ESTIMATION OF DOMINANT TREE SIZE IN CONIFEROUS STANDS USING LANDSAT TM DATA

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ABSTRACT

LANDSAT TM data cannot resolve size of individual trees directly since the 30-meter pixel cell is too large. However, an estimate of dominant tree size within a coniferous stand of trees can be obtained based on two factors associated with tree size: ecological conditions and textural variability. Classifying the various ground conditions associated with varying ecological environments provided information on probable tree size. Also, information about textural variability across groupings of pixels was useful in segregating trees of differing size. A brightness-greenness-wetness transformation combined with additional textural layers was useful in a hybrid classification scheme utilizing unsupervised and supervised procedures. A plot of brightness vs. greenness displayed patterns associated with ground conditions that could be correlated with tree size.

INTRODUCTION

Tree size is often a necessary piece of information in studies of forest management. It is not only related to age, fire susceptibility, harvest potential, and silvicultural treatment of tree stands, but also to biodiversity and ecological health of the forest environment. It can often be related to specific ecological environments and the biological maturity of those environments. It would be very useful to quickly map this structural characteristic over a regional area at low cost. The LANDSAT Thematic Mapper has traditionally been very useful in a variety of natural resource studies, including the mapping of vegetation life form and structure. However, LANDSAT TM data cannot resolve individual trees directly since the 30-meter pixel cell is too coarse to resolve even the largest trees. Thus tree size must be determined indirectly by spectrally defining the aforementioned ecological conditions, which then can be correlated with tree size. Particular ground conditions are often associated with tree stands that may extend for several acres. These stands contain a community of trees sufficiently uniform in life form, structure, age, and arrangement from surrounding ground conditions that they are very distinguishable on LANDSAT data even though the individual trees are not.

The study area (Figure 1) was located along the northwest coast of California between the Oregon border and San Francisco. A tract of mostly private land, 8 to 40 miles inland from the coast depending on similarity of ecological systems, was selected. This area included redwood forests, which contain some of the largest trees in the world. It also is an area of extensive and intensive forest management, containing large areas that has been harvested for timber and thinned at various times. These harvested areas provide contrast to the old growth redwood forests that have been protected in state parks. In addition to this contrast between harvested and protected areas, the coastal environment provides a wide diversity of natural ecological environments with varying sizes of trees (Noss, ed., 2000). The natural diversity of this area also translates to wide diversity in spectral reflectance that could be detected from a satellite sensor.

In most vegetation mapping exercises, tree size is defined as either crown diameter or diameter of the stem at breast height (dbh). Crown diameter and stem diameter can be related to each other through a simple mathematical relationship, albeit this relationship varies with different tree species. From field observation, it is generally recognized that this relationship is less variable and more consistent for conifer species than for hardwood species (Warbington and Levitan, 1993). Thus, by observing only the crown diameters from above, more reliable estimates of stem diameter can be obtained for conifers than for hardwoods. Also, the conical apex of most conifers lend them to be more distinguishable when observed from above as compared to the broad, overlapping crowns of many hardwoods. Therefore, this study focused on coniferous tree stands in order to obtain the best estimates of tree size. Table 1 shows the size classification used in this study.

In addition to spectral diversity related to ecological condition, the textural characteristics of tree stands were investigated as a means of determining tree size. Specifically, this study sought to determine if the textural variability within a stand of predominantly large trees is different and separable from a stand of predominantly smaller trees. If so, then the correlation between the size of trees in a stand and its textural variability, as seen on imagery, was also sought. This textural information was studied in combination with spectral reflectance to determine its usefulness in determining tree size.

A hybrid classification procedure combining supervised with unsupervised classifications was used. Once an initial size classification was produced, the map was inspected and compared to large-scale aerial photography. Field reconnaissance assessed map quality and identified problematic areas. Map improvements were made through an editing process where tree stands could be relabeled manually. This combination of procedures was utilized in order to produce a map of acceptable accuracy within a limited time frame and cost structure.

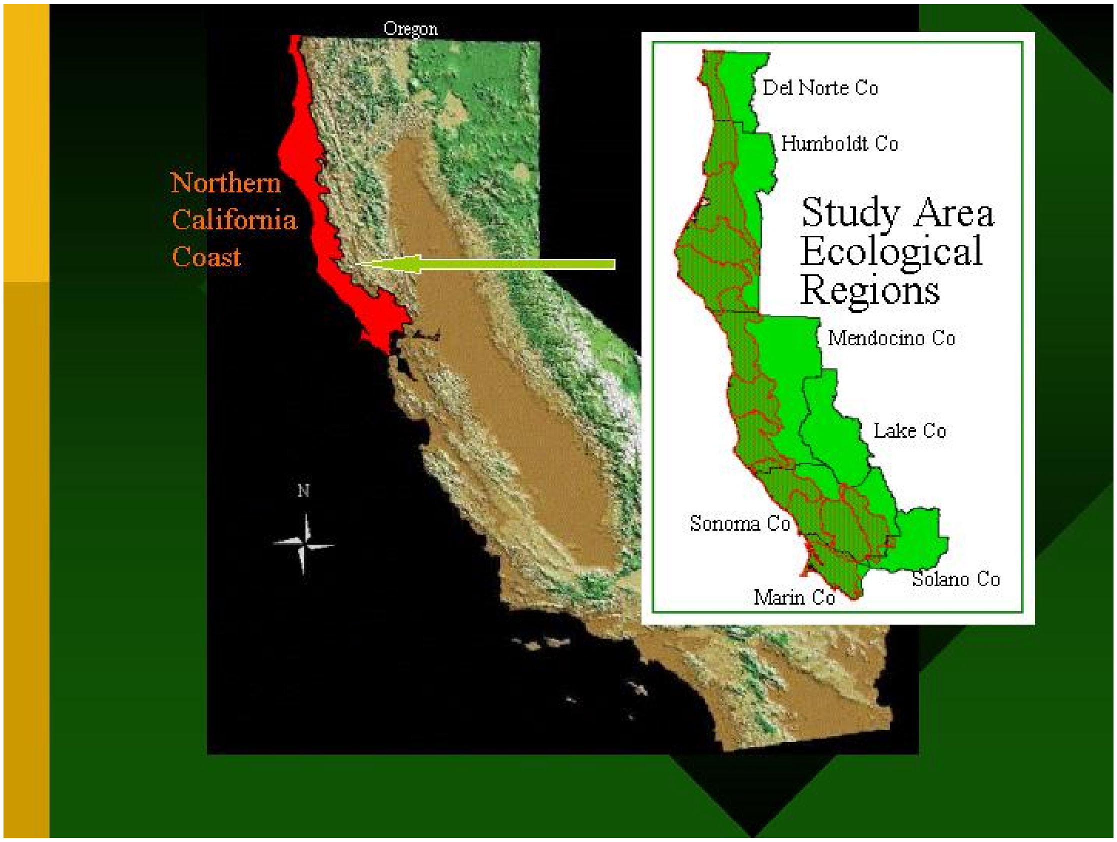


Figure 1. Project study area along the northwest coast of California.

Table 1.

Northwest Size Classification		R5 Size Classification	
Value	*DBH*	*Value*	*DBH*
1	1.0” - 4.9”	1	1.0” - 4.9”
2	5.0” - 11.9”	2	5.0” - 11.9”
3	12.0” - 19.9”	3	12.0” - 23.9”
4	20.0” - 23.9”		
5	24.0” - 29.9”	4	24.0” - 39.9”
6	30.0” - 39.9”		
7	40.0” - 49.9”	5	40.0” +
8	50.0” +		

The above table defines tree size classification for conifers in two different systems. The northwest size classification was used in this study because it could better differentiate between the larger tree sizes that are present along the northwest coast of California. The traditional size classification used by U. S. Forest Service Region 5 is shown for comparison.

PROCEDURE

Delineation of Natural Regions and Tree Stands

The study area along the northern coast of California was first subdivided into twelve processing units, or natural regions, where ecosystems were thought to be fairly similar throughout the region. These boundaries were based on ecosystem subsections and watershed boundaries. The purpose of these natural regions was to provide better data management during image processing and streamline mapping of vegetation types. In general, the area of each natural region ranged between 250,000 and 500,000 acres (Figure 2).

Tree stands were delineated within each natural region. Each stand was defined as a grouping of trees with similar structural and spectral characteristics. This was accomplished using a segmentation process that has been described in the literature (Woodcock and Harward, 1992; Woodcock et al, 1993; Ryherd and Woodcock, 1990). Only the salient characteristics of this procedure will be discussed here.

It has been shown that a three-band combination was useful in delineating segments based on tree stands: LANDSAT TM bands 3 and 4, with a texture band based on band 4. Spectral and textural patterns were found using this combination, represented by groupings of contiguous pixels with sufficiently similar reflectance. The minimum mapping unit was 2.5 acres in area, so any tree stands identified to be less than this area were merged into the adjacent stands. Also, very large tree stands (greater than 200 acres) were split into at least 2 smaller stands, resulting in two or more stands within a spectrally homogeneous condition. The theoretical range of area for stands could vary between 2.5 acres and 227 acres; however, due to spectral variability of the vegetation and landscape, it was observed that most stands were between 5 and 25 acres. Each tree stand contained a population of pixels with reflectance characteristics more similar to each other than to the population of pixels in the adjacent stand. This indicated that each stand had reflectance characteristics representing vegetation and ground conditions that were sufficiently different and identifiable from the adjacent stand. All pixels within each stand were labeled with a unique number associated with the particular stand, and this product was exported as a grid. This grid was converted into a vector coverage where each polygon, or region, represented a tree stand with a unique label. Each natural region contained at least 30,000 polygons but did not exceed 65,535 polygons.

Delineation of Training Sites

Since a supervised classification was used in creating the preliminary map for tree size, it was critical that well-defined spectral signatures be acquired for each tree size and ground condition in which it can be found. In order to minimize confusion related to shadow, illuminated sites were separated and classified apart from shaded sites, and each natural region was considered separately.

In order to obtain representative training sites, three to five specific areas that represented variations in the landscape were selected within each natural region. Each of these sites was defined as the area covered by one color or black-and-white aerial photograph at a scale of 1:24,000 (or approximately 7400 acres). Training sites were widely separated and generally represented 5 to 10 percent of the forested area to be mapped for tree size; these sites were delineated on LANDSAT TM imagery and the polygon coverage defining tree stands was overlaid on the imagery. By comparing the photo with the imagery, and also utilizing field knowledge of the area, each polygon was manually labeled for dominant tree size within the particular tree stand (Figure 3). The average tree size was not considered as a label, due in part to the inability to determine the size and frequency of suppressed trees. Only the tree size of the observable and reflecting canopy was labeled. During this labeling, the Northwest Forest Plan size classification scheme (see Table 1) was used. For example, if a stand of trees had equal amounts of size 8 conifers and size 4 conifers, the size label would not be size 6, but size 8; the larger size would dominate the stand and presumably define its spectral signature.

The product at this stage consisted of a polygon coverage indicating tree size for three to five small, geographically specific, widely separated areas of the natural region. This coverage was used as a guide to define spectral signatures.

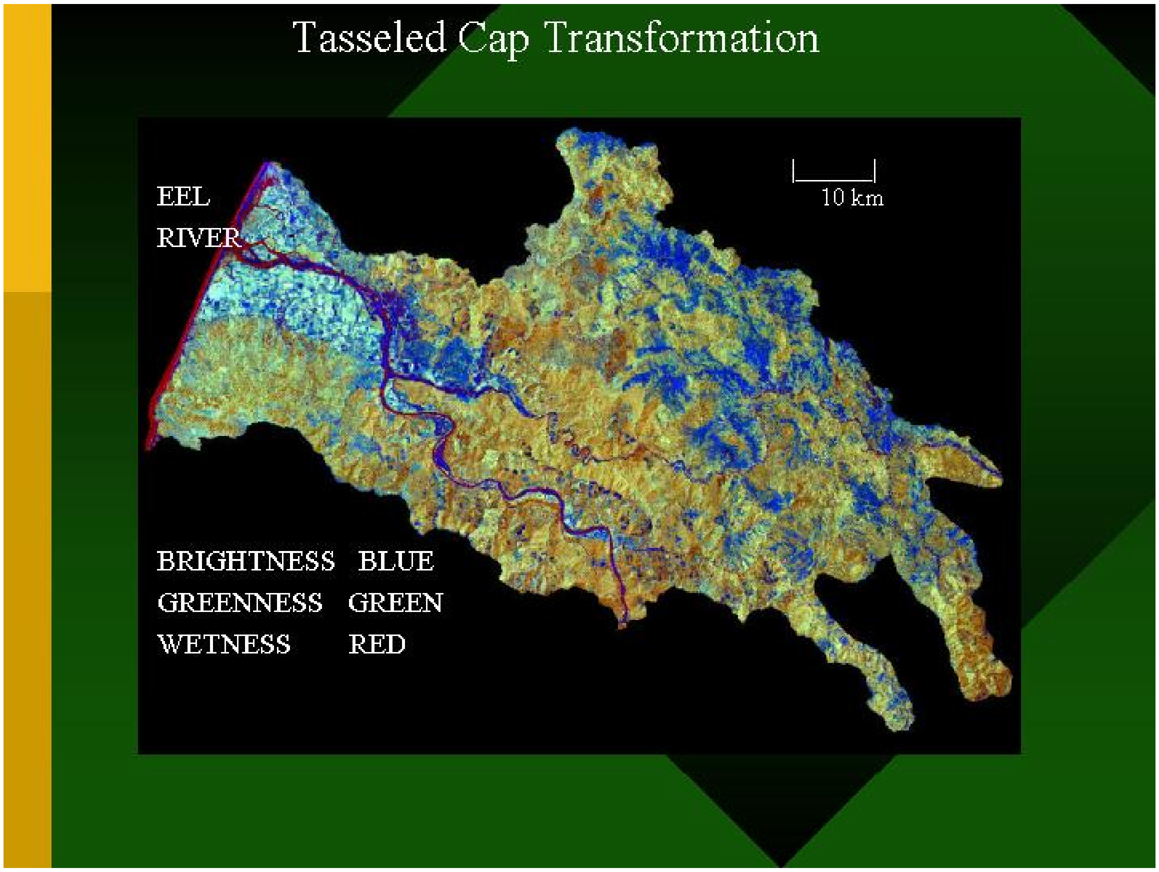


Figure 2. Natural region with original LANDSAT 5 TM bands transformed into brightness, greenness, and wetness bands through the tasseled cap transformation.

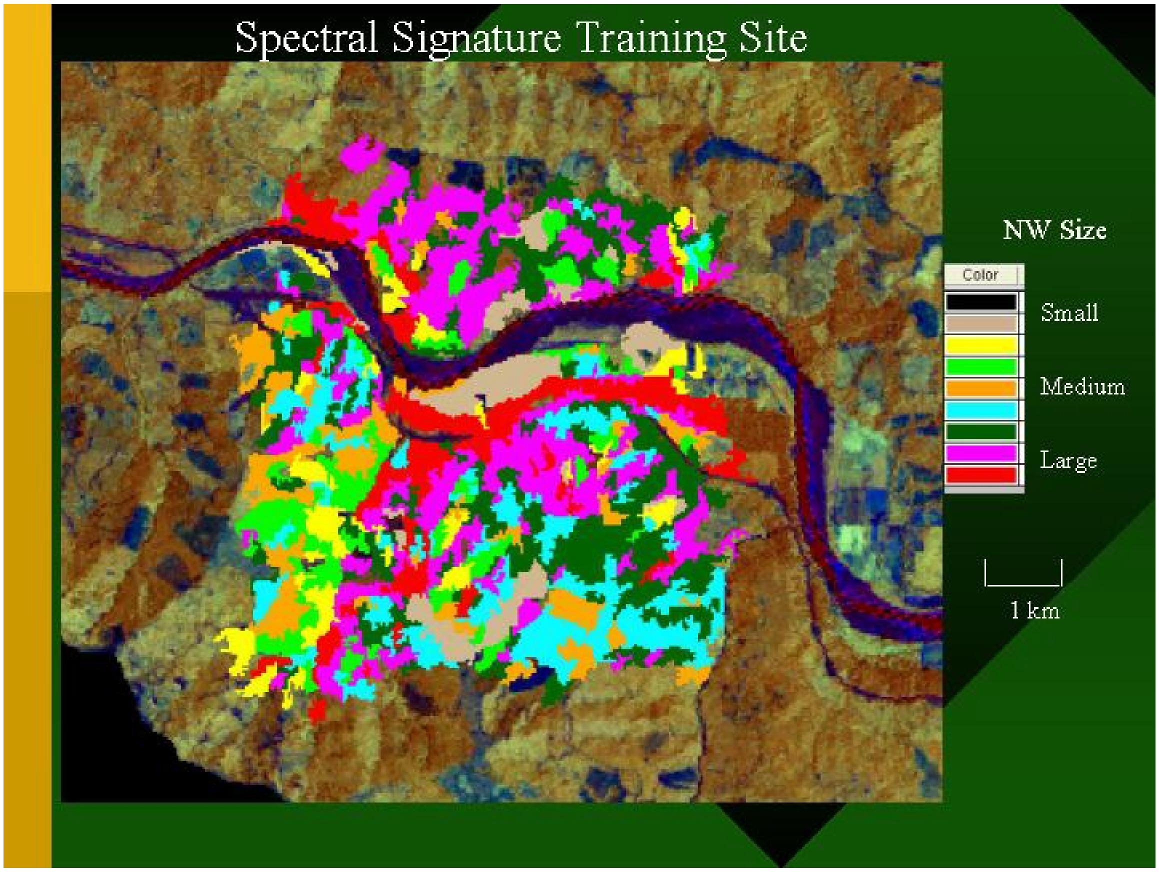


Figure 3. Training sites were chosen and tree stands within the site were labeled for dominant tree size by comparison of the imagery with 1:24,000 scale aerial photos. Each training site covered the land area seen on one of these photos (approx. 7400 acres). The label for tree size was based on inspection of the photo and field knowledge of the area.

Definition of Spectral Signatures

A five-band combination was used in definition of the spectral signatures for tree sizes. The first three bands were brightness, greenness, and wetness outputs from the tasseled cap transformation of LANDSAT TM bands 1 through 5 and band 7. This transformation was chosen because the majority of the information in the image can be condensed into two bands, brightness and greenness, which can be easily correlated with vegetation and other visual information of the image. The wetness band can sometimes be related to soil moisture, which may be helpful in separating ecological environments based on availability of moisture (Lillesand and Kiefer, 1994).

The fourth and fifth bands were derived from textural information of the image. An initial texture band was derived from TM band 4; this band was chosen because of its sensitivity to reflectance of vegetation in the near infrared portion of the spectrum. This texture band was useful is defining edges of tree stands and delineating polygons based on tree stands. However, the DN values for each pixel represent only a local comparison between contiguous pixels, and due to this locality effect, similar features on the ground may not have similar DN values associated with them in different portions of the image. As such, the usefulness of this preliminary texture band in a supervised classification seemed questionable. However, this study was only concerned with tree stands, which were represented not by single pixels but groupings of pixels. Thus, even though similar tree stands may have different absolute DN values for texture, they may have similar differences between those values. In other words, tree stands containing similar size trees may have similar variations in texture within the grouping of pixels representing the stand. Therefore, an additional fifth band of textural variance was generated from the preliminary texture band.

A zonal statistics function was used to calculate the standard deviation of textural DN values within each zone, or tree stand; standard deviation has a direct correlation to variance. These values were stretched to 8-bit data and added as the fifth band in the image from which signatures were obtained. It was hypothesized that similar tree stands would have similar textural variance and that larger trees would have greater variance than smaller trees.

Thus, signatures were obtained from a five-band image stacked as follows: brightness, greenness, wetness, texture derived from TM band 4, and standard deviation of textural values per stand. It is important to recognize that DN values for the first four bands varied with each pixel whereas the fifth band only varied with tree stand.

Initial signatures were generated for the training sites where tree size was manually labeled. This was accomplished by utilizing a cluster output from an unsupervised classification applied only to the pixels within the training sites. Using this cluster output to generate spectral signatures had two advantages; it reduced analyst bias in the selection of pixels for each signature, and it also increased the probability that each signature was invertible with a normal distribution. Each cluster of pixels for each signature was studied and compared with the polygon labels for tree size in the training sites. Each cluster was assigned a label for tree size based on the training map of labeled polygons. If a cluster could not be uniquely identified with a particular tree size, it was flagged as confused and included in the next iteration, and if it could not be uniquely identified after three unsupervised classifications, it was discarded. Two complete sets of spectral signatures were generated; one set for illuminated and one set for shaded.

Even though there were many signatures for any particular tree size, these signatures were not combined because they inferred great variability of ground conditions. Changes in illumination, slope, soil, canopy cover, moisture, and other factors created different signatures for any particular tree size. Therefore, it was best to leave the signatures uncombined in order to have maximum flexibility in labeling the clusters.

Supervised and Unsupervised Classification

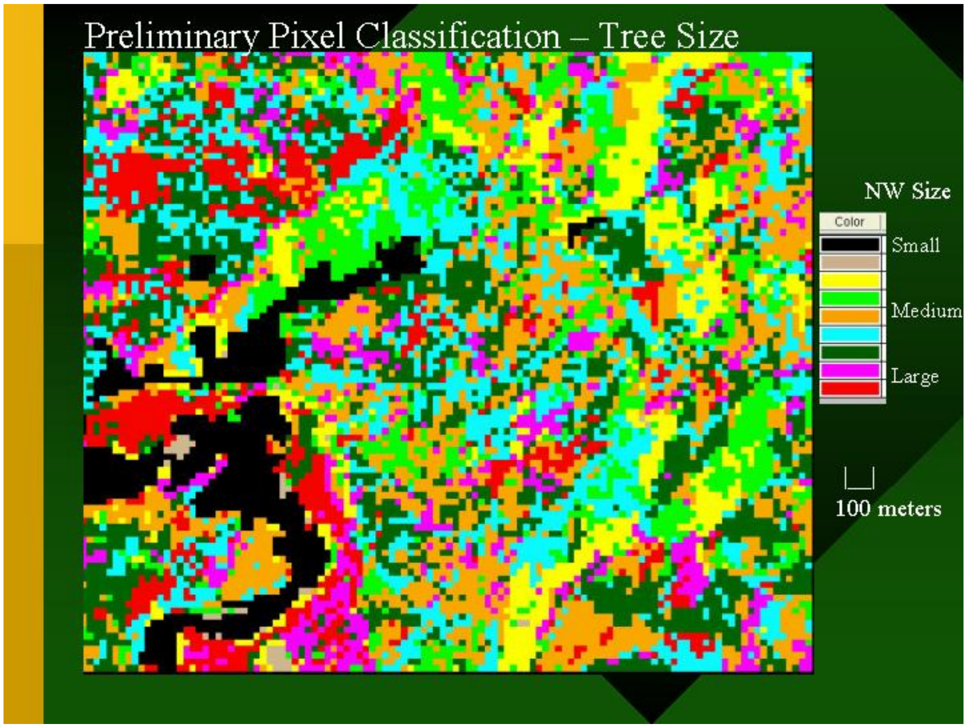
A supervised classification was performed on the image for the entire natural region using the spectral signatures collected by the aforementioned procedure. Only those portions of the image mapped as coniferous forest types were classified for tree size. Outputs for illuminated and shaded areas were were inspected visually by comparing the label for tree size with apparent tree size seen on 1:24,000 scale aerial photographs. If necessary, the cluster was relabeled to more accurately represent the observed conditions. If the cluster could not be relabeled adequately, it was flagged as confused and compiled for an additional unsupervised classification.

An unsupervised classification was performed only on the pixels identified as confused in the supervised classification. An iterative approach was used, with each cluster either reliably labeled for tree size or thrown back into another iteration. As many as four iterations were performed to accurately label tree size. If a cluster could not be assigned a reliable label for tree size after four iterations, it was discarded. After all clusters were labeled they were combined and recoded into a single thematic map showing approximate tree size per pixel (Figure 4a).

Labeling of Coniferous Tree Stands for Dominant Tree Size

This hybrid classification scheme utilizing both supervised and unsupervised procedures generated a pixel map of approximate tree size. However, this study was concerned only with tree stands represented by groupings of pixels, not single pixels. Since each polygon represented a tree stand, each polygon was labeled for tree size based on the population of labeled pixels within it (Figure 4b). The simplest method was to assign a size label to the polygon based on the plurality of pixels within it; in other words, the size class with the most pixels in the polygon would be the size label assigned to the polygon. However, due to the regional significance of large sized trees (> 40 " dbh), the classification system was biased to ensure identification of larger trees. Without sensitizing the labeling logic to the largest size classes, it was observed that stands with large trees were missed using simple plurality logic. To account for this, each polygon was first screened for large trees (size classes 7 and 8); if those sizes comprised at least 25 percent of the polygon, it was labeled one of these large sizes. If large trees were not detected in this initial screening, then a simple plurality rule was applied to the pixels within the polygon.

After the polygons were labeled, a map was produced showing tree stands with dominant tree size per stand. Since these tree stands could also be described as regions on a map, this labeling procedure was described as regionalization. The map produced at this point was a preliminary size map (Figure 5).



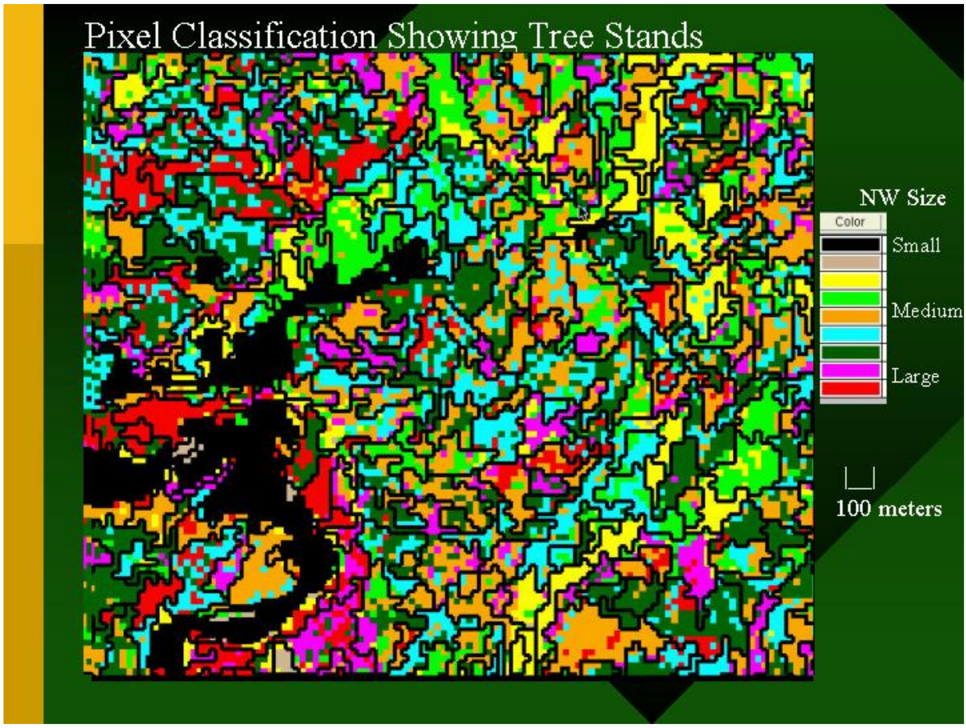


Figure 4a (top) shows pixel classification generated by application of spectral signatures. Shaded and illuminated areas were processed separately.

Figure 4b (bottom) shows delineation of tree stands generated by segmentation. Each stand was labeled for tree size based on the values of individual pixels within each stand.

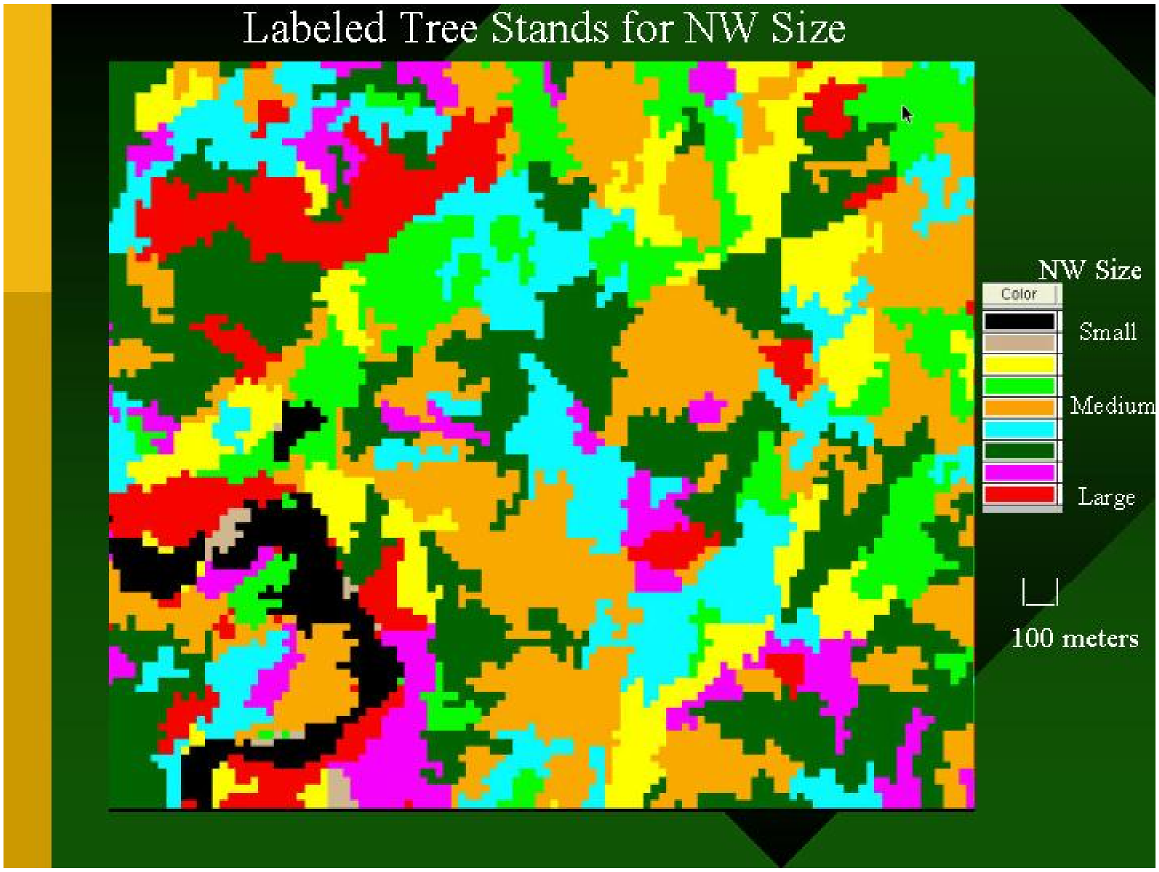


Figure 5. Tree size classification showing labeled tree stands. Since each tree stand in the field represents a region on the map, this product is a "regionalized" version of the preliminary pixel classification.

Field Observation and Manual Editing of the Preliminary Size Map

Selected areas were chosen for field reconnaissance. By comparing actual tree size in the field to labeled size on the map, systematic patterns were recorded and labeling errors were corrected. Tree size measurements in the field were compared with visual appearance of tree size on aerial photos; this relationship aided image analysts in assigning better size labels based on visual inspection of the photos. The preliminary map was updated based on this field information.

The final step in producing this size map was manual editing of polygons based on a systemic inspection of the entire natural region using 1:24,000 aerial photos. Due to the very large number of polygons involved, the analyst focused on complex areas or areas with known confusion. Also, systematic corrections were applied if the analyst noticed consistent problems with a particular size label or ground condition. Once this final manual inspection was completed, the data from all of the natural regions was combined into a single database that comprised the final size map.

DISCUSSION OF RESULTS

The final map of tree stands labeled for tree size showed promising results. A formal accuracy assessment study has not yet been completed, but field inspection and comparison with estimated tree size from aerial photographs indicated that overall accuracy was good. This evaluation was based on the usefulness of the map to foresters and ecologists in watershed assessments. The largest and smallest trees in relatively undisturbed ecosystems were readily identified and mapped with a reliable degree of accuracy. In a broad sense, this classification procedure was successful in delineating large, moderate, and small sized trees; relative accuracy for each class depended on which size classification scheme was used (see Table 1). The identification of mid-range tree sizes displayed more confusion but still tended to be mapped within one size class of ground truth for the middle range of the northwest forest plan size classification (Table 1, column 1). Of course, the accuracy of the map for R5 size classes (Table 1, column 2) was improved simply due to less categorical detail.

Typically, between 10 and 25 percent of the area within each natural region was manually edited to improve accuracy; however, some regions required virtually no editing at all while others had nearly half of the polygon labels manually adjusted. Generally, the natural regions which required more editing contained a greater abundance of land cover types that were also associated with systematic errors. Those systematic errors were noticed in three types of forested land cover: a) heavily harvested areas where second and third generation growth was present; b) strongly shadowed areas where very dense stands of smaller trees were present; c) areas of mixed stands where hardwoods tended to dominate the spectral signature.

Systematic Errors and Probable Causes

The first form of systematic error occurred in areas of intensively managed silviculture, including heavily harvested areas where second and third generation growth was present. The classified image consistently tended to underclass tree size in these areas, which typically contained much shrub with isolated large trees scattered among the smaller trees in various stages of growth. Even though enough large conifers were present to warrant a forester on site to label the polygon for the larger tree size (based on field or photo observations), the spectral signature was still dominated by the larger area of smaller trees or shrub. In addition, isolated polygons within these areas could still be under-classed due to neighborhood effects of the much larger harvested area enclosing it. These harvested areas represented disturbed ecological conditions where extensive early seral patterns of tree growth were present. The relationship of tree size to its immediate surroundings, as reflected in the image data, was in a rapidly transitioning state due to factors such as altered floristic composition, site condition, and ongoing management activity. This successional transition is expected to slow over time; given limited disturbance, the correlation of tree size in a stand to the surrounding ecological conditions is expected to increase and stabilize over several years.

The second type of systematic error occurred in strongly shadowed areas where very dense stands of smaller trees were present. In these areas, the classified map consistently tended to over-class the size of trees present. In some extreme cases, groves of very dense conifers (over 90 percent canopy closure) consisting of very closely spaced size 2 trees were initially classified as size 8 trees. There are probably two reasons for this misidentification. One reason is simply the strongly shadowed nature of the site; much less reflectance also translates to much less information upon which to base reliable decisions. The other reason is likely one of texture; the densely packed small trees could texturally look like branches of larger trees, especially in shaded conditions.

The third type of systematic error occurred in areas of mixed stands where hardwoods tended to dominate the spectral signature. This is not surprising, since this entire classification procedure was designed for coniferous tree stands and based on the structural characteristics of conifers. Hardwood signatures are naturally brighter due to the higher reflectance characteristics of the leaves versus the less reflective needles of conifers. If hardwoods dominate within a mixed stand the signature looks brighter, and this sometimes could be confused with the increased brightness of sparser forest cover; this sparser cover may be interpreted as smaller branches on smaller trees. Consequently, if large conifers are scattered in a moderately dense stand of hardwoods, the conifers will be under-classed.

Observed Patterns: Spectral Reflectance and Tree Size

Significant relationships were observed for both illuminated and shaded areas when spectral signatures for tree size were plotted on a feature space image showing brightness vs. greenness (Figure 6). For illustration purposes, an illuminated area is shown. Forest types in this area primarily occur with moderate to dense canopy closure and are represented by the roughly linear pattern in the center of the plot. All bands have been independently stretched to 8-bit data; for this particular data set, each unit of increasing brightness corresponded to an increase of approximately 1.25 units in greenness. Illumination effects could cause these increases but separating illuminated areas from shaded areas has minimized these effects. The corresponding increase in greenness with brightness inferred that vegetation types were changing rather than a decrease in canopy closure, where there would be no corresponding increase in greenness with brightness. As both brightness and greenness increased for a given illumination and moderate canopy density, the forest types progressed from conifer dominant stands to mixed stands, and finally, to hardwood dominant stands. The relationship between greenness and brightness is not quite linear, as these values increase differently for different vegetation types.

The spectral signatures plotted on Figure 6 display a large degree of overlap with each other. Because of this large degree of overlap, it was important not only to consider the means of the signatures, but also the variances. For example, even when the means of two signatures were similar, they still were correctly differentiated with differences in variance for their respective spectral populations. Given the amount of signatures (typically 50 to 100 signatures for each of the two illumination conditions per natural region), only a small representative portion of the signatures is shown here in order to illustrate observable patterns.

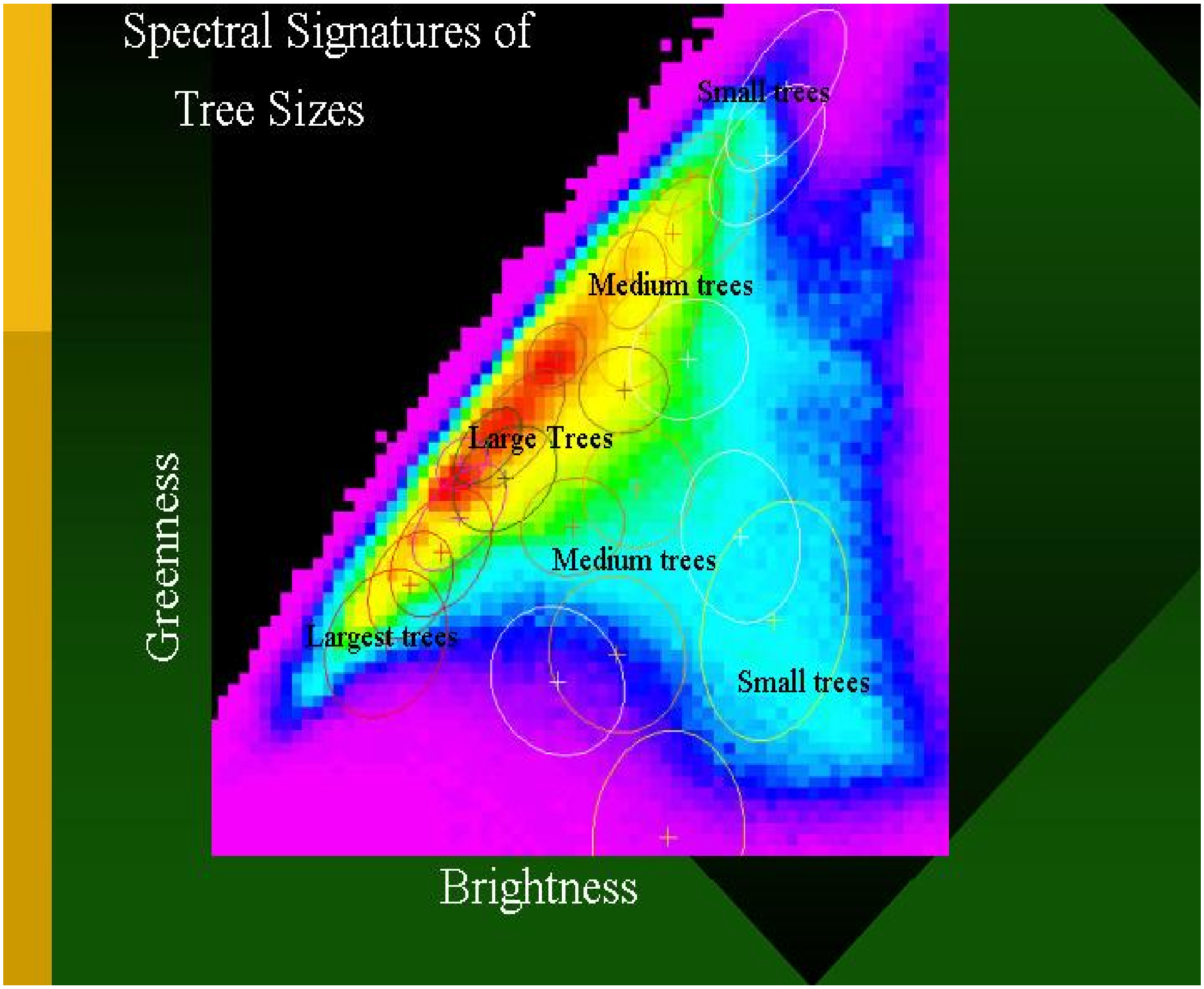


Figure 6. Brightness vs. greenness plot showing representative spectral signatures for tree sizes. Signatures of the largest trees exhibited the lowest reflectance in both of these bands but had the highest greenness/brightness ratios; as this ratio decreased in combination with increasing total reflectance, the probability of large trees decreased.

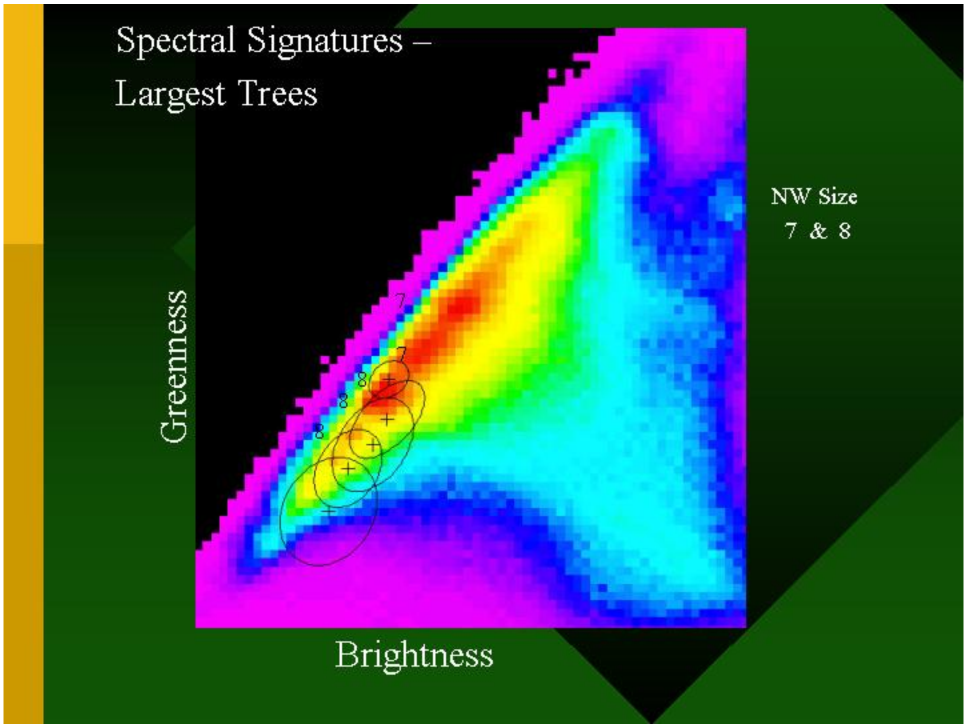


Figure 7a. Brightness vs.Greenness plot showing signatures for largest tree sizes 7 & 8.

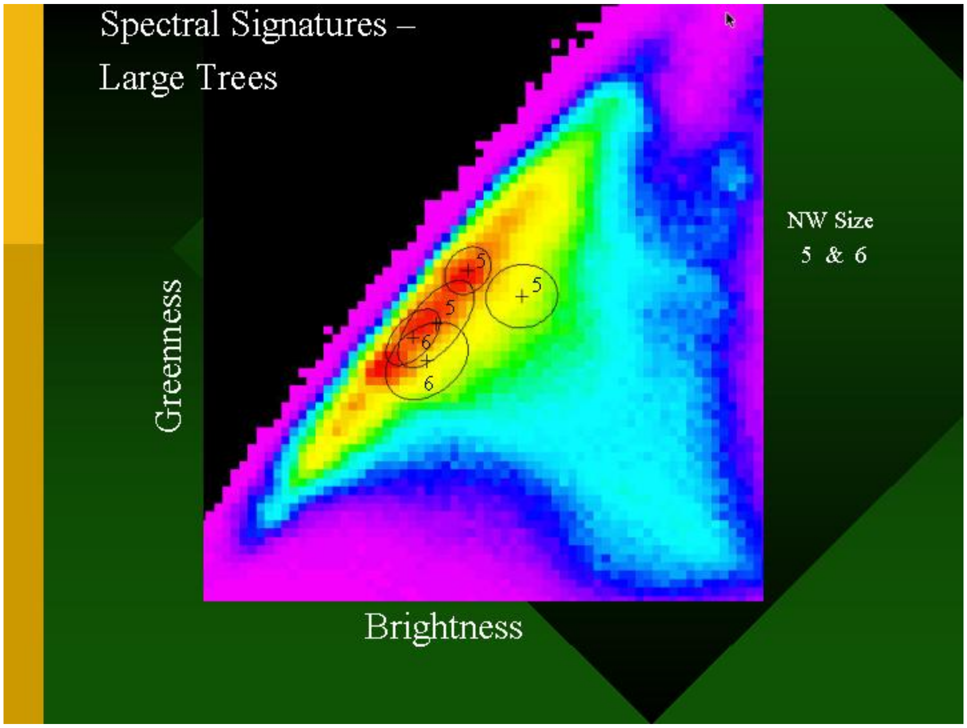


Figure 7b. Brightness vs. Greenness plot showing signatures for large tree sizes 5 & 6.

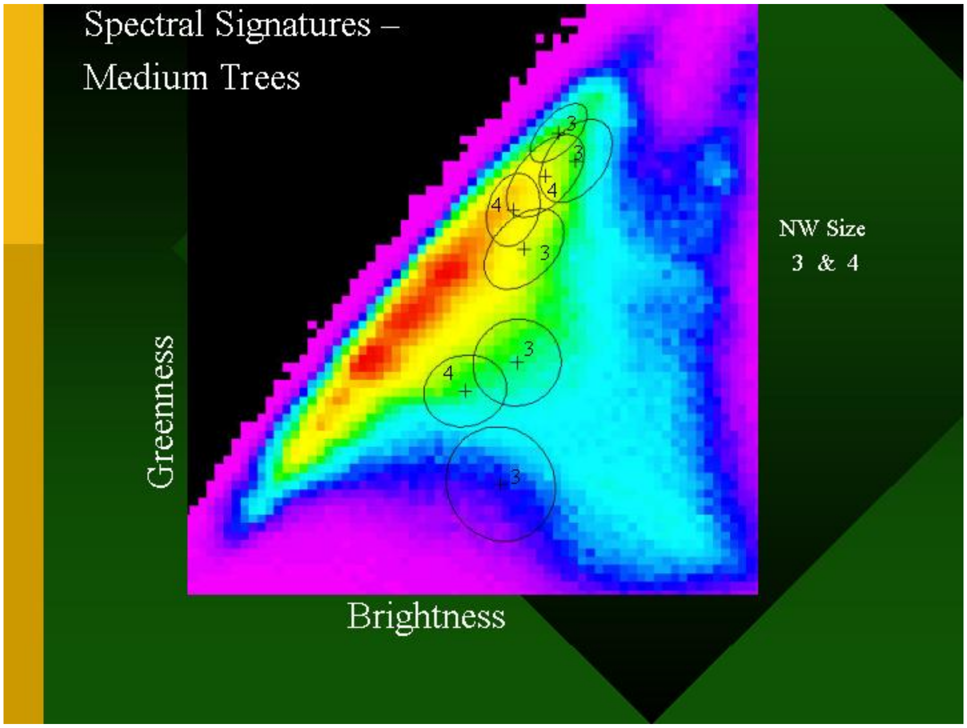


Figure 7c. Brightness vs. Greenness plot showing signatures of middle tree sizes 3 & 4.

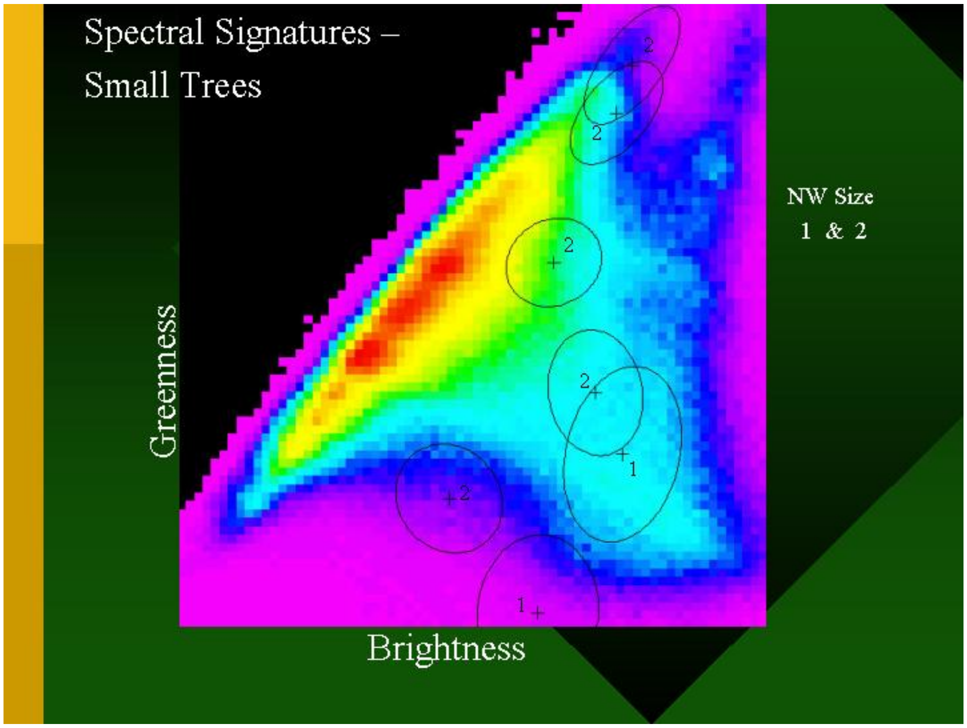


Figure 7d. Brightness vs. Greenness plot showing signatures of smallest tree sizes 1 & 2.

It was observed that all of the large conifer tree sizes (sizes 6,7,and 8) plot exclusively at the lower end of this quasi-linear pattern of brightness vs. greenness. The lower the absolute values of brightness and greenness along this portion of the plot, the more likely that larger trees were present. As the absolute values of brightness and greenness increased, the likelihood of larger conifers decreased (Figure 7). Some of this effect could be explained by the structural characteristics of conifers; larger trees display a larger coverage area of poorly reflective needles. Also, as hardwoods began to dominate the signatures towards the greatest values of greenness, the larger sized conifers were probably restrained due to increased competition for resources; environmental disturbance and management factors may limit the number of large trees present in hardwood stands.

It was also observed that the signature means of all the larger trees display the greatest greenness/brightness ratios; for this particular data stretch, the ratios varied between 2.4 and 2.8. The higher the ratio, the more likely that large trees were present. As this ratio decreased (in this case, below 2.4), the likelihood of moderately sized trees dominating the spectral signature increased dramatically. As this ratio dropped further to its lowest levels (in this case, below 2.2), the likelihood of smaller trees was great. This ratio was reduced primarily as the result of two conditions. If canopy closure remained relatively constant, a significant increase in hardwoods lowered this ratio as brightness increased faster than greenness. But if canopy closure decreased, and soil reflectance added to brightness without a corresponding increase in greenness, the ratio also decreased. Canopy closure could be affected either by decreasing the number of trees present or by reducing the size of a constant number of trees.

A large number of spectral means also plotted far off the quasi-linear trend discussed above. On Figures 6 and 7, these means had low ratios of greenness/brightness (in this case, less than 2.2), and plotted towards the right-hand side of the chart. This portion of the chart contained no large-sized trees at all and was the exclusive domain of moderate and small sizes; the lower this ratio, the smaller the tree size. These signatures displayed lower greenness/brightness ratio due to increased soil reflectance. For a constant number of trees, this means smaller tree sizes; but it could also indicate a lesser number of trees. If the total number of trees dropped below a certain threshold (approximately 20 percent of the exposed ground area), the spectral signature no longer represented the trees present. However, it was still possible to infer the probable size of trees present by considering the surrounding ecological conditions noted below and their relationship to tree size.

Ecological Conditions and Tree Size

In an undisturbed site, tree size is dependent on the ecological conditions within and adjacent to any particular tree stand. As succession of tree species occurs over time, an ecological community in equilibrium with the local environment will be established (Young, 1982). This equilibrium point depends on several interacting factors including, but not limited to, available sunlight, slope aspect and steepness, soil moisture and availability of water, soil nutrients and bacteria, elevation and temperature, growth rates of different tree species, and shade tolerance of tree species. The tree species and their size at any particular equilibrium point reflect the cumulative effect of ecological conditions; the entire ecological community at the site has a unique spectral signature representing those conditions. This signature, therefore, not only includes reflectance of the trees, but also the shrub and plant communities in the understory, soil composition and moisture, and structural characteristics of all species within the community. In other words, in an undisturbed tree stand, tree size is more closely related to the ecological conditions in which it is found; these conditions contribute to the reflectance recorded by the satellite sensor. Separating illuminated from shaded areas has minimized illumination effects. Thus the spectral signature of the associated ecological condition in which the trees are found can indirectly infer tree size, rather than independently detecting tree size alone.

Given the great variety of environmental conditions where each tree size can be found, it is not surprising that many spectral signatures were needed for each size class. Each signature represented another variation conducive to that particular size class. For instance, large conifers were commonly associated with moderate slopes having north-facing aspects, higher elevations, cooler temperatures, and higher moisture retention. The floristic composition of the understory contained species in equilibrium with this environment, and many of these species were far more sensitive to changes in the environment than the conifers. Thus, an adjacent south-facing slope could support the same size conifers, but the type of species and their relative abundance in the understory were different from the north-facing slope. Two different signatures, reflecting these different environments, were needed for each set of ecological conditions associated with these conifers.

As floristic composition and site conditions change with variations in the landscape, limiting factors constrain maximum tree size. Most importantly, age of the stand and availability of resources for the ecosystem limit maximum tree size. Resources include the availability of light, water, and soil nutrients; these limitations affect all species of the ecosystem. Each set of distinct conditions will tend to be associated with a maximum tree size for conifers in equilibrium with the site conditions, and these conditions could be detected with spectral signatures.

Thus, even though LANDSAT TM imagery cannot resolve individual trees, the ecological conditions associated with patterns of tree size can be detected.

This procedure for tree size classification was most inaccurate in areas where the natural ecosystem was disturbed and no longer represented an ecological community in equilibrium with its environment. For this study, disturbance was defined as any activity that results in a significant change in the composition and/or structure of a tree stand; the activity can be natural or caused by humans. The disturbed areas in this study area were primarily associated with extensive harvesting of timber, but also included some changes in land use and recent fires. For example, selective harvesting of timber created some situations where a few very large trees were left standing amid a field of shrub or barren soil. Since the satellite sensor could not resolve the individual trees, the spectral signature was dominated by shrub and soil. Therefore, the area was misclassed as an ecological system containing small trees. However, this environmental situation did not arise naturally and did not represent an ecosystem in equilibrium. The best results for tree size were obtained in areas where tree size could be reliably inferred from its associated ecosystem. If an area had been disturbed from its natural state, the more likely the size classification was erroneous; the more recent the disturbance, the greater effect on size classification.

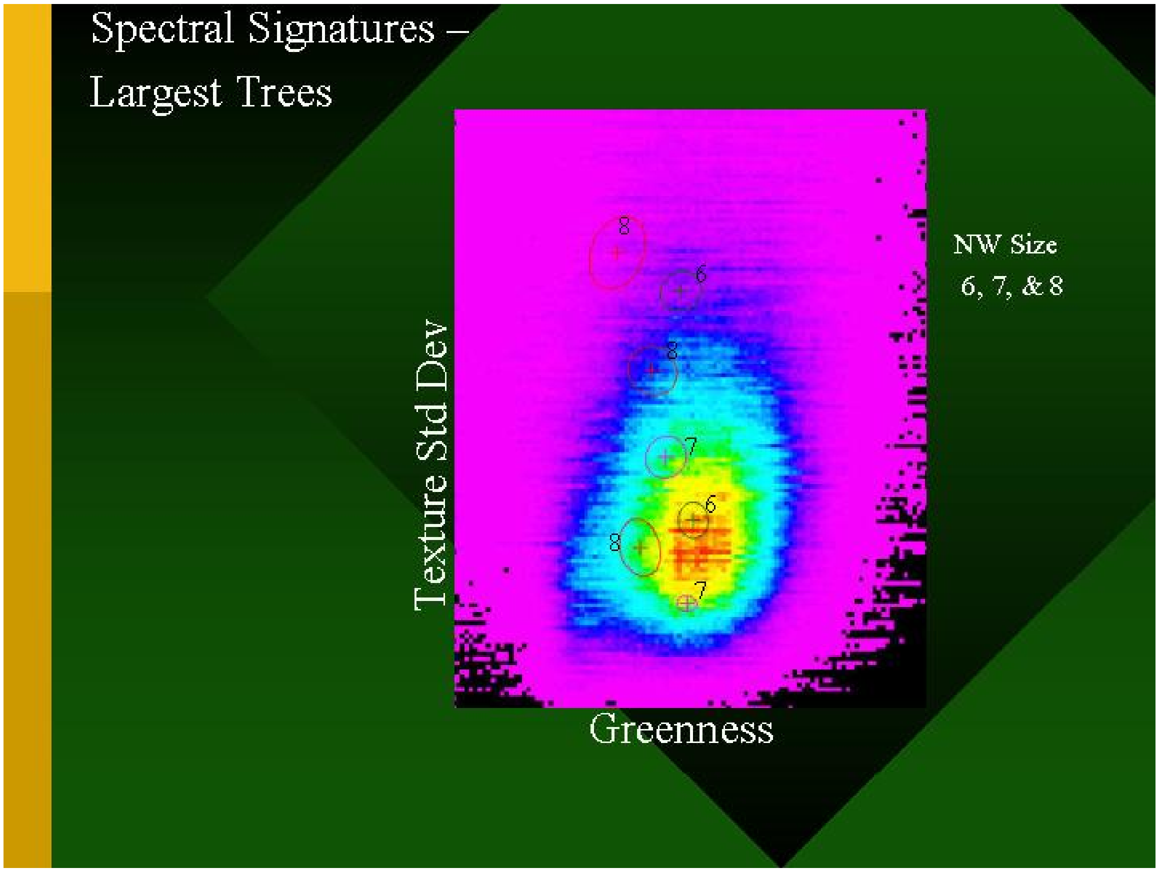
The brightness, greenness, and wetness bands of the tasseled cap transformation detected reflectance of an accumulation of site conditions; tree size was inferred indirectly from the environmental characteristics of that ecosystem. But an attempt to detect tree size directly by focusing on structural characteristics of conifers was performed utilizing additional bands based on textural features of the image.

Image Texture and Tree Size

An attempt to correlate tree size with texture variability per stand was performed by determining the standard deviation of texture values within each polygon and comparing it to the label for tree size. Texture variability was based on TM band 4 reflectance and was observed to be highly correlated with topography or topographic features; the highest values were found along river valleys. Based on this pattern, it was reasonable to hypothesize that the same topographic effects that influenced site conditions affected textural variability; thus, if site conditions were correlated to tree size as argued above, textural variability could also show some pattern with tree size.

The following hypothesis was tested: as tree size increases within a tree stand, the corresponding textural variability per stand increases. The graph of brightness vs. textural variability shown in Figure 8 shows that the spectral signatures of tree size had widely varying values of textural variability that overlapped each other significantly; this graph does not support the hypothesis. There was apparently no simple correlation between textural variability per stand and tree size. Probable tree size could not be predicted based on values of textural variability alone.

However, information on textural variability was still found to be useful in separating stands of similar reflectance for tree size. For example, if two tree stands had similar reflectance in the visual and infrared bands, textural variability was used to separate these stands for tree size. It was observed that two stands of different tree size had different values of textural variability, and these two stands were separated on this value despite the lack of correlation with tree size; textural variability added useful information when the other reflectance bands were unable to distinguish the stands from each other. However, tree size could not be predicted from this textural information alone; other sources of information (such as aerial photos) were needed to label tree size. Thus, stands of very similar reflectance in all bands except textural variability could be separated, visually inspected by comparison with aerial photos, and labeled independently for tree size.



Spectral Signatures –
Largest Trees

Figure 8. A relationship between tree size and textural variability per stand was sought. Textural variability was defined as the standard deviation of texture values within a tree stand; texture was based on LANDSAT TM band 4. The above plot shows greenness vs. texture standard deviation per tree stand with spectral signatures of the largest tree sizes. This plot shows no obvious correlation between tree size and textural data. However, textural data was still useful in separating stands containing trees of differing size; but the textural data alone could not predict the value of tree size.

Since textural information was found to be useful in separating stands of different sized trees, it might be fruitful for future studies to investigate the use of imagery that is sensitive to textural features of the surface. Therefore, radar imagery would most likely provide the most insight into any correlation between textural information and tree size.

CONCLUSIONS

A hybrid classification scheme involving both supervised and unsupervised classifications was able to provide satisfactory results in mapping dominant tree size for coniferous tree stands. Best results were obtained with illuminated areas classified separately from shaded areas. Accuracy was improved with field technicians providing input on observed conditions for training sites and also manually relabelling stands that were known to be in complex areas. A five-band combination, including brightness-greenness-wetness and two texture bands, was found to be very useful in delineating spectral signatures. The final size map indicated improved utility for landscape assessments and land management planning.

The most significant observations of this study were:

1. The largest trees occurred in stands having a relatively high ratio of greenness/brightness with relatively low reflectance of each of these values; as this ratio decreased along with increasing total reflectance, the probability of moderate or small sized trees dominating the stands increased.

2. Spectral signatures most accurately classified tree size in areas where natural ecosystems were relatively undisturbed, or had not been disturbed for many years, and these ecosystems could be reliably correlated with tree size; the satellite sensor most likely detected the cumulative effect of ground conditions associated with ecosystems and tree size could only be indirectly inferred.

3. Systematic errors occurred in areas where: a) harvesting and selective thinning of tree stands was active or recent, b) closely spaced small trees exhibiting very high canopy closure were growing in very shaded conditions, and c) hardwoods dominated the spectral signature.

4. The variability of texture (based on TM band 4) within stands could be a useful parameter in separating stands of different sized trees if other reflectance data cannot distinguish between them; however, textural variability alone could not predict, nor be directly correlated with, tree size.

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