5.0 IMAGING ANALYSIS

Remote sensing images obtained from airborne multispectral scanning, IKONOS satellites and digitized aerial photography were analyzed by D'Appolonia and SenSyTech personnel using the latest version of the IMAGINE software developed by ERDAS. The software, image characteristics, image analysis methodology and results of the image analysis in terms of identified areas of distressed tree canopy are discussed in the following paragraphs.

5.1 SOFTWARE/DATA

D'Appolonia and SenSyTech utilized the IMAGINE 8.4 software from ERDAS for analyzing the imagery obtained for the project. This program has geocorrection, image and spatial analysis, and map making capabilities and is compatible with the most frequently used geographic information systems (GIS) programs. The program normally operates with images in the IMAGINE format (*.img), but is also capable of handling data in TIFF (*.tif) and other formats. The program can convert data from one format to the other and this feature was used to convert some images for presentation using AutoCAD software.

The airborne multispectral scanning imagery provided by SenSyTech was in the IMAGINE format, while the IKONOS satellite imagery and digitized aerial photographs obtained from BAE Systems ADR were in the TIFF format. The airborne multispectral scanning imagery data generally corresponded to an area slightly larger than the study sites and required no modification. The satellite and aerial photograph data were generally received in the form of very large files in the range of 200 to 400 megabytes (Mb) that were subsequently reduced to a much smaller size corresponding to an area slightly exceeding the boundaries of the study sites. The subsetting of these large files resulted in data files in the range of 40 to 50 Mb that were manageable in terms of system capabilities and computing time.

The airborne multispectral scanning imagery and the satellite imagery data were rectified to State Plane coordinates (NAD83) as received and thus could be easily overlaid for comparison using the IMAGINE 8.4 software. The digitized aerial photography was not orthorectified.

5.2 IMAGE ANALYSIS METHODOLOGY

The airborne multispectral scanning data provided by SenSyTech were used to identify areas of stress to the tree canopy. The images used in this process were the following:

- Natural Color
- Color Infrared
- NDVI
- Night Thermal
- Day Thermal

A brief discussion of these types of images is provided in the following paragraphs.

5.2.1 Natural Color

Natural color images are similar in appearance to actual color photographic images and thus the name. On natural color images, healthy tree canopy generally shows up as medium green to a dark, slightly purplish green. Stressed tree canopy exhibits a pinkish or in some cases grayish color that generally stands out from the surrounding canopy. Some nearly pure purple areas were noted on the natural color images and the ground truthing generally indicated that these areas corresponded in part to distressed or dead oak trees, as further discussed in Section 6.0. Some examples of the above conditions on natural color imagery are shown on Figure 20.

Open fields generally have a light green appearance on natural color imagery, and bare areas (no vegetation) show up as white or very light in color. Open areas in the tree canopy can be white, light purple or a more reddish/pinkish color, and care was required in order to distinguish these areas from areas of distressed tree canopy.

5.2.2 Color Infrared

On color infrared images the healthy tree canopy has a distinct reddish tone, while stressed tree canopy shows up as medium green that generally stands out clearly. In some instances the green tends more to gray making the stressed canopy more difficult to identify. Bare areas are generally cyan, but in some cases these areas may be light pink. On the digitized aerial photographs, the healthy canopy is a coral color and the stressed vegetation is green to gray and does not stand out as distinctly. Some examples of the above conditions on color infrared imagery are shown on Figure 20.

5.2.3 NDVI

As discussed in Section 3.1.3, NDVI images used for the project were generated by ratioing a near-infrared spectral band with a red spectral band. Both red and green NDVI images were evaluated, and it was determined that the red NDVI images were slightly better for detecting stressed tree canopy. The red NDVI imagery senses changes in the leaf chlorophyll content and thus shows areas of stressed or dead vegetation. On a red NDVI image, the light areas indicate healthy tree canopy and dark gray or black areas indicate stressed tree canopy. Streams show up as black and bare areas are generally dark. Some examples of the above conditions on NDVI imagery are shown on Figure 20.

5.2.4 Night Thermal

The night thermal imagery is based upon relatively small thermal differences detected in the tree canopy and ground surface during the night hours. Healthy tree canopy can be distinguished from stressed tree canopy because the stressed tree canopy has impaired transpiration and, therefore, will be relatively warmer at night. Higher temperature features show up as light areas on night thermal imagery, and lower temperature features show up as dark areas.

At night streams and roads are warmer than the nearby ground surface and tree canopy and show up as white on the images. Open fields are relatively cold and show up as black. Buildings can clearly be seen on the night thermal imagery and show up as black (in the summer). Topographic variations are frequently evident as the cool air in the valleys shows up as dark, while the relatively warmer air on the ridges shows up as light. In one instance, a mine ventilation facility could be seen on the night thermal imagery as a light area. Some examples of the above conditions on night thermal imagery are shown on Figure 21.

5.2.5 Day Thermal

The day thermal imagery is based upon relatively small thermal differences detected in the tree canopy and ground surface during the daytime. Warmer areas show up as light, while cool objects are dark. Typically roads and other bare areas are light because of heat absorbed from the sun, while streams are cooler during the day and show up as dark at the time of year the imagery was collected. Sunlit areas show up clearly lighter than shaded areas. Thus, topographic high and low areas can be determined from the positioning of sunlit and shaded areas.

Stressed tree canopy should be lighter on the day thermal imagery, because stressed trees are less able to efficiently cool themselves during the day. Temperature variations across the tree canopy are fairly small, as compared with the contrast between roads and streams. Thus, the temperature change in the tree canopy shows up as variations in shades of gray.

5.3 IDENTIFICATION OF POTENTIALLY STRESSED TREE CANOPY SITES

Airborne multispectral scanning images of the 9 selected study sites (3 each at the Bailey, Blacksville and Humphrey No. 7 mines) were analyzed by D'Appolonia and SenSyTech personnel using the ERDAS IMAGINE 8.4 software. The analysis initiated with the opening of the various types of images in a minimum of two viewers. The viewers are software windows in which the images can be displayed in layers. Because of the orthorectification, the images were aligned such that features of interest could quickly be cross-compared between layers and windows.

Using two side-by-side viewers, the images for each site were analyzed by traversing vertically up and down a magnified portion of the image(s) until an anomaly or area of interest was found. Typically, one viewer provided a natural color and infrared image, while the other viewer provided NDVI and nighttime thermal images for the same magnified portion of the site. Anomalous areas believed to exhibit canopy stress were found by repeated comparison of the various images. Identified potential areas of stressed tree canopy were then marked on a paper copy of one of the images.

Identified stressed canopy areas ranged in size from individual tree crowns (large trees) to forest stands extending over areas up to several acres. Small areas of distressed tree canopy were indicated by pinkish zones on the natural color images, by gray or green zones on the color infrared images, by dark gray zones or points on the NDVI images, and to a lesser degree dark or light points on the day and night thermal images. This type of stressed canopy area often appeared to represent individual tree canopies and could be found within healthy stands on ridges, on slopes of any orientation, and at undermined or non-undermined study sites.

Larger areas of stressed tree canopy were sometimes found within circular to elongated forms comprising clusters of tree crowns. Generally the same image anomalies were observed as with smaller areas of canopy stress. For these larger areas, distressed tree crowns were frequently intermixed with healthy tree crowns. The larger areas of stressed tree canopy were generally found at mid- and upper slopes at the study sites.

The imagery was also examined for the presence of linear features that might follow the alignment of longwall mine panels or zones of high strain associated with panel boundaries. No linear features corresponding to the orientation of mine panels or high strain zones were detected. Linear features on the imagery were generally associated with property boundaries, utility cuts and other man-made surface disturbances.

As an example of the identification of potentially stressed tree canopy sites, Figure 21 shows four images (color infrared, natural color, NDVI and night thermal) for a portion of the B-1 study site. Field site B-1-1 is located in the left-central portion of the images and is delineated by a dashed yellow line on the natural color image. An area that has been logged is located on the right central portion of the images and is particularly evident on the night thermal image. Note that roads, streams and buildings are particularly easy to locate on the night thermal image. Also evident on the night thermal image is the topographic effect, i.e., the image lightens at higher elevations and darkens in lower elevations. Areas of stressed tree canopy can be compared on the four images.

Figure 20 shows the natural color, color infrared and NDVI images for the A-1 study site at the Bailey Mine and D-2 study site at the Humphrey No. 7 Mine. Enlow Fork flows through this area and is clearly evident on the images. Because the effects of longwall panel subsidence were particularly evident on Enlow Fork, resulting in the creation of a number of pools in the stream, the tree health immediately adjacent to these pools was studied in the field in addition to identified stressed tree canopy sites. The locations of subsidence-induced pools along Enlow Fork are shown on the color infrared image on Figure 22 by yellow dashed lines. Segments between pools that were used as a basis for comparison to conditions around the pools are shown by white dashed lines and are referred to as Segments 1 to 6.

Figures 23 to 31 show each study site at the three mines. A grid in state plane coordinates (NAD83) is provided on the study site images to allow orientation to USGS topographic maps or other figures or maps. Areas of potentially stressed tree canopy are designated with the study site number followed by a numerical designation of the area (i.e., A-1-1 is the first stressed canopy area at Bailey Mine study site A-1). Because the analyzed images were somewhat larger than the areas defined by the study site boundaries, some areas of potentially stressed tree canopy were identified that were subsequently found to lie outside the site boundaries. Thus, not all of the stressed tree canopy areas that were identified during the image analysis are shown on the figures.

Table 6 summarizes the numbers of potentially distressed tree canopy areas (field sites) that were identified from the imagery and are shown on Figures 23 to 31.

5.4 MULTISPECTRAL SCANNING DATA

The multispectral scanning images provided by SenSyTech and subsequently used for identifying stressed tree canopy sites are provided in Appendix A. For each study site one large natural color image on a single sheet and four smaller images (color infrared, day thermal, NDVI, and night thermal) on a second sheet are presented. The study site boundaries are indicated on the images with an orange dashed line. Approximate mine panel locations are shown on the images in solid and dashed yellow lines.

Comparison of the potential tree canopy stress detected at the younger (mined during 1995 to 1999) and older (mined in or before 1990) study sites with non-undermined control study sites was conducted by viewing the natural color, color infrared, NDVI, and thermal imagery presented in Appendix A. This comparison was aided by ground truthing to associate the pattern or color of distress indicated in the imagery with the type of trees and observed canopy stress in the field.

The primary type of distress observed at the Bailey and Blacksville mines was leaf browning and defoliation due to insect infestation, particularly in black locust and elm trees. Figure 32 presents a comparison of the imagery for selected field sites with insect infestation at the three Bailey Mine study sites. The area encircled on each panel is the position of the tree survey; the actual distress is more extensive and the field site limits include a substantial portion of the panel. The black locust and elm tree distress is most evident in the natural color and color infrared images, discernable in the NDVI, and difficult to distinguish in some cases in the thermal imagery. Similar characteristics are evident, whether over younger or older study sites or control study sites. Similar insect infestation stress is evident at the three study sites for Blacksville Mine, as shown on Figure 33.

At the Humphrey No. 7 Mine site, areas of canopy stress were frequently determined to be the result of branch dieback associated with oak, aspen, and maple trees. Figure 34 presents a comparison of the imagery depicting this type of stress at the younger and older undermined study sites and the non-undermined control study site. While canopy stress is less distinct on the natural color and color infrared images, as compared to insect infestation at the Bailey and Blacksville mines, the canopy stress on the NDVI and thermal imagery is more distinct. The appearance of this type of canopy stress is similar, whether at the younger or older undermined study sites or the non-undermined control study site.

5.5 REPLICATE COLOR INFRARED IMAGERY

Color infrared images for each study site were obtained for at least three of four time periods during the summer of 2000. A summary of these images indicating the mine, time period and source of the image is provided in Table 7.

Figures B-1 through B-9 in Appendix B show the color infrared imagery for each study site at each of the three mines. The approximate boundaries for each study site are shown as orange dashed lines on the images. Clouds and associated shadows are present to varying extents on the satellite imagery.

Note that colors vary somewhat from image to image. The reason for the tonal variation relates to the angle of the sun, the photographic angle, reflectance and atmospheric conditions, which are never identical for images obtained at different times[18]. The IMAGINE software was used to minimize tonal differences. Tonal variation is most noticeable in the digitized aerial photographs, which have more subdued colors. Some distortion is evident when the various types of images are compared, and this distortion relates to the origin of the images. For instance, the multispectral scanning data are orthorectified, while the digitized aerial photographs are not rectified to any coordinate system.

Figures 35 and 36 show enlarged color infrared images of some of the field sites identified with stressed tree canopy. Figure 35 shows field sites B-1-1 and B-3-3 on July 2, July 25, August 30 and September 22, 2000. The images show a clear progression of the canopy stress over the nearly three-month period covered by the images. This progression is related to insect infestation that became more severe as the summer progressed. No difference between undermined and non-undermined control study sites was observed in this regard. Figure 36 shows the same progression for field sites B-2-2 and B-2-6. Three color infrared images for field sites A-1-1 and A-1-2 are also shown on Figure 36, but the progression is less clear because of tonal differences between images.

By contrast, stressed canopy not related to insect infestation (e.g., branch dieback) was not observed to change on the multispectral imagery, satellite color infrared imagery and digitized aerial photographs.