1.48)	0.32 (0.00-0.85)	0.206 (0.00-0.62)
Geranium richardsonii **Richardson's geranium**	0.00	0.844 (0.00-4.22)	0.05 (0.00-0.25)	0.00
Goodyera oblongifolia **western rattlesnake plantain**	0.00	0.00	0.094 (0.00-0.27)	0.00
Heuchera grossulariifolia **gooseberryleaf alumroot**	0.00	0.03	0.036 (0.00-0.18)	0.8 (0.00-2.68)
Hieracium albiflorum **white hawkweed**	0.07 (0.00-0.32)	0.37 (0.00-0.93)	0.00	0.076 (0.00-0.27)
Hydrophyllum capitatum **ballhead waterleaf**	0.00	0.04 (0.00-0.20)	0.00	0.00
Lupinus argenteus **silvery lupine**	0.00	0.112 (0.00-0.43)	0.016 (0.00-0.08)	0.054 (0.00-0.27)
Mahonia repens **creeping barberry**	4.362 (0.00-7.33)	4.496 (0.00-12.72)	2.43 (0.02-4.33)	1.45 (0.00-3.88)
Maianthemum racemosum **feathery false lily of the vally**	0.5 (0.00-2.50)	0.266 (0.00-1.25)	1.072 (0.00-3.83)	0.266 (0.00-1.08)
Nemophila parviflora **smallflower nemophila**	0.856 (0.00-3.70)	2.082 (0.00-6.78)	0.4 (0.00-2.00)	1.016 (0.00-2.83)
Nothocalais troximoides **weevil prairie-dandelion**	0.016 (0.00-0.08)	0.012 (0.00-0.02)	0.00	0.036 (0.00-0.18)
Osmorhiza occidentalis **western sweetroot**	2.614 (0.00-5.35)	1.722 (0.00-3.73)	4.072 (0.00-9.10)	4.37 (0.68-9.99)

Vascular Plants	Conifer Encroachment Classes			
	Pure Aspen	**Aspen 1-15% Df**	**Aspen 16-30% Df**	**Aspen >30% Df**
Paxistima myrsinites **mountain lover**	0.65 (0.00-2.58)	0.8 (0.00-2.80)	3.392 (0.00-10.38)	1.922 (0.00-9.18)
Platanthera hyperborea **northern green orchid**	0.00	0.026 (0.00-0.08)	0.036 (0.00-0.18)	0.8 (0.00-2.68)
Polygonum aviculare **prostrate knotweed**	0.2 (0.00-0.88)	0.096 (0.00-0.33)	0.164 (0.00-0.80)	0.038 (0.00-0.17)
Potentilla pensylvanica **Pennsylvanica cinquefoil**	0.00	0.00	0.116 (0.00-0.58)	0.416 (0.00-2.08)
Pseudostellaria jamesiana **tuber starwort**	0.422 (0.00-1.33)	0.366 (0.00-1.33)	0.004 (0.00-0.02)	0.95 (0.00-0.28)
Senecio inegerrimus **lambstongue ragwort**	0.116 (0.00-0.58)	0.044 (0.00-0.12)	0.02 (0.00-0.10)	0.00
Silene menziesii **Menzies' campion**	0.57 (0.00-2.22)	0.85 (0.00-1.85)	0.714 (0.17-2.30)	0.524 (0.12-1.17)
Stephanomeria exigua **small wirelettuce**	0.096 (0.00-0.43)	0.014 (0.00-0.07)	0.02 (0.00-0.08)	0.01 (0.00-0.03)
Taraxacum officinale **common dandelion**	0.834 (0.02-1.77)	1.786 (0.00-4.48)	0.76 (0.00-3.60)	1.202 (0.00-3.13)
Thlaspi arvense **field pennycress**	0.00	0.00	0.00	0.004 (0.00-0.02)
Tragopogon miscellus **Moscow salsify**	0.178 (0.00-0.53)	0.314 (0.00-1.17)	0.024 (0.00-0.07)	0.194 (0.00-0.35)
Trifolium repens **white clover**	0.08 (0.00-0.18)	0.00	0.00	0.026 (0.00-0.13)
Verbascum thapsus **common mullein**	0.004 (0.00-0.02)	0.066 (0.00-0.33)	0.036 (0.00-0.18)	0.00
Veronica biloba **twolobe speedwell**	2.366 (0.00-6.63)	1.08 (0.00-2.25)	0.09 (0.00-0.35)	0.156 (0.00-0.73)
Vicia americana **American vetch**	1.794 (0.68-4.33)	1.8 (0.00-7.85)	2.444 (0.00-6.67)	0.376 (0.00-1.85)
Viola adunca **hookedspur violet**	2.11 (0.25-3.98)	1.274 (0.13-3.00)	2.264 (0.00-4.87)	1.32 (0.35-2.48)
Wyethia amplexicaulis **mule-ears**	0.25 (0.00-1.25)	0.00	0.00	0.00
Acer glabrum **Rocky Mountain maple**	4.794 (0.00-22.00)	0.48 (0.00-0.40)	3.386 (0.00-13.00)	5.792 (0.00-23.00)
Acer grandidentatum **bigtooth maple**	0.00	0.00	1.048 (0.00-3.67)	1.6 (0.0-8.00)
Amelanchier alnifolia **Saskatoon serviceberry**	11.648 (1.09-24.00)	10.398 (107-17.92)	11.638 (1.00-19.91)	7.346 (1.73-12.00)
Artemisia tridentata spp. ***vaseyana*** **mountain big sagebrush**	0.314 (0.00-1.57)	0.88 (0.00-4.40)	0.014 (0.00-0.07)	0.00
Ceanothus velutinus **snowbrush ceanothus**	0.00	0.246 (0.00-0.90)	0.00	0.00
Chrysothamnus viscidiflorus **yellow rabbitbrush**	0.006 (0.00-0.03)	0.00	0.00	0.00

Vascular Plants	**Conifer Encroachment Classes**			
	Pure Aspen	**Aspen 1-15% Df**	**Aspen 16-30% Df**	**Aspen >30% Df**
Physocarpus malvaceous **mallow ninebark**	0.00	10.98 (0.00-54.90)	14.376 (0.00-60.88)	8.4 (0.00-39.00)
Populus tremuloides **quaking aspen**	0.886 (4.00-1.13)	1.16 (0.00-5.00)	0.8 (0.00-2.00)	0.81
Prunus virginiana **chokecherry**	2.626 (0.00-7.90)	1.42 (0.00-5.00)	3.578 (0.00-15.76)	1.48 (0.00-5.00)
Pseudotsuga menziesii **Douglas-fir**	0.1 (0.00-0.50)	0.98 (0.00-3.00)	2.36 (0.00-4.00)	0.82 (0.00-2.00)
Ribes viscosissimum **sticky currant**	0.00	1 (0.00-5.00)	0.106 (0.00-2.00)	0.00
Rosa woodsii **Woods'rose**	0.96 (0.00-4.30)	1.866 (0.00-4.00)	2.112 (0.00-5.00)	0.738 (0.00-2.29)
Salix scouleriana **Scouler's willow**	0.00	1.2 (0.00-6.00)	1.38 (0.00-3.20)	0.00
Symphoricarpos oreophilus **mountain snowberry**	9.592 (2.65-2510)	10.512 (0.13-25.00)	2.318 (0.04-6.83)	8.746 (0.13-31.00)

TABLE 1. Twelve general vegetation cover types found in the Pleasantview Hills of southeastern Idaho. These twelve types were used in all three classification procedures.

Vegetation Cover Types	**Dominant Overstory Species**
Pure Douglas-fir	*Pseudotsuga menziesii*
Aspen with 1-15% Douglas-fir encroachment	*Populus tremuloides/Pseudotsuga menziesii*
Aspen with 16-20% Douglas-fir encroachment	*Populus tremuloides/Pseudotsuga menziesii*
Aspen with +30% Douglas-fir encroachment	*Populus tremuloides/Pseudotsuga menziesii*
Pure aspen	*Populus tremuloides*
Agriculture active	N/A
Agriculture fallow	N/A
Maple	*Acer grandidentatum*
Mountain shrub	*Amelanchier alnifolia/Prunus virginiana*
Grassland	*Pseudoroegneria spicata/Poa bulbosa/Bromus tectorum*
Sagebrush	*Artemisia tridentata* spp. *vaseyana*
Juniper/sagebrush	*Juniperus scopulorum/Juniperus osteosperma*

TABLE 2. Parametric discriminant analysis linear equation coefficients for all twelve general vegetation cover types. Layers used in classification include Landsat 7 ETM+ bands 1-5 and 7 from both July and October 1999 satellite images, July NDVI, October NDVI, and solar insolation.

	Vegetation Cover Class Coefficients											
Layers	Douglas-fir	pure aspen	1-15% encroach	16-30% encroach	+ 30% encroach	agr. active	agr. fallow	maple	mountain shrub	grassland	sagebrush	juniper
Constant	-58.79719	-52.67001	-52.61221	-52.68941	-55.09698	-99.05956	-69.67432	-52.81677	-45.04506	-45.87326	-43.62474	-47.41021
July blue	-9.12297	-3.56527	-6.08716	-6.47208	-7.15827	-23.26663	-2.29688	-6.59418	-6.20703	-5.37287	-4.92934	0.12022
July green	4.15835	-2.9138	-3.0547	0.56486	2.4606	25.43335	7.03028	7.75939	3.86939	1.09853	3.55374	9.7191
July red	10.48863	10.14018	15.69108	10.73372	10.53044	-11.81889	6.95066	-3.21514	6.40405	7.73852	3.48438	-7.98824
July NIR	-4.95216	-1.42472	-3.84508	-4.04743	-4.4415	16.39427	4.25119	0.64889	-0.69131	2.55182	1.4574	5.47395
July MIR	-23.34357	-19.84651	-19.80652	-19.36152	-21.19386	-44.77625	-39.07974	-16.67482	-18.01231	-21.44884	-19.74985	-29.8905
July MIR	31.75408	32.42722	31.30948	31.23084	30.64789	43.69081	47.31152	30.04259	26.22694	26.49051	26.32454	27.86319
October blue	6.27691	9.29593	10.03072	8.52902	6.59902	-3.47404	14.41439	5.92983	7.0013	8.55917	8.69435	8.69135
October green	9.3089	15.53823	13.86419	13.71091	10.67646	10.74354	14.45942	11.56874	12.22817	14.50885	15.01617	15.97828
October red	13.28635	-12.92079	-9.62603	-7.0832	8.90791	24.45611	-1.35694	-1.19299	-5.42334	-0.71309	-5.62918	-14.10265
October NIR	-36.058	-21.38953	-21.93997	-22.90136	-33.44829	-29.86439	-23.72869	-24.35229	-20.9637	-27.08636	-22.9791	-10.26678
October MIR	89.34913	89.63645	86.76671	89.76634	86.916	93.24088	73.78622	89.45076	87.75835	86.89014	85.03392	69.03215
October MIR	-110.9235	-114.3213	-112.4866	-115.9071	-109.2489	-133.2825	-105.1776	-113.0816	-113.9925	-112.0889	-111.4055	-99.95647
July NDVI	20.40775	23.96889	26.71047	23.3622	21.67949	-16.30363	6.54087	15.82582	11.83859	2.26815	3.59287	-9.68078
October NDVI	14.6815	2.23923	4.6119	5.57979	13.37757	4.1048	5.94451	5.17091	3.13717	5.37775	3.90158	0.56537
Solar insolation	-0.02665	2.36713	1.67192	1.9455	0.7223	2.5874	-1.03273	1.21907	1.16596	1.4262	1.43595	3.48183

TABLE 3. Vascular plant species average canopy cover by conifer encroachment class. Species listed have 5% or greater canopy cover in one or more of the permanent aspen plot(s). Numbers in parenthesis indicate range of canopy cover values.

Vascular Plants	**Pure Aspen**	**Aspen 1-15% Df**	**Aspen 16-30% Df**	**Aspen >30% Df**
Calamagrostis rubescens	1 (0.00-4.58)	3 (0.00-8.53)	5 (0.67-12.11)	2 (0.00-6.93)
Dactylis glomerata	3 (0.08-4.43)	0.004 (0.00-0.02)	3 (0.00-14.92)	2 (0.00-11.43)
Phleum pratense	2 (0.00-8.00)	0.02 (0.00-0.08)	0.28 (0.00-1.42)	0
Poa bulbosa	1 (0.00-3.52)	2 (0.00-7.92)	0	0.004 (0.00-0.02)
Poa pratensis	10 (5.12-16.93)	12 (0.00-22.85)	3 (0.00-8.98)	7 (0.00-26.60)
Arnica cordifolia	2 (0.00-7.83)	1 (0.00-4.92)	9 (0.00-33.75)	8 (0.00-25.52)
Mahonia repens	4 (0.00-7.33)	4 (0.00-12.72)	2 (0.02-4.33)	1 (0.00-3.88)
Nemophila parviflora	1 (0.00-3.70)	2 (0.00-6.78)	0.4 (0.00-2.00)	1 (0.00-2.83)
Osmorhiza occidentalis	3 (0.00-5.35)	2 (0.00-3.73)	4 (0.00-9.10)	4 (0.68-9.99)
Paxistima myrsinites	1 (0.00-2.58)	1 (0.00-2.80)	3 (0.00-10.38)	2 (0.00-9.18)
Veronica biloba	2 (0.00-6.63)	1 (0.00-2.25)	0.09 (0.00-0.35)	0.15 (0.00-0.73)
Vicia americana	2 (0.68-4.33)	2 (0.00-7.85)	2 (0.00-6.67)	0.37 (0.00-1.85)
Acer glabrum	5 (0.00-22.00)	0.48 (0.00-0.40)	3 (0.00-13.00)	6 (0.00-23.00)
Acer grandidentatum	0.00	0	1 (0.00-3.67)	2 (0.0-8.00)
Amelanchier alnifolia	12 (1.09-24.00)	10 (107-17.92)	12 (1.00-19.91)	7 (1.73-12.00)
Physocarpus malvaceus	0	11 (0.00-54.90)	14 (0.00-60.88)	8 (0.00-39.00)
Prunus virginiana	3 (0.00-7.90)	1 (0.00-5.00)	4 (0.00-15.76)	1 (0.00-5.00)
Ribes viscosissimum	0	1 (0.00-5.00)	0.10 (0.00-2.00)	0
Rosa woodsii	1 (0.00-4.30)	2 (0.00-4.00)	2 (0.00-5.00)	1 (0.00-2.29)
Salix scouleriana	0	1 (0.00-6.00)	1 (0.00-3.20)	0
Symphoricarpos oreophilus	10 (2.65-2510)	11 (0.13-25.00)	2 (0.04-6.83)	9 (0.13-31.00)

TABLE 4. Average elevation, slope, aspen and Douglas-fir canopy cover, total overstory canopy cover, grass, forb, and shrub canopy cover, aspen age and diameter at breast height (dbh), species richness, and aspen sucker density for permanent aspen plots by conifer encroachment class in the Pleasantview Hills of southeastern Idaho. Numbers in parenthesis indicate range of values.

Variables	Pure Aspen	Aspen 1-15% Df	Aspen 16-30% Df	Aspen >30% Df
average elevation (m)	1910 (1865-1943)	1952 (1756-2130)	1916 (1768-2082)	1898 (1759-1999)
average slope (%)	27 (15-40)	35 (20-50)	41 (18-62)	45 (35-60)
aspen canopy cover (%)	44 (16.90-68.06)	37 (23.32-52.07)	38 (33.02-49.08)	10 (1.20-30.15)
Douglas-fir canopy cover (%)	1 (0.00-0.45)	6 (2.54-12.68)	26 (18.72-31.40)	56 (48.24-72.90)
total overstory canopy cover (%)	45 (16.90-68.06)	43 (28.34-64.74)	66 (61.82-70.07)	66 (54.98-78.39)
grass canopy cover (%)	20 (17.27-25.85)	18 (8.73-26.78)	13 (3.63-29.20)	12 (3.55-27.37)
forb canopy cover (%)	27 (19.47-42.36)	23 (6.71-39.42)	30 (8.07-57.38)	29 (10.21-47.22)
shrub canopy cover (%)	43 (6.31-124.64)	41 (19.03-75.65)	42 (8.5-70.34)	36 (12.19-61.30)
average aspen age (years)	94 (49-114)	61 (44-89)	72 (52-95)	88 (74-102)
average aspen dbh	10.23 (5.8-13.04)	7.80 (6.13-9.33)	6.21 (3.95-7.59)	9.01 (6.10-10.33)
average species richness	33 (30-35)	33 (27-45)	28 (19-36)	32 (25-40)
average aspen sucker density (#/150m^2)	17 (7-31)	67 (24-102)	31 (14-59)	29 (4-90)

TABLE 5. Error matrix for unsupervised classification using the ISODATA algorithm. Bold numbers along diagonal indicate number of correctly classified reference pixels.

	Reference Pixels													
Map classification	Douglas-fir	pure aspen	aspen 1-15% Df	aspen 16-30% Df	aspen +30% Df	agriculture active	agriculture fallow	maple	mountain shrub	grassland	sagebrush	juniper	**Total Map**	**User's Accuracy**
Douglas-fir	**44**	0	0	6	31	0	0	0	1	0	0	0	82	**54%**
pure aspen	0	**26**	0	0	0	9	0	24	8	0	0	0	67	**39%**
aspen 1-15% Df	0	0	**0**	0	0	0	0	0	8	0	0	0	8	**0%**
aspen 16-30% Df	12	17	22	**50**	22	0	0	5	4	0	0	0	132	**38%**
aspen +30% Df	5	0	5	1	**7**	0	0	0	3	3	0	0	24	**29%**
agriculture active	0	0	0	0	0	**10**	0	0	0	0	0	0	10	**100%**
agriculture fallow	0	0	0	0	0	0	**16**	0	0	0	0	0	16	**100%**
maple	0	0	1	0	0	10	0	**13**	21	9	5	0	59	**22%**
mountain shrub	0	10	16	1	1	0	0	0	**57**	22	37	6	150	**38%**
grassland	0	0	0	0	0	0	16	0	4	**255**	23	0	298	**86%**
sagebrush	0	0	2	0	0	5	3	0	40	156	**106**	7	319	**33%**
juniper	0	0	0	0	0	0	0	0	0	3	3	**5**	11	**45%**
total reference	61	53	46	58	61	34	35	42	146	448	174	18	**1176**	
Producer's Accuracy (%)	**72%**	**49%**	**0%**	**86%**	**11%**	**29%**	**46%**	**31%**	**39%**	**57%**	**61%**	**28%**		

Overall Accuracy	**50%**
Kappa Statistic (obs-exp)/(1-exp)	**0.3999**

TABLE 6. Error matrix for supervised classification using parametric discriminant analysis. Bold numbers along diagonal indicate number of correctly classified reference pixels.

	Reference Pixels													
Map classification	Douglas-fir	pure aspen	aspen 1-15% Df	aspen 16-30% Df	aspen +30% Df	agriculture active	agriculture fallow	maple	mountain shrub	grassland	sagebrush	juniper	**total map**	**User's Accuracy**
Douglas-fir	**40**	0	0	6	26	0	0	0	0	0	0	0	72	**56%**
pure aspen	0	**43**	21	0	1	0	0	2	10	4	1	0	82	**52%**
aspen 1-15% Df	6	6	**15**	37	21	0	0	4	5	0	0	0	94	**16%**
aspen 16-30% Df	0	0	8	**5**	4	0	0	2	0	0	0	0	19	**26%**
aspen +30% Df	14	0	2	10	**5**	0	0	0	2	0	0	0	33	**15%**
agriculture active	0	0	0	0	0	**34**	0	0	0	0	0	0	34	**100%**
agriculture fallow	0	0	0	0	0	0	**24**	0	0	0	0	0	24	**100%**
maple	0	0	0	0	0	0	0	**30**	1	0	0	0	31	**97%**
mountain shrub	1	4	0	0	4	0	0	4	**99**	24	31	0	167	**59%**
grassland	0	0	0	0	0	0	8	0	9	**337**	50	0	404	**83%**
sagebrush	0	0	0	0	0	0	3	0	20	83	**91**	1	198	**46%**
juniper	0	0	0	0	0	0	0	0	0	0	1	**17**	18	**94%**
total reference	61	53	46	58	61	34	35	42	146	448	174	18	**1176**	
Producer's Accuracy (%)	**66%**	**81%**	**33%**	**9%**	**8%**	**100%**	**69%**	**72%**	**68%**	**75%**	**52%**	**95%**		

Overall Accuracy	**63%**
Kappa Statistic(obs-exp)/(1-exp)	**0.5436**

TABLE 7. Error matrix for supervised classification using nonparametric discriminant analysis. Bold numbers along diagonal indicate number of correctly classified reference pixels.

	Reference Pixels													
Map classification	Douglas-fir	pure aspen	aspen 1-15% Df	aspen 16-30% Df	aspen +30% Df	agriculture active	agriculture fallow	maple	mountain shrub	grassland	sagebrush	juniper	**total map**	**User's Accuracy**
Doug-fir	**56**	0	0	13	26	0	0	0	0	1	0	0	96	**58%**
pure aspen	0	**41**	13	0	12	0	0	2	9	0	1	0	78	**53%**
aspen 1-15% Df	0	11	**29**	34	14	0	0	0	3	0	0	0	91	**32%**
aspen 16-30% Df	0	0	3	**10**	3	0	0	0	2	4	0	0	22	**45%**
aspen +30% Df	5	0	1	1	**5**	0	0	0	2	0	0	0	14	**36%**
agriculture active	0	0	0	0	0	**34**	0	0	0	0	0	0	34	**100%**
agriculture fallow	0	0	0	0	0	0	**35**	0	1	0	0	0	36	**97%**
maple	0	0	0	0	1	0	0	**40**	0	6	3	0	50	**80%**
mountain shrub	0	1	0	0	0	0	0	0	**110**	12	17	0	140	**79%**
grassland	0	0	0	0	0	0	0	0	8	**405**	34	0	447	**91%**
sagebrush	0	0	0	0	0	0	0	0	11	20	**119**	1	151	**79%**
juniper	0	0	0	0	0	0	0	0	0	0	0	**17**	17	**100%**
total reference	61	53	46	58	61	34	35	42	146	448	174	18	**1176**	
Producer's Accuracy (%)	**92%**	**77%**	**63%**	**17%**	**8%**	**100%**	**100%**	**95%**	**75%**	**90%**	**68%**	**94%**		

Overall Accuracy	**77%**
Kappa Statistic (obs-exp)/(1-exp)	**0.70992**

TABLE 8. Error matrix for supervised classification using nonparametric discriminant analysis. Conifer encroachment classes have been combined into one aspen/Douglas-fir mixed class. Bold numbers along diagonal indicate number of correctly classified reference pixels.

	Reference Pixels											
Map classification	Douglas-fir	pure aspen	mixed aspen/Df	agriculture active	agriculture fallow	maple	mountain shrub	grassland	sagebrush	juniper	**total map**	**User's Accuracy**
Douglas-fir	**61**	0	58	0	0	0	0	1	0	0	120	**51%**
pure aspen	0	**50**	33	0	0	7	5	1	0	0	96	**52%**
mixed aspen/ Df	0	1	**66**	0	0	1	5	0	0	0	73	**90%**
agriculture active	0	0	0	**34**	0	0	0	0	0	0	34	**100%**
agriculture fallow	0	0	0	0	**35**	0	1	0	0	0	36	**97%**
maple	0	0	6	0	0	**32**	2	4	2	0	46	**70%**
mountain shrub	0	2	2	0	0	2	**115**	23	14	0	158	**73%**
grassland	0	0	0	0	0	0	4	**395**	38	0	437	**90%**
sagebrush	0	0	0	0	0	0	14	24	**118**	0	156	**76%**
juniper	0	0	0	0	0	0	0	0	2	**18**	20	**90%**
total reference	61	53	165	34	35	42	146	448	174	18	**1176**	
Producer's Accuracy (%)	**100%**	**94%**	**40%**	**100%**	**100%**	**76%**	**79%**	**88%**	**68%**	**100%**		

Overall Accuracy		**79%**
Kappa Statistic	(obs-exp)/(1-exp)	**0.73249**

FIGURE 1. Permanent aspen plot dimensions adapted from the National Park Service Fire Monitoring Handbook (forest plot layout).

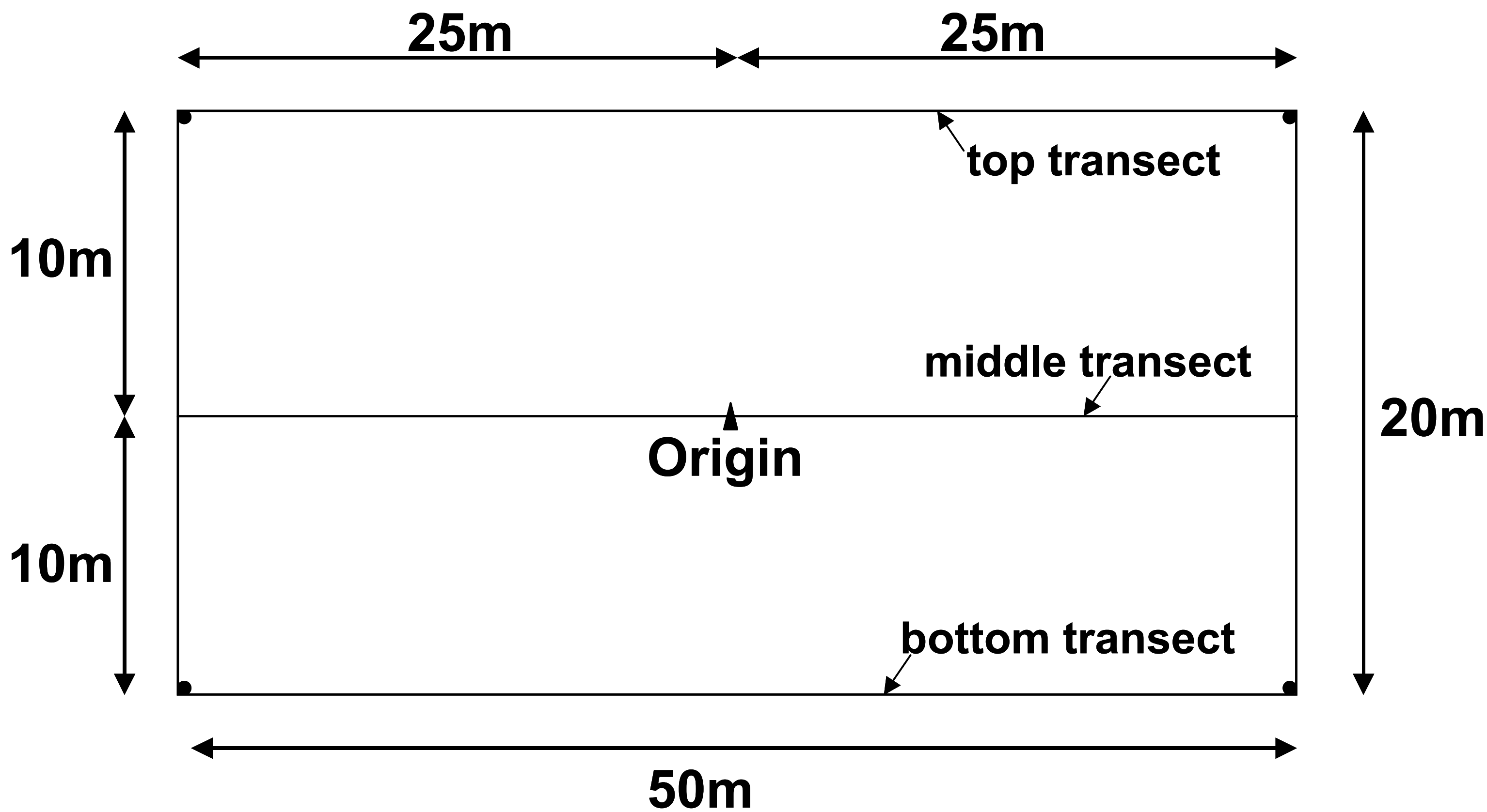

FIGURE 2. Average aspen age (n=4/plot, 5 plots/class) across the four conifer encroachment classes in the Pleasantview Hills of southeastern Idaho.

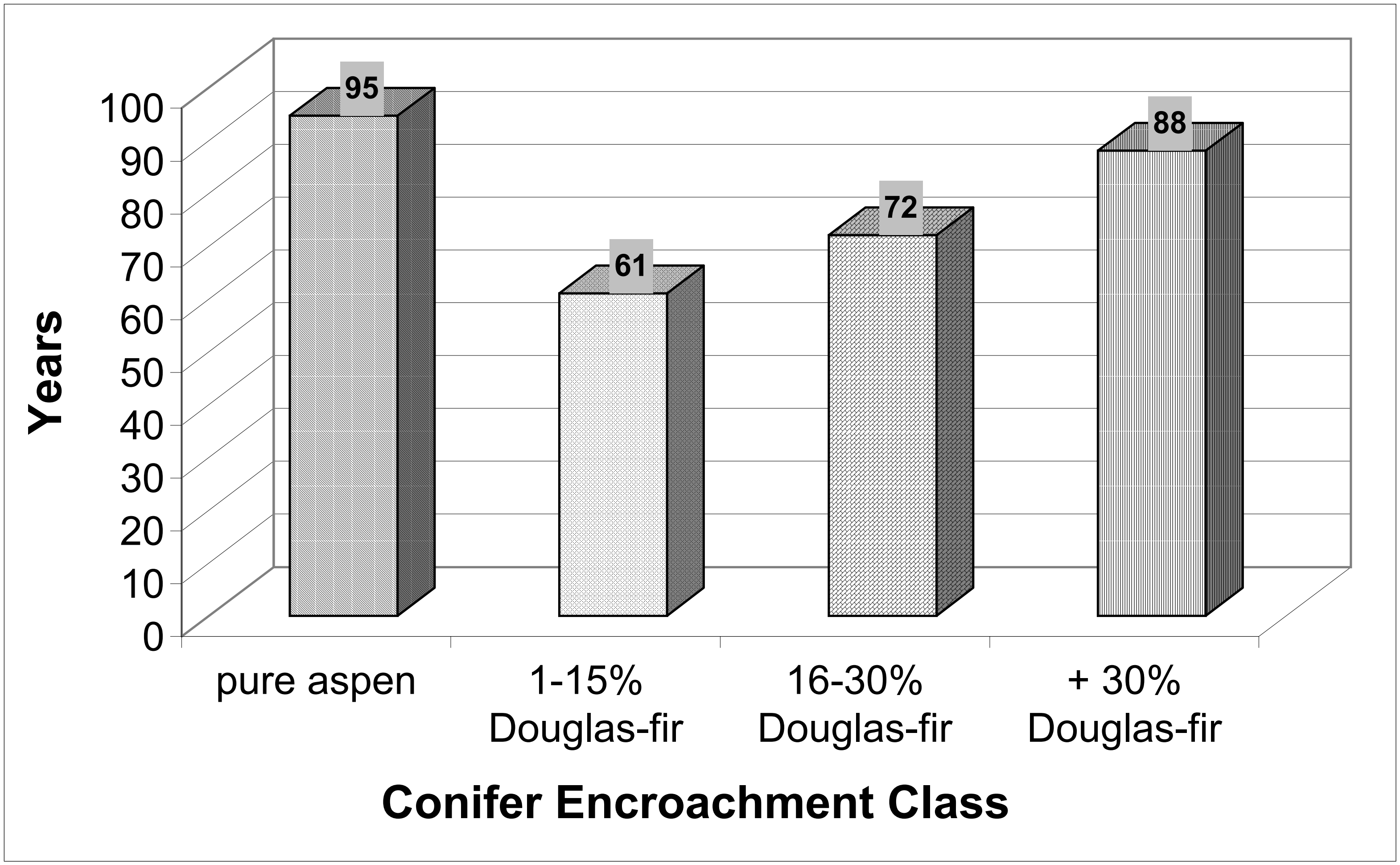

FIGURE 3. Average aspen sucker density (# suckers/750m^2) across the four conifer encroachment classes in the Pleasantview Hills of southeastern Idaho.

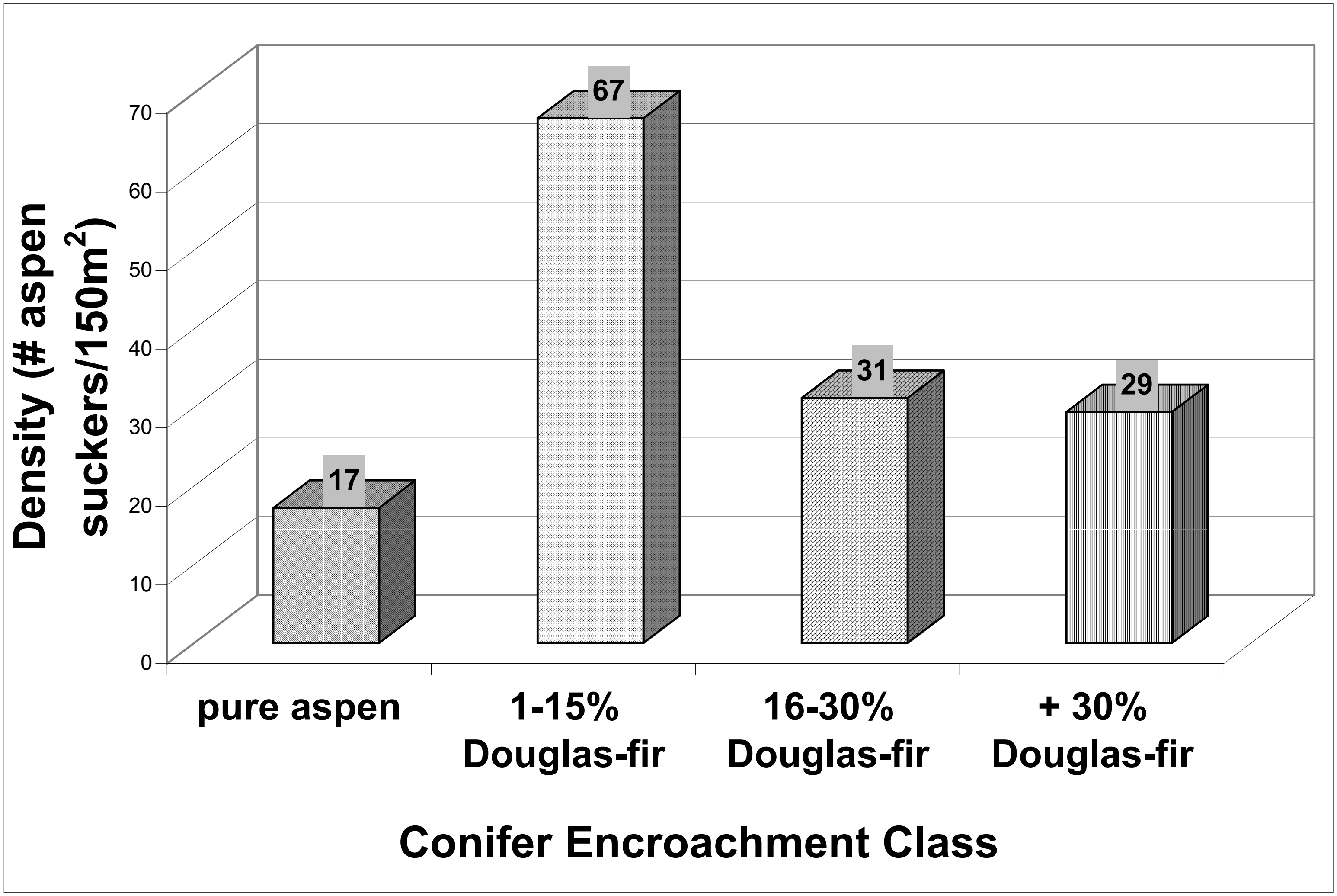

FIGURE 4. Map developed with unsupervised classification using the ISODATA algorithm. Overall accuracy is 50%.

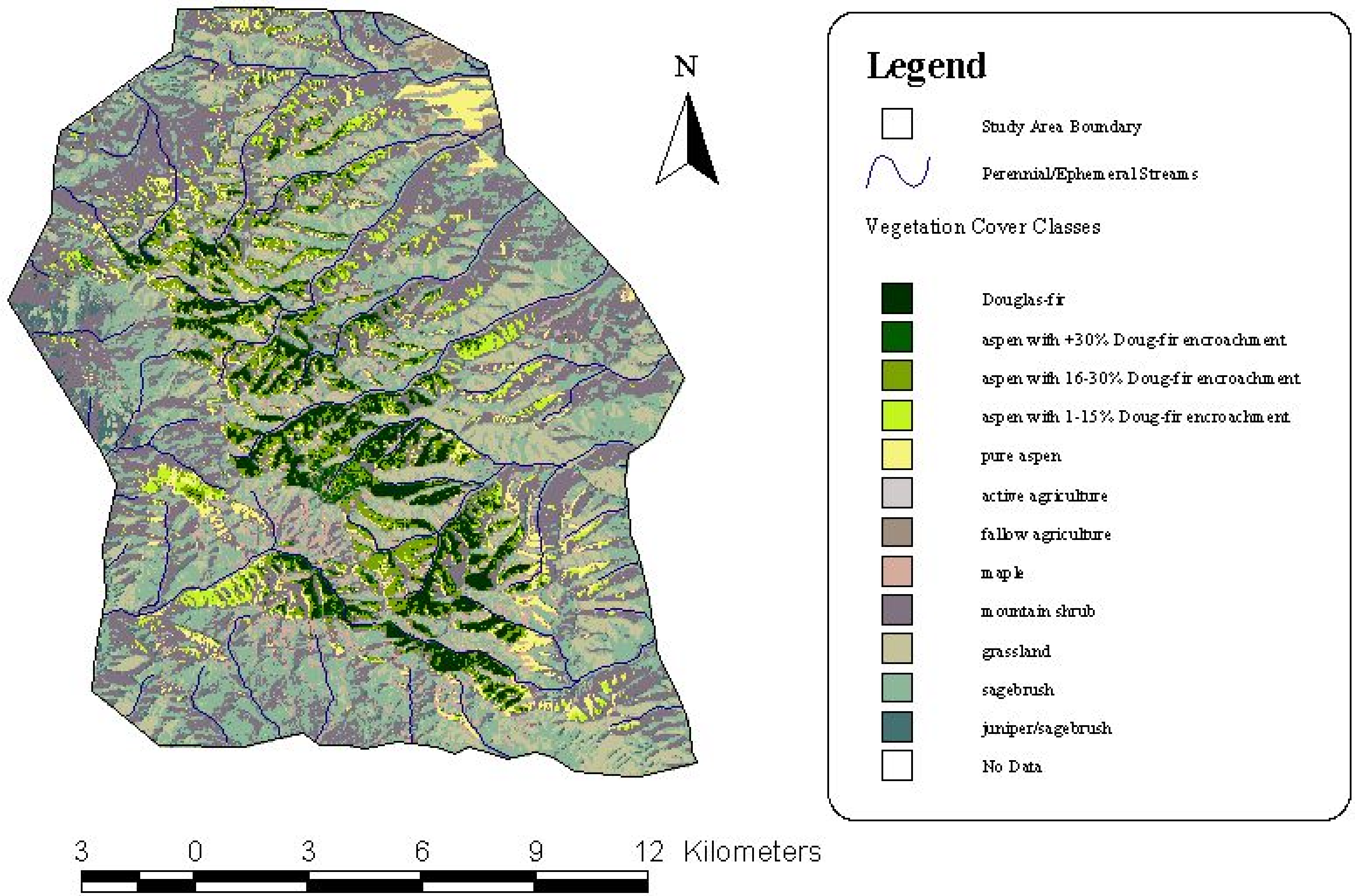

FIGURE 5. Map developed with supervised classification using parametric discriminant analysis. Overall accuracy is 63%.

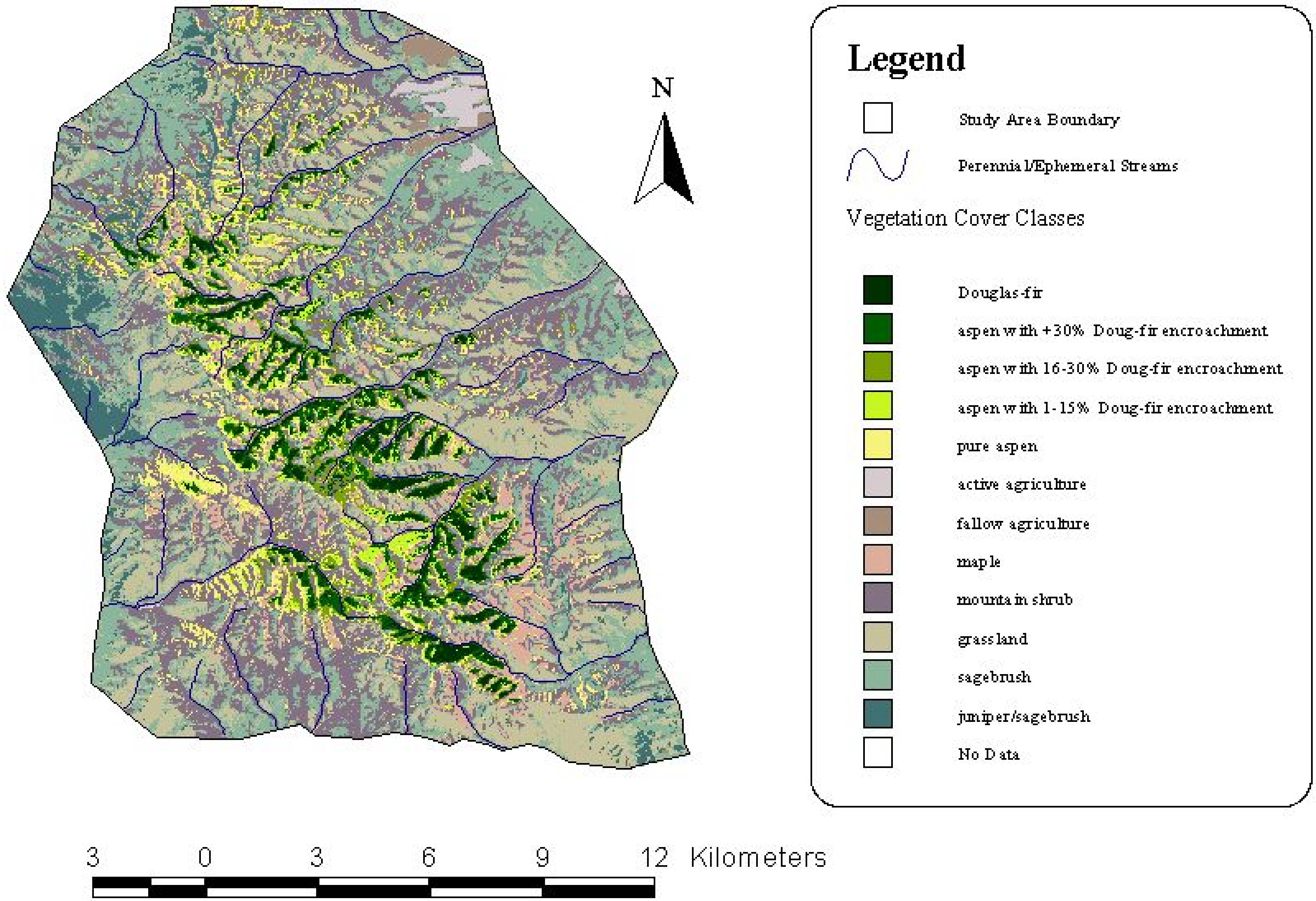

FIGURE 6. Map developed with supervised classification using nonparametric discriminant analysis. Overall accuracy is 77%.

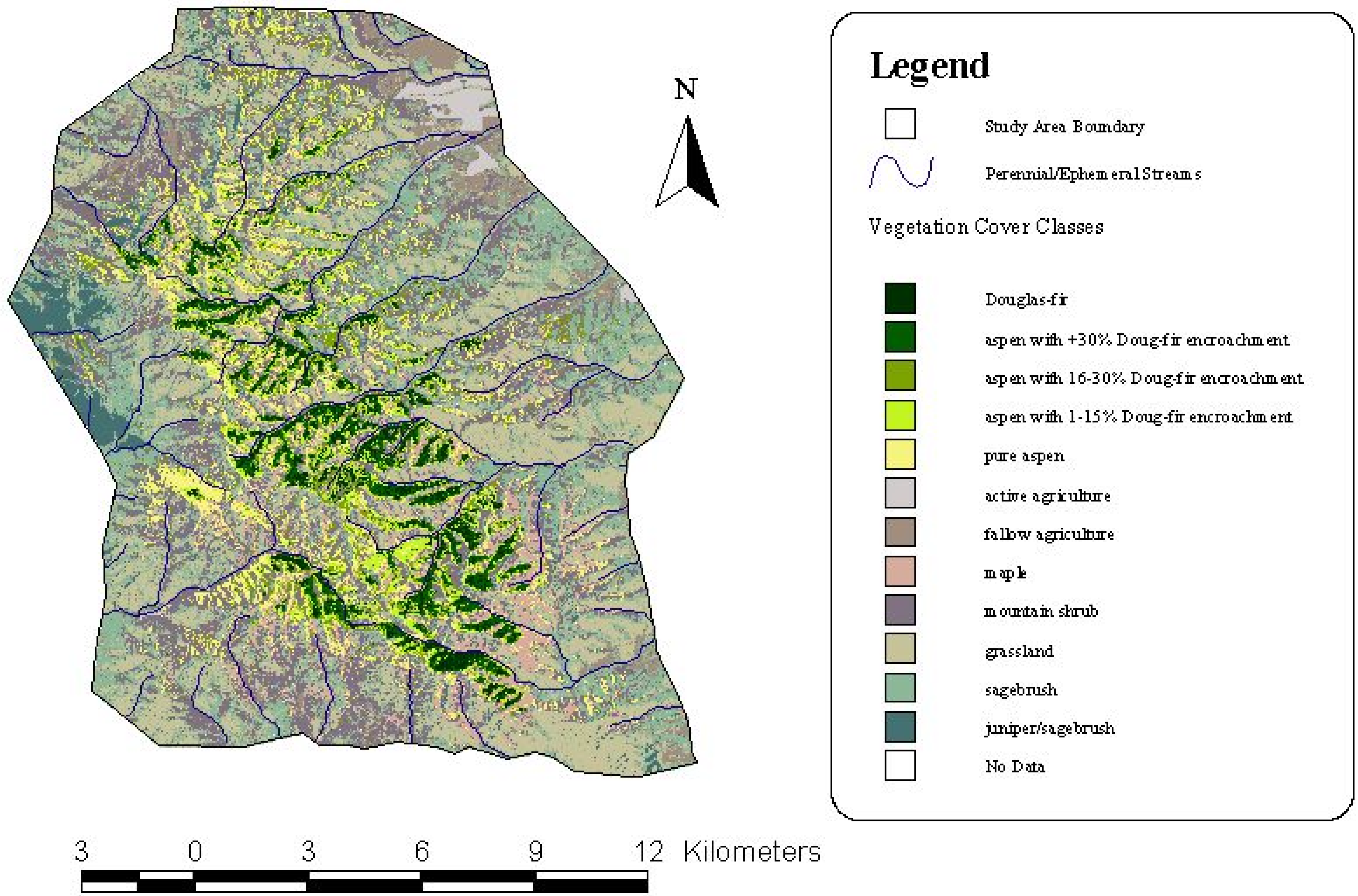

FIGURE 7. A comparison of user's accuracy across conifer encroachment classes for the three data processing techniques used to classify the Landsat 7 satellite image of the Pleasantview Hills.

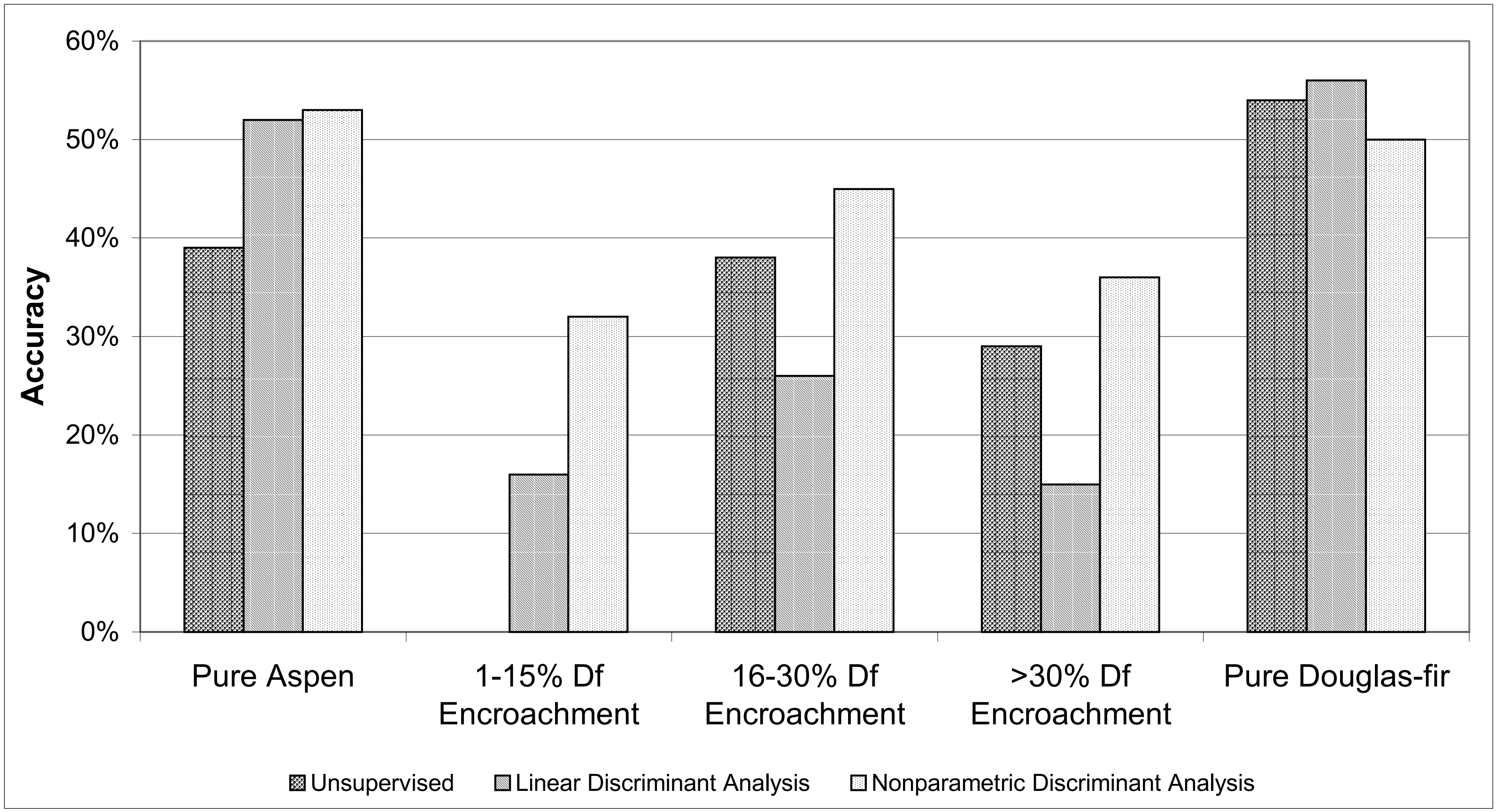

FIGURE 8. Map developed with supervised classification using nonparametric discriminant analysis. Conifer encroachment classes are combined into one aspen/Douglas-fir mixed class. Overall accuracy is 79%.

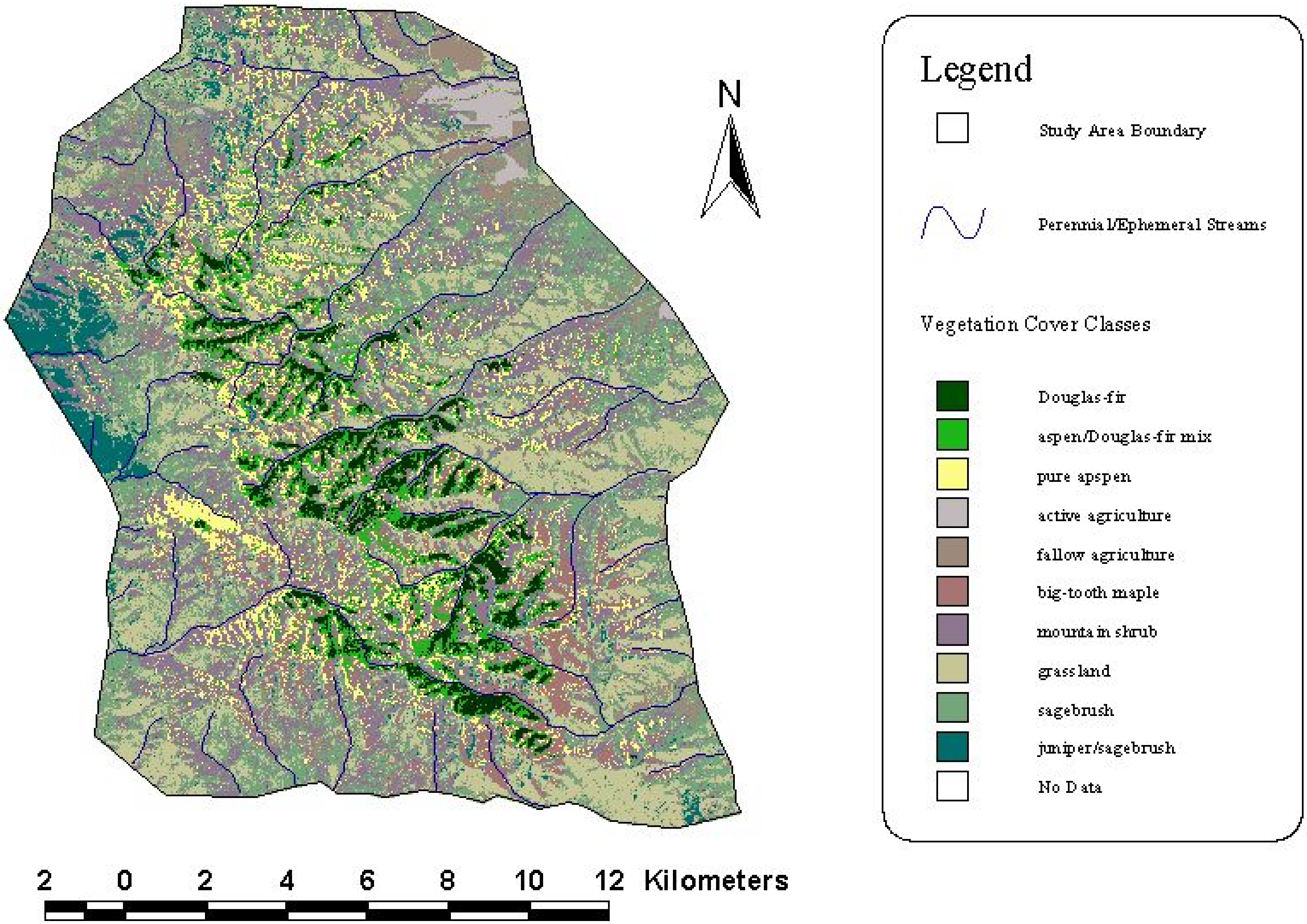

FIGURE 9. Proportion of landscape occupied by pure aspen, pure Douglas-fir, and the three intermediate encroachment classes in the Pleasantview Hills of southeastern Idaho. Percentages based on a pixel count of the raster-based thematic map developed using supervised classification procedures.

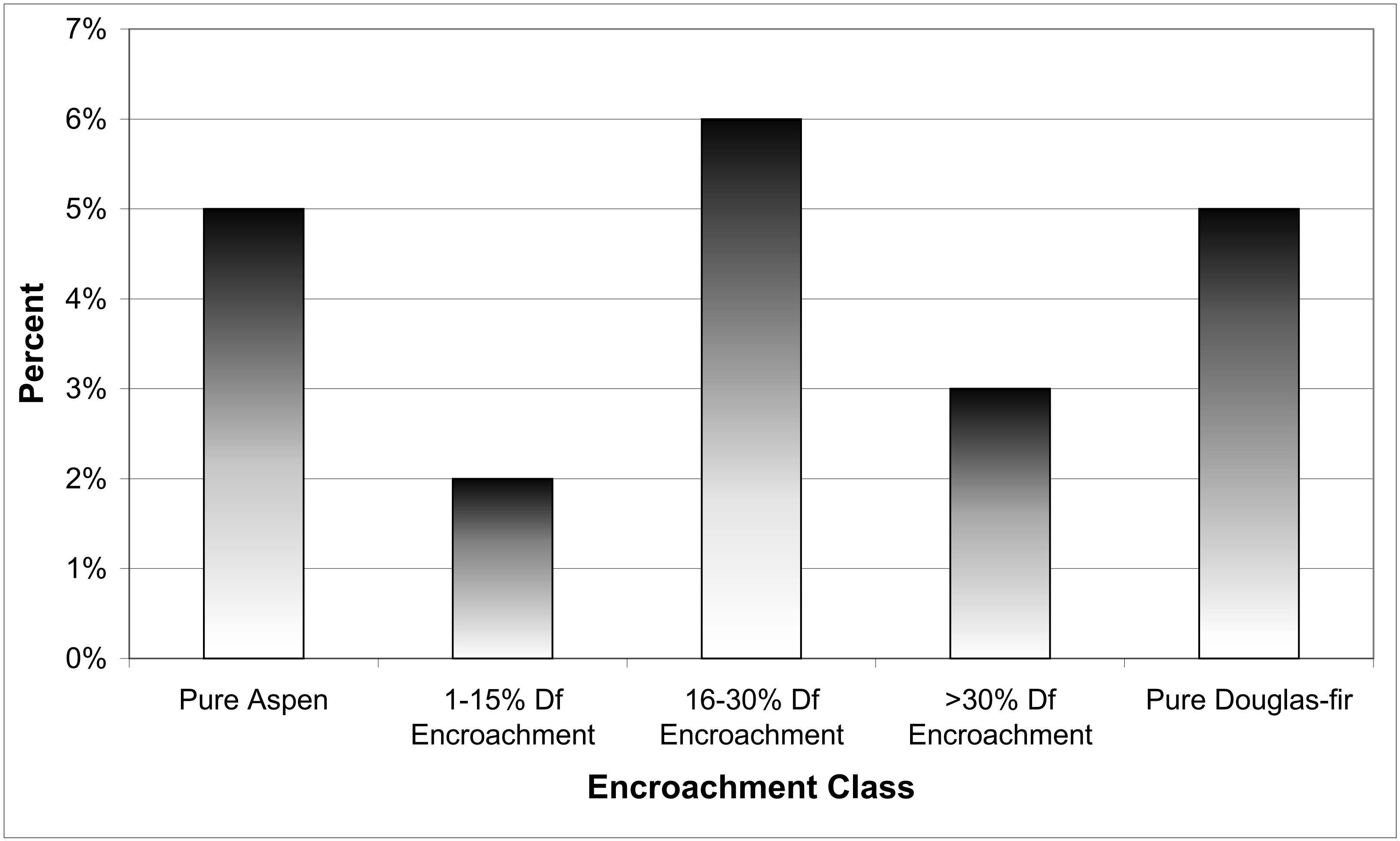

FIGURE 10. Percent cover for three selected understory species across the four conifer encroachment classes in the Pleasantview Hills of southeastern Idaho.

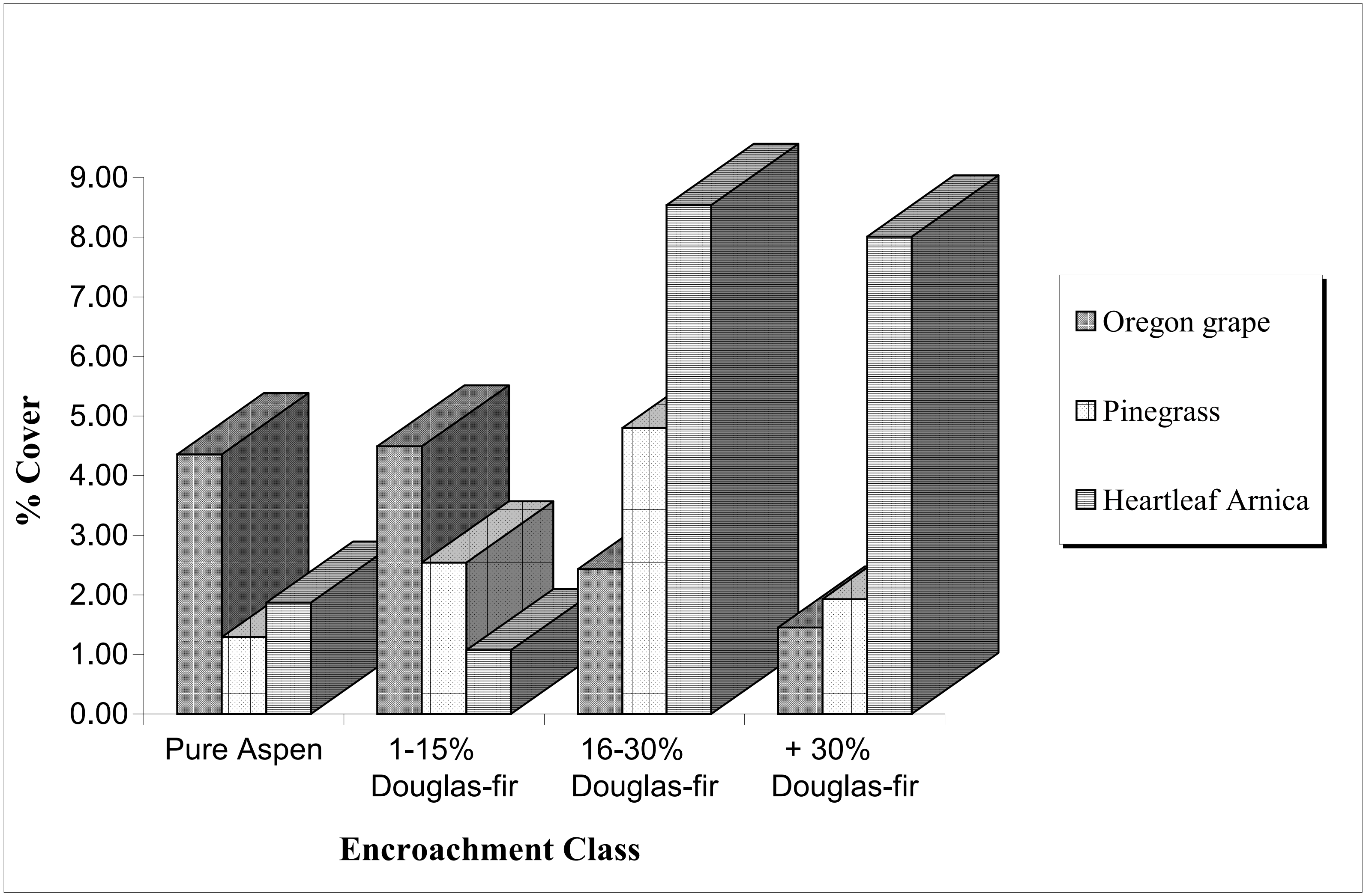

FIGURE 11. Percent cover for three additional understory species across the four encroachment classes in the Pleasantview Hills of southeastern Idaho.

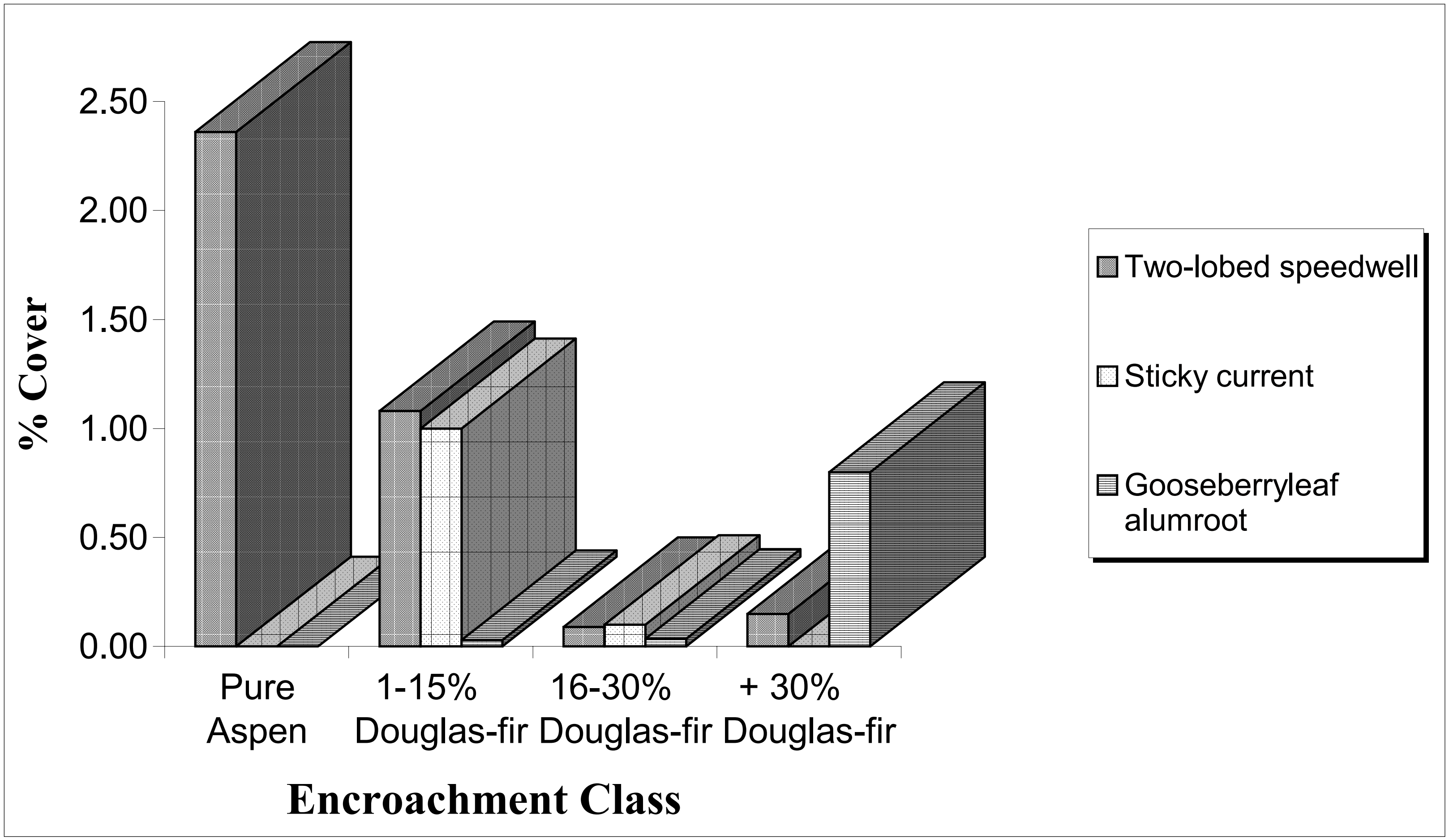

FIGURE 12. Range or spread of linear discriminant analysis function coefficient values for all twelve vegetation classes across all fifteen variables (layers) used in the Landsat 7 satellite image classification of the Pleasantview Hills. Variables with wide value ranges were most important for separating the multi-spectral data into vegetation cover classes. For each box plot from top to bottom: maximum of range, third quartile, first quartile, and minimum of range (J. = July , O. = October).

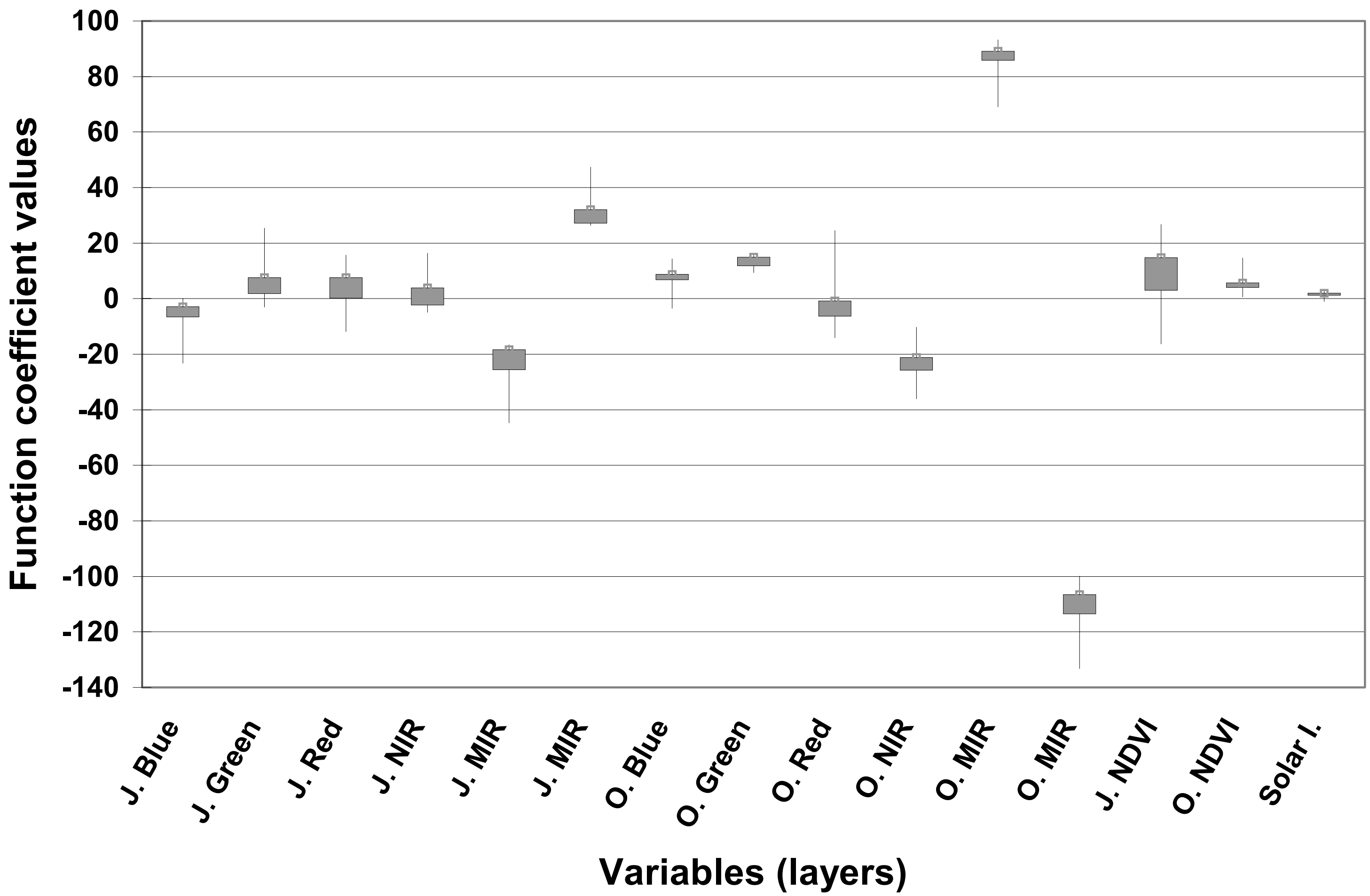

FIGURE 13. Ellipse plot of band 3 along the x axis (red) and band 13 along the y axis (NDVI) from the July 1999 Landsat 7 ETM+ satellite image of the Pleasantview Hills.

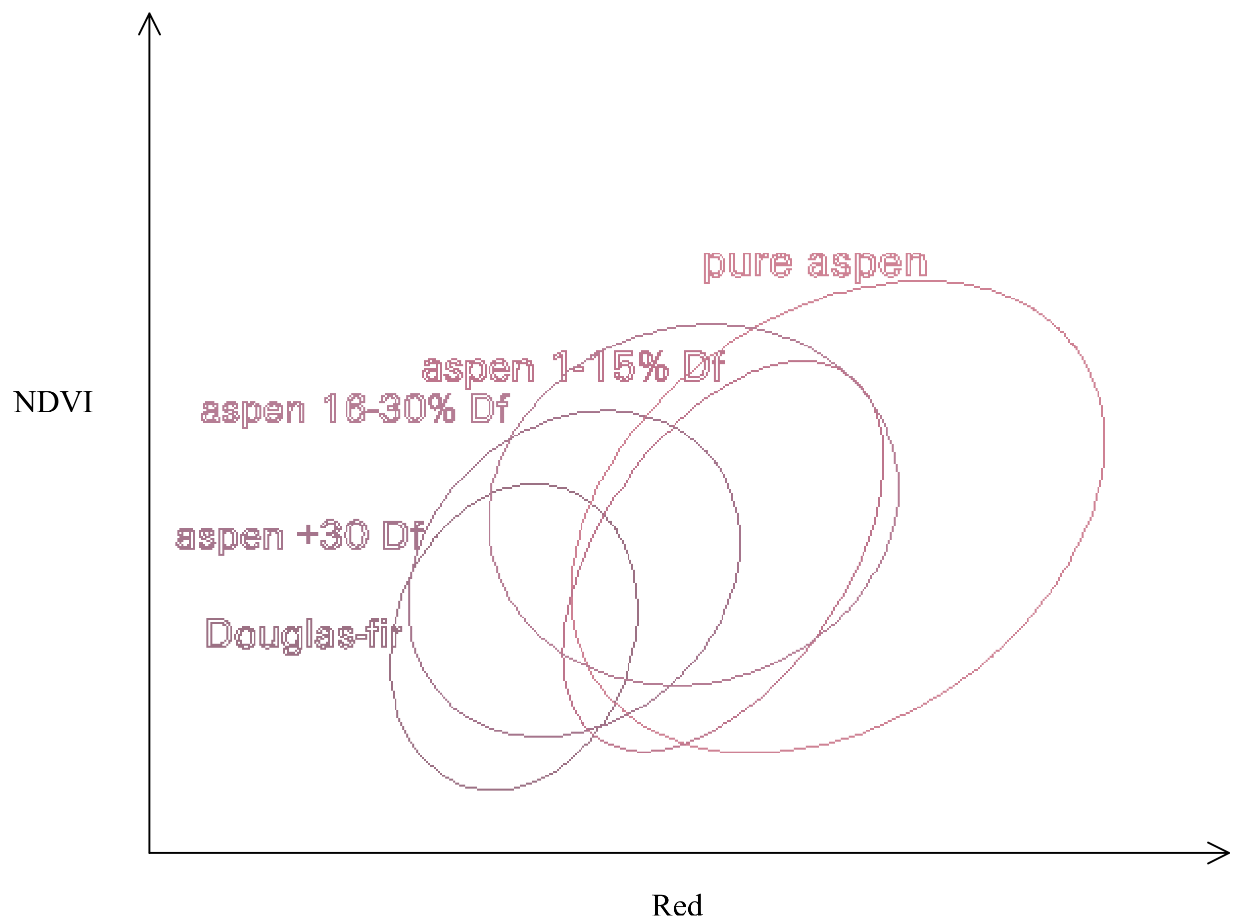

FIGURE 14. Ellipse plot of band 3 along the x axis (red) and band 4 along the y axis (near-infrared) from the July 1999 Landsat 7 ETM+ satellite image of the Pleasantview Hills.