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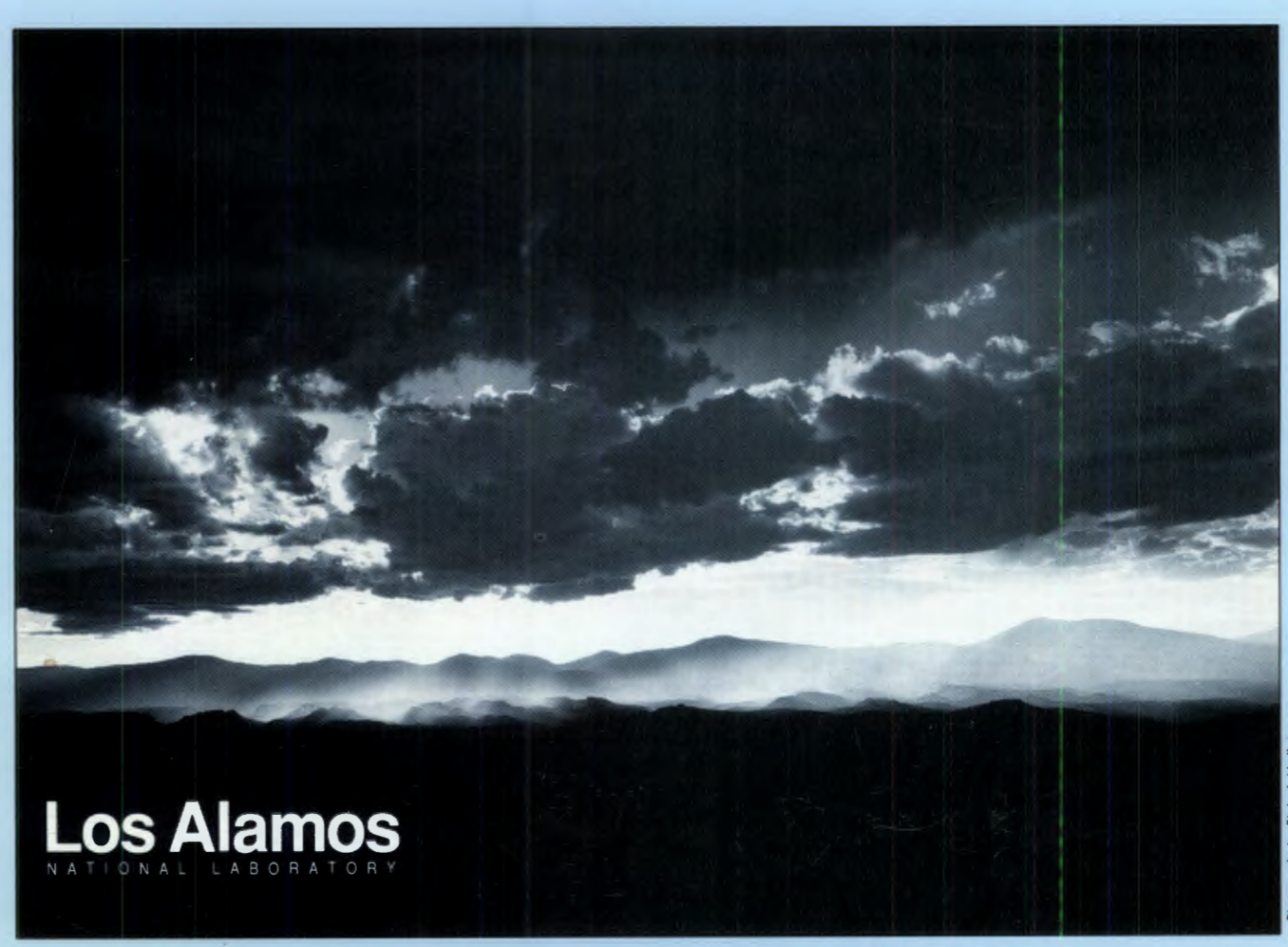
Pilot Study to Evaluate the Use of Microhabitat Plant Species Characteristics for Predicting the Presence of Jemez Mountains Salamander (*Plethodon neomexicanus*)

Authors

Juanita A. R. Ladyman and
Marilyn Altenbach



Photograph: by Chris J. Lindberg

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Pilot Study to Evaluate the Use of Microhabitat Plant Species Characteristics for Predicting the Presence of Jemez Mountains Salamanders (*Plethodon neomexicanus*)

by
Juanita A. R. Ladyman, Ph.D. and Marilyn Altenbach, B.S.

Introduction

This pilot study tested two hypotheses. The first was that the microhabitat of Jemez Mountains salamanders (*Plethodon neomexicanus*) can be characterized by other life forms that specifically require similar environmental conditions. It is believed that the Jemez Mountains salamander needs a damp, relatively cool environment, and many cryptogam species, e.g., foliose lichens, also need such conditions. The second hypothesis was that areas of high phyto-diversity are the preferred salamander habitat.

The project consisted of two interlinked parts. The first was to characterize and compare the ground cover, especially the cryptogamic cover, of transects that were laid in areas where salamanders were known to be either present or absent. The second part of the project entailed photographing defined areas and characterizing and comparing the spectral profiles of those areas. The aim of the latter procedure was to make the process more objective and less reliant on expert biological knowledge.

A very good start was made in identifying some of the microhabitat characteristics of Jemez Mountains salamander habitat. In general, lichen and moss species were both in greater abundance at the sites where Jemez Mountains salamanders were found. In addition, a greater cover of foliose rock lichen was found at the salamander positive sites. The higher cover of lichen at the positive sites agreed with the initial hypothesis in that foliose and fruticose lichens were expected to be higher at more moist sites, but black crustose rock lichens were expected to be less at these sites. The model that has been developed needs to be improved, and one important future addition to the model may be to add foliose rock lichen. This lichen was not included within the framework of the current model. A preliminary attempt to use owl scat, elk scat, and cow dung as indicators of disturbance and biodiversity led to no statistically significant conclusions, but there was indication that there was more owl and elk scat at positive sites and no cow dung.

A simple model was developed to predict the likelihood of finding salamanders. The model included gravels (2 to 6 cm diameter), stones, wood (~30 cm to 1 m), total *Cladonia* (all species), total *Peltigera* (all species), total moss (all species), litter/basal vegetation, grass canopy, forb canopy, and shrub canopy. It was noticed however that the moss species should really be defined in the model, and that this definition would be an important future refinement. There are several indications that the areas that definitely do not have salamanders may be easier to predict than those that do, and it may be that that is the best approach when modeling predictors of habitat for management purposes.

The results from the image analysis work hint at the possibility of using digital images for habitat screening. Environmental conditions affect the spectral profiles of the sites. Cluster analysis made on "normalized" histograms with the gray levels from 220 to 255 removed to avoid the artifacts from sun flecks gave the most promising results. Using the correlation coefficient distance and complete linkage, the histograms from the green and blue bands sorted into two clusters. In each case, approximately (greater than) 90% of negative quads were in cluster 1 and approximately (greater than) 90% of the positive quads were in cluster 2. After sorting the red band histograms into two clusters, there were only six images in the second cluster, one of a negative quad and five from positive ones. In our studies the histogram pattern from the red channel was most affected by environmental (e.g., wet or dry) conditions. Green and blue band histogram characteristics appear to have some ability to discriminate between positive and negative sites. These are surprisingly promising results that should be confirmed and

extended by a more thorough analysis and testing in the field. An important additional analysis that may be useful to perform on this data set is to apply exactly the same analyses on the single sub-quads rather than on the color band histograms of the whole quad images. This would be directly equivalent to our observations on the ground cover components. Our experience indicates that an important addition to the experimental protocol should be to include a standard color and intensity chart in the photograph at the time of taking the picture.

Positive transects were recorded as those with a salamander(s) found within 50 ft of the transect in the summer of 1997. This was rather arbitrary and it is a reasonable criticism of the study. By measuring cover and taking photographs of the exact sites where salamanders were (and were not) found we may find even stronger predictive power.

Even though the number of cryptogamic species at each site was very similar, the actual species differed. A method to determine a biodiversity index incorporating cryptogams could be investigated in a more lengthy project.

Methods

Initially, it was decided to select five sites where relatively high numbers of salamanders were previously detected and five areas where no salamanders had been found. This selection was to be paired with respect to elevation and aspect. When the sites were examined in detail one of the best positive salamander sites (i.e., one that had been consistently inhabited by many salamanders) had no equivalent site (with respect to elevation, etc.) where salamanders were absent. Even so, this site was included so that, before surveying for salamanders, six sites where relatively high numbers of salamanders were previously detected and five areas where no salamanders had been found were selected. Three transects at each of the 11 areas were established. The sites are located on the maps in Appendix A.

At each of the six sites there were at least three discrete areas where salamanders had been found in the past. At each of these three areas a 2-m-long transect was laid. The ground cover along the transect was recorded using a frame (0.25 x 0.5 m) that was divided into four subquads (0.25 x 0.125 m). There were thus 16 "subquads" per transect in which percent cover was estimated. At the Dome sites where there was a high degree of cover variation, four transects were laid.

The cover studies were made in June and July. In August, as the conditions became suitable, surveys for salamanders were made. Salamanders were found on seven of the sites and only five were negative. One of the areas where transects had been established was slightly farther up a slope than where a previous, negative survey had been made. At one site one of the three transects was not found by the salamander search crews and eliminated from the analyses. It was decided that a positive transect would be one where salamander(s) were found within 50 ft of the transect. This was somewhat arbitrary. On one transect a salamander was actually found on the transect. A summary of salamander presence at the sites and at what distance away from each transect is given in Table 1. Using this criteria for determining "salamander presence," there were 17 transects that were positive for salamander presence and 17 that were negative.

The cryptogam cover was primarily divided into the life forms moss, algae, and lichens. Lichens were subdivided into *Cladonia* species, *Peltigera* species, *Psoroma hypnorum*, *Psoroma*-type species, rock lichen, and tree lichen. The rock lichens were subdivided into orange crustose, black crustose, gray crustose, green crustose, cream foliose, and green foliose rock lichen. Tree lichens were subdivided into *Usnea* and other. Cryptogam specimens were collected and genus and species identification have been made where a particular species is abundant and easily identified by a nonspecialist. Simple chemical tests were used to identify some of the species. Vascular plants were divided into forbs, grasses, and shrubs, and species identification was made where there were sufficient plant organs available, i.e.,

sometimes a species could not be determined without the flowers and/or fruits. Woody debris, litter, gravels, soil, rocks, and other ground cover were also recorded.

Tree canopy cover was measured using a concave spherical densiometer. The operator held the densiometer level at waist high and stood facing, sequentially, north, south, east, and west. Slope was also measured at each site, and the primary and secondary aspect of each transect were also recorded. Species richness, i.e., the number of species per transect, was also determined for each site and analyzed by analysis of variance. Pearson's correlation and Spearmans rank correlation were used to measure the covariation occurring at the sites.

A color photograph was taken of each quad and transferred to a CD-ROM. The spectral analysis of the quads by a variety of methods is described later in the report.

Results

Analysis of Microhabitat Cover and Characteristics

Data were collected for a total of 28 variables that comprised the microhabitat features of the sites (see Table 2). Each variable was not necessarily present at each site. Nonparametric methods were used to analyze the cover data. Transformation of the data (by square root and arcsine transformation of the square root) was considered but manipulation did not change the data in a way to permit parametric analysis of variance.

The presence of fruticose (e.g., *Cladonia*) and foliose (e.g., *Peltigera*) lichens tend to indicate more moist habitats. These life forms were predicted to colonize the same habitats as the Jemez Mountains salamander. Therefore, the first question was: Is the cryptogam abundance, especially foliose and fructicose lichens, higher at the sites that had salamanders present?

Positive transects were recorded as those with a salamander found within 50 ft of the transect in 1997. Comparing all positive (i.e., with salamanders present) to all negative transects, there was statistically significantly more total terrestrial cryptogam cover on positive transects (see Table 2 and Figure 1). The more abundant and ubiquitous terrestrial cryptogams were *Cladonia* species, *Peltigera* species, *Psoroma hypnorum*, and the mosses that preliminarily were lumped together. The most abundant *Cladonia* species included *C. chlorophaea*, *A. cariosa*, and *C. coniocraea*. The *Peltigera* species observed included *P. canina*, *P. aphthosa*, and *P. horazontalis*. To see these species see the photographs at the end of the report in Appendix B.

When considering the individual components there was statistically significantly more *Cladonia* on the positive transects (See Figure 1). The salamander-positive sites tended to have more *Peltigera* cover but the difference was not statistically significant at the 5% level. However, after the probability of a difference was adjusted for ties in the Kruskall-Wallis test, there was a statistically significant probability that there was more *Peltigera* on positive sites at the 0.07% level. Moss cover was variable depending upon the site. Overall there was more on the positive transects. There were two species that were the most common. In the field they were designated A and B. A is *Hypnum revolutum* and B is *Dicranum rhabdocarpum*. When the cover of these two species were compared individually it was observed that there was comparatively more *Hypnum revolutum* at the positive sites but more *Dicranum rhabdocarpum* at the negative sites (for photographs see Appendix B).

Lichen cover of the rocks, stones, and gravels was also recorded. Overall there was no difference in the cover of rock lichen between positive and negative transects (Figure 1). Rock lichen comprises two life forms, foliose and crustose. The former tends to be found in more moist environments than crustose forms. There was no difference in the total crustose lichen cover on positive or negative transects but statistically more foliose lichen was found on positive sites (Table 2). Foliose lichens were mostly of the

Parmelia type. This observation is in agreement with the original hypothesis that salamanders inhabit moist habitats where foliose lichens would also occur. The crustose lichens were divided according to color. It was observed that there was comparatively less green-colored and black-colored crustose lichen on positive transects (Figure 2). One would expect black-colored lichens to act as heat sinks. It is unknown whether the lichen colors affect the heat capacity of the rocks.

Differences in the cover of the other variables are described in Table 2. It is notable that the litter/basal vegetation cover of salamander-absent transects are statistically significantly higher than the salamander-positive transects. Canopy of grass and forb overall were, statistically, about the same between positive and negative transects. However, individual forb canopy differed. One forb that was relatively abundant and ubiquitous was *Fragaria americana*. This abundance was unlike many of the species that tended to occur at only one or two transects. For example, the fern *Cystopteris fragilis* was found only at the positive salamander sites at Oat Canyon, *Pyrola chlorantha* only at 90A (positive), and *Linnea borealis longiflora* was found only at site 379 (negative), although it was in the vicinity of site 69 (positive) but off the transects. *Fragaria americana* covered significantly more of the negative transects (Figure 2).

Cover of transects was compared among sub-quads at each of the five sites where transects had originally been paired. Unfortunately, there were uneven numbers of transects at the sites that proved to be either positive or negative. I feel that these individual comparisons are not that helpful. The probabilities, using the Kruskal-Wallis test, that differences exist between the two types of transect are tabulated in Table 3 for reference. The differences observed at each site match, for the most part, the conclusions when all the data were considered. At first it seemed that there was one inconsistency at the Dome site. There was a significantly greater abundance of moss on the negative transects than on the positive transects. The only moss that was on the negative transects was moss A. Therefore, the discrepancy between the Dome site results and the overall conclusion that there is greater moss cover on positive sites is not inconsistent. The overall conclusion was that moss A was found in greater abundance on negative transects. The Dome sites differed from the other sites as the area had experienced a light and patchy burn. How this affects the cryptogamic community and the salamander abundance in the long term could not be judged.

The amount of open canopy over each transect was measured using a densiometer. The data were transformed taking the square root of the value and then the arcsine. In this way the values conformed to normality and were analyzed by an analysis of variance. Although the salamander-positive transects tended to be more open, except in the southern aspect, the differences were not statistically significant (Figure 3). Slope was also not different between the two types of transect (Figure 4). The primary aspect was similar between the two classes of transect. Using the Kruskal-Wallis test to analyze for differences in the secondary aspect (because of non-normality of the data), the probability that a difference existed between the two types of transect was significant at the 9% level (Figure 5).

Correlation

Pearson's and Spearman's rank correlations were made between the various co-variates. There was agreement in statistical significance and in the relationship between both methods. Not surprisingly, the cryptogamic cover components were all positively correlated as many cryptogams grow together. It is not unusual to find two species of lichen and three species of moss in a 4-cm^2 "carpet" of cryptogams.

The correlation between litter/basal vegetation and total *Cladonia* (Spearman rank correlation = -0.28; P = 0.0000), total *Peltigera* (-0.13; P = 0.003) and, especially total moss (-0.33; P = 0.0000) was statistically significantly negative. This negative correlation was not universal for cryptogams as there was no relationship between *Psoroma* and litter/basal vegetation. Generally, there were no relationships or weak negative relationships between the cover classes. Spatial considerations tend to make negative relationships among cover classes unsurprising.

Grass canopy cover was statistically significantly negatively correlated with total *Cladonia* cover (Spearman's rank correlation = -0.15; P = 0.0006) and to a lesser extent moss (Spearman's rank correlation = -0.09; P = 0.03), and forb canopy (Spearman's rank correlation = -0.12; P = 0.004). Forb canopy cover was also statistically significantly negatively correlated with total *Cladonia* cover (Spearman's rank correlation = -0.09; P = 0.036), but shrub canopy was statistically significantly positively correlated with both total *Cladonia* cover (Spearman rank correlation = -0.13; P = 0.003) and total moss cover (Spearman's rank correlation = -0.11; P = 0.01, respectively). As litter/basal vegetation is strongly negatively correlated to certain cryptogam components, it seems that it is the grass and forb components that are "avoided" by the cryptogams. Shrub cover may provide shade. Table 4 outlines the Pearsons correlation coefficients for selected covariates.

Microhabitat Model

Discriminant analyses and linear binary logistic regression were used to begin to model the microhabitat features of the two transect categories. Various covariates were tested using linear binary logistic regression methods. See Table 5 for examples of the different variable combinations that were examined. After considering all the covariates and then assessing the time constraints, the course of action that was taken to choose those covariates that were different between the positive and negative transects.

Therefore, the following rational was used in developing the current model. First, all those covariates that were statistically significantly different, i.e., gravels (Grvl6; 2 to 6 cm diameter), stones (Stn15), wood (Wd12; 12 in. to 3 ft; ~30 cm to 1 m), total *Cladonia* (Totcla), total *Peltigera* (Totpelt), total moss (Totmoss), litter/basal vegetation (Littrbv), grass canopy (Cangrs), forb canopy (Canfrb), and shrub canopy (Canshb) were tested. After the first analysis using all these covariates (predictors) was made, Totmoss was eliminated, and it seemed no discrimination was lost between plus/minus salamander transects. After eliminating Canshrb, it seemed there was again little loss in predictability (the log-likelihood difference generated a Chi^2 value of less than 3.841). A fourth analysis when both wood (Wd12) and litter/basal vegetation (Littrbv) was eliminated made it a much worse model (Chi^2 value = 12.7). Also the number of concordant pairs dropped (see Table 5).

Before testing this abbreviated model with a classification table. Discriminant analysis methods were also considered. The first combination of variables, "Grvl6, Stn15, Wd12, Totcla, Totpelt, Totmoss, Littrbv, Cangrs, Canfrb, Canshb" gave slightly fewer correct assignments than the model without Totmoss; 332 as compared to 339. Eliminating Canshrub decreased the number of concordant values by one. See Table 6 for results of some of the discriminant analysis results. The output from the discriminant function analysis from the statistical package, Minitab, was a little different than the standard textbook description.

The current model comprises gravels (Grvl6; 2 to 6 cm diameter), stones (Stn15), wood (Wd12; 12 in. to 3 ft; ~30 cm to 1 m), total *Cladonia* (Totcla), total *Peltigera* (Totpelt), total moss (Totmoss), litter/basal vegetation (Littrbv), grass canopy (Cangrs), forb canopy (Canfrb), and shrub canopy (Canshb). Using this model the equation is thus:

$$\text{Log}\,(P_{finding}/1\text{-}P_{finding}) = 0.0049 + 0.0465\,(\text{Grvl6}) + 0.034\,(\text{Stn15}) + (-0.02\,(\text{Wd12})) + 0.04\,(\text{Totcla}) - 0.088\,(\text{Totpelt}) + 0.004\,(\text{Totmoss}) + (-0.009\,(\text{Littrbv})) + 0.059\,(\text{Cangrs}) + 0.011(\text{Canfrb}) + 0.003\,(\text{Canshb}).$$

Using this model with an observed set of parameters, the classification table (Table 7) indicates that, if the predicted probability level for finding salamanders is 0.45 and we use the cut off of 0.5, we will correctly classify 60.1% of the sites with a false positive rate of 37.6% and false negative rate of 41.5%. Using a cut off of 0.2 probability level, the number of false negatives drops to 22.2%, but false positives rise to close to 50%.

At the present time, the Grvl6, Stn15,Wd12, Totcla, Totpelt, Littrbv, cangrs, Canfrb, Canshb model is considered the best combination of predictors, but this model was built from a very small sample and obviously needs to be improved. Covariates (predictors) may need to be either added or eliminated. For example, foliose rock lichen and some other parameters have not yet been tested within the model.

Considering the above model, the number of mismatched sub-quads on a transect was plotted against the approximate distance the salamanders were found from that transect. There was a trend of the mismatches increasing as the salamanders were found at increasingly farther distances away. However, the transects at 50 ft from the observed salamanders broke the trend (Table 8 and Figure 6). It is a concern, however, that the microhabitat features of positive salamanders sites are "diluted" by the way positive sites were assigned.

Species Richness

Species richness was estimated by counting all the species that occurred on the transect and determining if there were more species on positive transects. This criteria does not meet the strict definition of species richness as defined by Grieg-Smith (1983). However, our hypothesis was that there was a greater diversity of plant species, i.e., species richness, at the positive sites. On average there were a total of 14.5 species on all the transects with 5.8 species of vascular plants on the negative transects and 5.2 species on the positive transects. As the numbers suggest, there were no significant differences between the positive and negative. When the results were plotted graphically, it was obvious that the total number of species per transects was highly variable and that there was no relationship between number of species and the transect category (Figures 7a and 7b and 8a and 8b). In addition, the total number of species was plotted against the distance from which the salamander(s) was found and no clear relationship could be observed. The number of species recorded is of course very dependent upon the time of year that the data was collected and may not reflect the true diversity of either class of site.

Another element of biodiversity in the community are the tree lichens. These are lignicolous, or lichens that prefer wood as their substrate. Lichens that dropped from the tree branches on to the transects were recorded. It is understood that this is unlikely to be a very sensitive measure of the amount and variation of lichens in the trees but served as a crude measure only. Three tree lichens were identified: *Usnea arizonica*, *Pseudevernia intensa*, and another *Usnea*, preliminarily identified as *Usnea cavernosa*. The southwestern *Usneas* can be quite difficult to identify, and the chemical tests on the latter were not conclusive and need to be confirmed. The total tree lichen cover on the transects were approximately the same and were not different between the transect categories.

In order to explore the concept that salamanders are likely in a more bio-diverse habitat, scat from elk, owl, and cows was noted when found on the transect. Statistically, the significance was absent, but it was notable that at the positive sites there was numerically more elk and owl scat but cow dung was absent.

Spectral Characterization of Transects

A photograph was taken of each quad that was subdivided for cover estimation into four sub-quads. At the present time, time constraints have made it possible to only analyze each quad, i.e., essentially pooling the information for each of the four sub-quads. Photograph A in Figure 9 shows a typical quad. The photograph was cropped to isolate the interior of each quad using Adobe PhotoShop 4.0 software. Photograph B shows the cropped photograph used for processing.

The program to process the photographs was developed in Khoros Version 1 software. The photographs were analyzed such that the histograms of blue, green, and red spectral bands were generated for each quad. The initial program (Figure 10) generated histograms, but on closer inspection some of the histograms had spikes which were probably due to quantization problems in the digitization process.

Median filtering was applied to smooth the curves and reduce the artifacts in a second program that was used on the quads. This program is described in Figure 11. In order to standardize the data the number of pixels at each of the 255 intensity levels was converted into a percentage of the total. Figure 12 shows a sample of the original spectra generated and the spectra after median filtering was applied. Histograms were thus generated for each quad for each Red (R), Green (G), and Blue (B) color band. An additional test was made to determine the cause of the spikes in the histograms. Using a different slide scanner, two slides were scanned and color band histograms generated. Photographs of the original and second scans are in Figures 13 and 14, respectively. The original and second histograms are presented in Figures 15 and 16. What is obvious is that the scanning procedure has significant effects on the spectra generated. The spikes were significantly fewer in the histograms from the "second scan" images, but the color spectra have shifted to lower intensities (grey levels) and the shape of the curves changed. The X-axis in all the histograms have been assigned the label "intensity." Another designation may be gray level; brightest being 255 and darkest being 0.

To determine the effects of weather conditions on the photographed quad, and thus the spectral histogram, a transect on the Guaje trail (84A) was read two times specifically in dry conditions (June 30) and after a few rainstorms (July 10). For comparison of the quads, see photographs a-d in Figure 17. Between the first set of photographs and the second, i.e., during the intervening ten days and at least two rainstorms, it is clear that some disturbance of the ground cover occurred. The profiles of the green and blue spectral bands looked a very similar shape for all transects and between both dates (Figure 18). The histogram profiles of the red band appears to be more affected by environmental conditions. The easiest way to observe this is to compare the purple "x" line to the deep red closed circle in Figure 18. These were histograms of the same quad photographed at the different times.

Uneven sunlight illumination was also a problem. On transect B in site 412 the photograph in Figure 19a shows sub-quads 1-4. The resulting histograms for all the spectral bands have a sharp peak at the high intensity region, which is intuitively expected after looking at the photograph in Figure 19a. By eliminating the first quad, the shape of the histogram remains but the artifactual high-intensity regions are eliminated (see Figure 20). Uneven sunlight flecks such as those in the photograph in Figure 9 were examined. Figure 21 shows the spectral histograms for sub-quads 9-12 on transect A site 977 (Photograph 19B). In this case, the red spectral band is affected much more than the other two bands, i.e., there is a peak at the higher intensity region.

Photographs were also taken with and without a flash. Firstly, it was thought that a flash may be necessary to clearly see certain features in shaded areas and also that a flash may mimic different light conditions and so estimates of variability can also be made. Unfortunately, it was impossible in the amount of time available to visit all transects twice as was done for transect A at site 84. The photographs A and B in Figure 22 show the sub-quads 13-16 at site 412, taken without and with a flash. Similarly, the photographs in Figure 23 show sub-quads 13-16 on transect B at site 82 (Posos) taken without and with a flash. The different histogram profiles are described in Figure 24 for sub-quads 13-16, transect A on site 412. In this case, the red band histograms look the least affected and in general, the flash did not appear to greatly affect the resultant histograms. This is in contrast to the histograms, shown in Figure 25, of the photographs of site 82 transect B, sub-quads 13-16 that had more green canopy color (see Figure 23). A flash greatly changed the green band and the shape of the blue band histogram; the red band shifted but seemed to be the least affected (see the histogram in Figure 25).

Magnification of the original image is another important consideration when comparing the photographs. Small sections that were covered by cryptogams were cropped from the photographs. This served two purposes. One was plainly to see the spectral profiles of a pure cryptogam "stand." The second was to see how magnification affects the histogram profile. A patch of *Cladonia* and moss was "cropped out" of sub-quad 4 on transect A at site 82 from two photographs of sub-quad 4. One photograph was taken as all the others were taken, i.e., of all 4 sub quads (Figure 26). The other photograph was taken of only quad 4 at a higher magnification (Figure 27). These two cropped images were exactly equivalent with respect to the

contents. The cropped images were then analyzed to characterize the moss/lichen spectral histograms. The histograms are shown in Figure 28. The profiles are about the same shape, but the curves shifted along the intensity scale, 13 levels in the case of the red band and 10 levels in the case of the green and blue bands.

Other portions covered by cryptogams were cropped as shown in Figures 29, 30, 31, and 32. Looking at the same patch of *Cladonia* and moss as in Figures 26 and 27, an image was "cropped out" of sub-quad 4 on transect A at site 82. Unlike the images of Figures 26 and 27 these areas were only approximately the same with respect to the contents of the cropped image. The cropped images were then analyzed to characterize the moss/lichen spectral histograms. The histograms are shown in Figure 33. The profiles are, once again, about the same shape but the curves shifted along the intensity scale, 14 levels in the case of the red band, 17 levels in the case of the green band, and 17 levels in the case of the blue band. This indicates shifts of intensity are very common amongst the similar images of different magnification and that small changes in the cropped image will result in shifts along the intensity scale.

The histograms in Figure 34 describe other cryptogam matches. "MossCla" denotes patches of moss and *Cladonia* and "MossPel" the patch of moss and *Peltigera.* The red and green bands were the most similar. The comparison of these bands lead one to consider which are the best to use when looking at similarities and differences between transects with or without salamanders. This information would be most useful where comparing all the sub-quads.

The first pass of image analysis was to compare all the histograms of the salamander-positive and negative transects as a group. The levels (intensity) higher than 220 were eliminated to avoid the sun fleck artifacts. In addition, it was important to try and "normalize" or correct for the intensity shifts due to processing and environment. An arbitrary member of each of the positive and negative groups was taken and named the "shift standard." Then each member of the group was compared to the shift standard. The curves were compared using linear correlation which slides the member past the standard and looks at the overall agreement in the profile. The shift that gives the best profile agreement is used to correct (by adding or subtracting bins, or zeros, from the ends) the member. For each color band the mean (average) and variance for each intensity (grey level) was generated as a separate dimension in hyperspace. This considers each intensity level as a separate "feature" of the image. Then each level for each member was averaged. See Figure 11(b) for program details. An average and variance was then generated using all positive and negative quads finally giving two points (means) in hyperspace that are associated with corresponding variances. In order to look at separation of these "clusters," it is important to consider the variance (standard deviation) in the direction of the means (i.e., along the vector between the means) and the dot product, or the projection of the variance on this vector.

In this way a subset of images was first analyzed using quads from sites 82, 412, 413, 90, 421, and 379. The values obtained are reported in Table 9. Not unexpectedly, the standard deviations tend to be larger than the distance between the means. However, it was noteworthy that in the red band when the comparison was reversed the variance of the negative sites was smaller than the mean and a difference is seen between the two categories. This indicates that negative sites may be more uniform, and it may be that it will be easier to say where the salamanders are definitely not rather than where they definitely are. The next analysis that was run included all the quad images. In this case, positive and negative transects were not clearly separated (Table 10).

Many other refinements of these analyses should be considered. One approach would be to vary the "shift standard," another would be to sub-group the quads depending upon the exposure of the photograph. Preliminary approaches using texture and fractal analyses were not successful, but they should be considered for future analysis.

Hierarchical cluster analysis was another approach applied to the histograms considering each quad as a variable. The distance measurements used were median, average, complete, McQuitty, centroid, single, and Ward. The correlation or absolute correlation was used to measure the distance between the clusters.

The dendrogram was cut to give 2 to 4 clusters in each case. As an internal control, the "duplicate" (i.e., from photographs taken at different times) histograms of quads along transect A at site 84 were included. If any pair did not fall in the same cluster then this was an indication of an inappropriate measure of distance.

This approach was applied to specific levels of the histograms as well as to the total histograms for the reasons that have been mentioned above. In addition, in some cluster analysis procedures the histograms for the isolated cryptogam images were included.

The first observation was that, in some red band analysis cases, those paired histograms of site 84, transect A did not fall into the same cluster. This is probably not unexpected as environmental conditions generally affected the red band histograms more strongly than the other two color bands. Another observation was that in some cases the exposure level of the photographs led to clustering of like exposed photographs. A typical distribution of the green band is shown in Figure 35 and, using all the same parameters, a typical distribution of the blue band is shown in Figure 36.

None of the cluster analyses discussed so far were made on the "normalized" histograms. Cluster analysis was then made on the zero-padded histograms, and the gray levels from 220 to 255 were eliminated to avoid the artifacts from sun flecks. In addition, the total number of pixels per gray level, rather than the percent of total pixels, were examined. Using the correlation coefficient distance and complete linkage the red band histograms sorted into two clusters but in the second cluster there was only six quads, one from a negative transect and five from positive ones. Thus the red band was not distinguishing between positive and negative sites. This result was in sharp contrast to the cluster pattern from the green and blue bands. The quad images clustered into two clusters quite well according to the positive and negative sites. About (greater than) 90% of negative quads were in cluster 1 and approximately (greater than) 90% of the positive quads were in cluster 2. Green and blue band histogram characteristics appear to have some ability to discriminate between positive and negative sites. These are surprisingly promising results that should be confirmed and extended by a more thorough analysis.

Conclusion

This pilot study made a good start in identifying some of the microhabitat characteristics of Jemez Mountains salamander habitat. In general, lichen and moss species were both in greater abundance at the sites where Jemez Mountains salamanders were found. In addition, a greater cover of foliose rock lichen was found at the salamander positive sites. The higher cover of certain lichens at the positive sites agree with the initial hypothesis. Foliose and fruticose lichens were expected to be higher at more moist sites, and black crustose rock lichens are expected to be lower at these sites. The model that has been developed needs to be improved. An important addition to the model may be to add foliose rock lichen, which was not tested within the current model framework. A preliminary attempt to use owl scat, elk scat, and cow dung as indicators of disturbance and biodiversity led to no statistically significant conclusions, but there was indication that there was more owl and elk scat at positive sites and no cow dung.

A simple model was developed to predict the likelihood of finding salamanders. The model included gravels (2 to 6 cm diameter), stones, wood (12 in. to 3 ft; ~30 cm to 1 m), total *Cladonia* (all species), total *Peltigera* (all species), total moss (all species), litter/basal vegetation, grass canopy, forb canopy, and shrub canopy. It became apparent however that moss species should really be defined in the model and that this would be an important refinement. There are several indications that the areas that definitely do not have salamanders may be easier to predict than those that do. This may be the best approach when modeling predictors of habitat for management purposes.

Environmental conditions affect the spectral profiles of the sites. Cluster analysis made on normalized histograms with the gray levels from 220 to 255 eliminated to avoid the artifacts from sun flecks gave the most promising results. Using the correlation coefficient distance and complete linkage, the histograms

from the green and blue bands sorted into two clusters. In each case, approximately (greater than) 90% of negative quads were in cluster 1 and approximately (greater than) 90% of the positive quads were in cluster 2. After sorting the red band histograms into two clusters, there were only six images in the second cluster, one of a negative quad and five from positive ones. In our studies the histogram pattern from the red channel was most affected by environmental (e.g., wet or dry) conditions. These are very promising results although more rigorous analysis must be undertaken and the procedure tested in the field. One important addition to the experimental protocol should be to include a standard color and intensity chart in the photograph at the time of taking the picture. Another important additional analysis to perform on this data set is to extend the same analyses to the single sub-quads rather than on the color band histograms of the whole quads. This would be more directly equivalent to our observations on the ground cover components.

Positive transects were recorded as those with a salamander(s) found within 50 ft of the transect in the summer of 1997. This was a rather arbitrary classification and is a limitation of the study. A way to measure cover and take photographs of the salamander positive site exactly may lead to stronger predictions.

Even though the actual number of cryptogamic species at each site was very similar, the actual species differed. A method to determine a biodiversity index incorporating cryptogams could be investigated in a more lengthy project.

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References

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Table 1. A summary of the site names, site numbers, and the numbers of salamanders found at each site. The approximate distance from each transect where the salamander(s) were found is also given in the last column of the table.

Site name	#	PLENEO	PLENEO	Transect	Checked	PLENEO	PLENEO near transect		
		at site	total			on transect			distance from
		Yes/No	#		Yes/No	Yes/No	Yes/No	#	transect (ft)
Posos*	**82**	Y		A	Y	N	Y	1	4
				B	Y	N	Y	1	6
				C	Y	N	Y	2	3
Guaje trail A	**421**	N	0	A	Y	N	N		
				B	Y	N	N		
				C	Y	N	N		
Guaje trail B	**84**	Y	1	A	Y	N	Y	1	20
				B	Y	N	N		
				C	Y	N	N		
Dome A	**513**	N	0	A	Y	N	N		
				B	Y	N	N		
				C	Y	N	N		
				D	Y	N	N		
Dome B*	**977**	Y	10	A	Y	N	Y	1	20
				B	Y	Y	Y	1	0
				C	Y	N	Y	1	15
				D	Y	N	Y	1	4
Upland A	**413**	Y	2	A	Y	N	Y	1	50
				B	Y	N	Y	1	35
				C	Y	N	N		
Upland B	**95**	Y	4	A	Y	N	Y	2	30
				B	Y	N	Y	1	15
				C	Y	N	N		
Barley A	**412**	N	0	A	Y	N	N		
				B	Y	N	N		
				C	Y	N	N		
Barley B	**90**	Y	5	A	Y	N	Y	2	30
				B	Y	N	Y	2	50
				C	Y	N	Y	1	15
Oat A	**379**	N	0	A	Y	N	N		
				B	Y	N	N		
				C	Y	N	N		
Oat B	**69**	Y	7	A	Y	N	Y	3	< 10
				B	Y	N	Y	2	< 10
				C	N	Searched hillside near gate, no salamanders on hillside at all.			

* Sites that were checked on two dates, the number reflects total found minus recaptures.

Table 2. The mean cover of positive and negative sites considering a total of 272 salamander-positive sub-quads and 272 salamander-negative sub quads.

Cover	Cover (%) Mean Negative transects	Cover (%) Mean Positive transects	Kruskal Wallis Test : Probability (P) P	Kruskal Wallis Test : Probability (P) P adjusted for ties
Gravel 1	1.4	2	0.420	0.348
Gravel 2	0.8	1.2	0.425	0.336
Gravel 6	2	3.2	0.060	0.025
Stones	1.9	4.2	0.074	0.008
Rocks	5.1	7.3	0.277	0.113
Boulder	0	0.05	0.941	0.317
Bedrock	0.01	0	0.940	0.317
Soil	1.1	1.1	0.826	0.779
Sand	0.01	0	0.941	0.317
Wood 1	0.2	0	0.604	0.008
Wood 3	4.1	3.5	0.762	0.683
Wood 6	3	2.7	0.612	0.336
Wood 12	2.7	0.9	0.456	0.036
Wood 3-0	3.9	2.8	0.811	0.623
Total terrestrial cryptogam	8.8	14	0.000	0.000
Total *Cladonia*	1.8	3.6	0.002	0.001
Total *Peltigera*	0.4	1.4	0.319	0.079
Psoroma hypnorum	0.08	0.02	0.939	0.731
Total *Psoroma*-type*	0.1	0.2	0.710	0.242
Total Moss	6.5	9	0.040	0.034
Total tree lichen	0.2	0.2	0.717	0.554
Total rock lichen	2.7	4.5	0.337	0.264
Crustose rock lichen	2.7	4.1	0.482	0.411
Foliose rock lichen	0.9	2.7	0.097	0.014
Algae	0.01	0.02	0.827	0.322
Litter/basal vegetation	64.5	56.8	0.000	0.000
Canopy - grass	0.6	1.8	0.938	0.903
Canopy - forb	8.1	10.35	0.202	0.172
Canopy - shrub	4.9	5.6	0.049	0.013
Scat - elk	0	0.02	0.767	0.045
Scat - cow	0.2	0	0.824	0.083
Scat owl	0	0.01	0.941	0.317
Fragaria americana	2.5	1.7	0.035	0.002

Table 3. A comparison of positive and negative transects paired by site for similarity in elevation, aspect, and superficial similarities in vegetation community.

Site name	Upland		Oat		Barley		Guaje Trail		Dome	
Negative sub-quads	32		48		48		80		64	
Positive sub-quads	64		32		48		16		64	
Negative transect(s)	2		3		3		5		4	
Positive transect(s)	4		2		3		1		4	
Factor	P	P adjusted for ties	P	P adjusted for ties	P	P adjusted for ties	P	P adjusted for ties	P	P adjusted for ties
Gravel <1	0.78	0.70	0.81	0.22	0.17	0.14	0.24	0.06	0.04	0.04
Gravel 2	0.65	0.55	*	*	0.35	0.28	0.27	0.07	0.16	0.15
Gravel 6	0.32	0.22	0.81	0.22	0.76	0.75	0.69	0.31	0.81	0.81
Stones	0.89	0.80	*	*	0.32	0.20	0.94	0.66	0.04	0.02
Rocks	0.78	0.65	*	*	0.62	0.48	*	*	0.41	0.36
Boulder	*	*	*	*	*	*	*	*	*	*
Bedrock	*	*	*	*	0.86	0.32	*	*	*	*
Soil	0.56	0.43	0.48	0.03	0.238	0.17	0.06	0.01	0.89	0.89
Sand	0.80	0.16	*	*	*	*	*	*	*	*
Wood <1"	*	*	*	*	*	*	*	*	0.29	0.01
Wood 1-3"	0.89	0.86	0.03	0.02	0.05	0.01	0.10	0.09	0.22	0.00
Wood 3.1-6"	0.05	0.00			0.90	0.83	0.48	0.16	0.65	0.08
Wood 6.1-12"	0.71	0.22	0.91	0.84	*	*	0.35	0.10	*	*
Wood >1'	0.17	0.01	0.16	0.03	0.73	0.16	0.04	0.01	*	*
Usnea	0.99	0.99	0.52	0.41	0.74	0.44	0.06	0.00	0.09	0.00
Total *Cladonia*	0.00	0.00	0.69	0.65	0.15	0.10	0.16	0.13	0.68	0.48
Total *Peltigera*	0.05	0.01	0.23	0.04	0.29	0.01	0.91	0.88	0.65	0.08
Psoroma sp.	0.44	0.13	*	*	*	*	*	*	*	*
Total Moss	0.73	0.73	0.00	0.00	0.01	0.01	0.67	0.67	0.02	0.07
Algae	0.71	0.22	*	*	0.73	0.16	*	*	0.54	0.04
Total cryptogam	0.03	0.03	0.00	0.00	0.01	0.01	0.21	0.21	0.16	0.09
Litter/basal veg.	0.04	0.04	0.02	0.02	0.00	0.00	0.91	0.91	0.73	0.73
Canopy - grass	*	*	0.05	0.02	0.11	0.00	0.77	0.56	0.50	0.39
Canopy - forb	0.69	0.42	0.01	0.01	0.78	0.73	0.19	0.17	0.00	0.00
Canopy - shrub	0.26	0.16	0.98	0.97	0.74	0.69	0.01	0.00	0.73	0.56

- Factor was absent

Table 4. Correlations between selected covariates.

	Gravel1	Gravel2	Gravel6	Stone	Rock	Bouldr	Bedrock	Soil
Grvl2	0.296							
Grvl6	0.227	0.186						
Stn15	0.051	0.083	0.126					
Rck1	0.055	0.019	0.008	0.012				
soil	0.080	0.120	0.035	0.040	0.055	0.013	0.013	
Wd1	0.061	0.069	0.065	0.002	-0.004	-0.005	0.005	0.001
Wd3	0.065	0.139	0.079	0.114	0.107	0.019	-0.019	0.076
Wd6	-0.089	0.136	0.111	0.034	0.046	0.012	0.012	0.073
Wd12	-0.079	0.091	0.094	0.064	0.066	-0.008	-0.008	0.038
Wd3_0	-0.108	0.128	0.130	0.096	0.088	0.011	0.011	0.075
Usnea	-0.004	0.020	0.101	0.045	0.058	0.011	0.011	0.100
Totcla	-0.034	0.030	0.031	0.071	0.074	0.017	0.011	0.115
Totpelt	-0.086	0.076	0.071	-0.039	-0.067	0.001	0.010	0.030
Psoroma	-0.028	0.035	0.014	0.026	0.023	0.003	-0.003	0.014
TotMoss	-0.061	0.117	0.090	0.075	0.149	0.035	-0.006	0.025
Algae	0.001	0.038	0.003	0.024	0.007	0.004	0.004	0.200
TOTCRY	-0.081	0.096	0.097	0.096	0.159	0.020	0.011	0.059
Lttrbv	-0.053	0.052	0.044	0.168	-0.433	0.012	0.029	0.071
Elkscat	0.045	0.015	0.076	0.062	0.041	-0.003	0.003	0.007
Cowdung	-0.032	-0.037	0.038	0.028	-0.026	-0.003	-0.003	0.022
owlscat	-0.019	0.022	0.023	0.017	-0.015	0.002	0.002	0.013
Cangrs	0.071	0.090	0.056	0.129	0.000	0.011	0.011	0.034
Canfrb	-0.064	-0.063	0.034	0.050	0.091	0.017	0.015	0.070
Canshb	-0.071	0.020	0.044	0.054	0.100	0.054	0.014	0.000
	Sand	**Wd1**	**Wd3**	**Wd6**	**Wd12**	**Wd3_0**	**usnea**	**Totcla**
Wd6	0.012	0.032	0.002					
Wd12	0.008	0.020	0.034	0.053				
Wd3_0	0.100	0.027	0.063	0.072	-0.045			
Usnea	0.011	0.064	0.021	0.019	0.043	0.048		
Totcla	0.008	0.045	0.027	0.025	0.037	0.051	0.011	
Totpelt	-0.010	0.025	0.003	0.050	0.009	0.006	0.059	0.108
Rdapoth	0.003	0.008	0.021	0.012	0.013	0.113	-0.018	-0.007
TotMoss	-0.023	-0.068	0.040	0.041	0.050	0.021	-0.027	0.244
Algae	-0.004	0.011	0.040	0.026	0.016	0.022	-0.022	-0.024
TOTCRY	-0.016	-0.076	0.042	0.054	0.055	0.034	-0.004	0.606
Lttrbv	-0.006	0.037	0.151	0.189	0.208	0.292	0.055	-0.268
Elkscat	-0.003	-0.009	0.027	0.024	0.015	0.020	-0.020	-0.032
Cowdung	-0.003	-0.008	0.053	0.021	0.013	0.018	0.074	-0.029
Owlscat	-0.002	-0.005	0.019	0.012	0.008	0.132	-0.011	-0.017
Cangrs	-0.011	-0.024	0.006	0.008	0.030	0.050	-0.032	-0.041
Canfrb	-0.019	0.023	0.010	0.044	0.007	0.043	0.046	-0.081
Canshb	-0.014	0.007	0.034	0.034	0.049	0.065	0.019	0.169
	Totpelt	**Psoroma**	**TotMoss**	**algae**	**TOTCRY**	**lttrbv**	**elkscat**	**cow dung**
Psoroma	-0.011							
TotMoss	0.096	0.117						
TOTCRY	0.347	0.124	0.885	0.023				
lttrbv	-0.108	0.088	0.364	0.008	0.412			
Cangrs	-0.010	0.017	0.053	0.022	-0.060	0.019	0.046	0.048
Canfrb	0.020	-0.027	0.048	0.039	0.007	0.147	-0.036	-0.022
Canshb	0.043	-0.018	0.060	0.030	0.101	0.112	-0.027	0.047

Table 5. A summary of some of the covariates modeled and tested by binary logistic regression.

Binary Logistic Regression																		
% Match	38.9	40.8	52.3	57.4	59.8	60.8	61.8	62.3	63.1	63.2	64.4	64.5	65.1	65.3	67.4	67.4	67.4	67.4
% Discordant	23.8	25.1	31.4	31.5	30.3	32.8	32.6	37.0	33.4	34.8	33.3	32.0	34.2	34.0	32.1	32.1	32.1	32.1
% Ties	37.3	34.1	16.3	11.1	9.8	6.4	5.5	0.7	3.5	2.0	2.3	3.5	0.7	0.8	0.5	0.5	0.5	0.5
Covariates																		
Gravel 1								Gravel 1										
Gravel 2								Gravel 2										
Gravel 6		Gravel 6		Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6
Stones		Stones		Stones	Stones	Stones	Stones		Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones
Rocks																		
Boulder																		
Bedrock																		
Soil																		
Sand																		
Rocks																		
Wood 1																		
Wood 3																		
Wood 6																		
Wood 12							Wood 12			Wood 12					Wood 12	Wood 12	Wood 12	Wood 12
Wood 3-0																		
Usnea																		
Totcla	Totcla		Totcla	Totcla	Totcla	Totcla	Totcla				Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla
Totpelt			Totpelt		Totpelt		Totpelt				Totpelt	Totpelt	Totpelt		Totpelt	Totpelt	Totpelt	Totpelt
Psoroma																		
TotMoss			TotMoss									TotMoss			TotMoss			
Algae																		
Litter/bv								Litter/bv					Litter/bv	Litter/bv	Litter/bv	Litter/bv	Litter/bv	Litter/bv
Can grass											Can grass				Can grass	Can grass	Can grass	Can grass
Can forb											Canforb				Canforb	Canforb	Canforb	Canforb
Canshrb						Canshrb	Canshrb			Canshrb			Canshrb				Canshrb	
Scat - elk																		
Scat - cow																		
Scat - owl																		
Tot crypto								Tot crypto	Tot crypto	Tot crypto								

Table 6. A summary of some of the covariates modeled and tested by discriminant analysis.

Using discriminant analysis																		
0 correct	173	174	187	190	190	192	194	194	195	196	198	200	200	201	201	204	206	209
1 correct	122	139	141	141	142	133	145	147	132	132	144	132	147	129	136	130	129	132
After cross validation																		
0 correct	168	172	185	186	185	192	192	193	194	196	196	196	195	199	199	203	204	205
1 correct	121	139	136	136	140	133	140	139	130	132	142	125	144	125	133	129	128	129
Total correct	289	311	321	322	325	325	332	332	324	328	338	321	339	324	332	332	332	334
Covariate																		
Gravel 1	Gravel 1																	
Gravel 2	Gravel 2																	
Gravel 6			Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6	Gravel 6
Stones			Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones	Stones
Rocks																		
Boulder																		
Bedrock																		
Soil																		
Sand																		
Rocks																		
Wood 1	Wood 1																	
Wood 3	Wood 3																	
Wood 6	Wood 6																	
Wood 12			Wood 12	Wood 12	Wood 12		Wood 12	Wood 12			Wood 12		Wood 12			Wood 12		
Wood 3-0																		
Usnea	Usnea																	
Totcla		Totcla	Totcla	Totcla	Totcla		Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla	Totcla
Totpelt			Totpelt	Totpelt	Totpelt		Totpelt	Totpelt	Totpelt	Totpelt	Totpelt	Totpelt	Totpelt		Totpelt	Totpelt		Totpelt
Psoroma																		
TotMoss	TotMoss		TotMoss	TotMoss	TotMoss		TotMoss	TotMoss	TotMoss	TotMoss					TotMoss			
Algae																		
Litter/bv		Litter/bv	Litter/bv	Litter/bv	Litter/bv		Litter/bv	Litter/bv	Litter/bv	Litter/bv	Litter/bv	Litter/bv	Litter/bv	Litter/bv				
Can grass							Can grass	Can grass			Can grass		Can grass					Can grass
Can forb							Can forb	Can forb			Can forb		Can forb					Can forb
Canshrb					Canshrb			Can shrb		Can shrb		Canshrb	Canshrb			Canshrb	Canshrb	
Scat- elk																		
Scat - cow																		
Scat - owl																		
Total crypto						Total crypto												

Table 7. Cassification table for the model described in the text that includes the following covariates: gravels (Grvl6; 2 to 6cm diameter), stones (Stn15), wood (Wd12; 12 in. to 3 ft; ~30 m to 1m), total *Cladonia* (Totcla), total *Peltigera* (Totpelt), total moss (Totmoss), litter/basal vegetation (Littrbv), grass canopy (Cangrs), forb canopy (Canfrb), and shrub canopy (Canshb).

	Correct		Incorrect		Percentages				
Prob. Level	Event	Non-Event	Event	Non-Event	Correct	Sensitivity	Specificity	False/ Positive	False/ Negative
0.050	272	0	272	0	50.0	100.0	0.0	50.0	
0.100	272	0	272	0	50.0	100.0	0.0	50.0	
0.150	271	0	272	1	49.8	99.6	0.0	50.1	100.0
0.200	271	5	267	1	50.7	99.6	1.8	49.6	16.7
0.250	270	7	265	2	50.9	99.3	2.6	49.5	22.2
0.300	263	13	259	9	50.7	96.7	4.8	49.6	40.9
0.350	240	63	209	32	55.7	88.2	23.2	46.5	33.7
0.400	211	104	168	61	57.9	77.6	38.2	44.3	37.0
0.450	169	149	123	103	58.5	62.1	54.8	42.1	40.9
0.500	138	189	83	134	60.1	50.7	69.5	37.6	41.5
0.550	115	215	57	157	60.7	42.3	79.0	33.1	42.2
0.600	94	237	35	178	60.8	34.6	87.1	27.1	42.9
0.650	74	250	22	198	59.6	27.2	91.9	22.9	44.2
0.700	58	258	14	214	58.1	21.3	94.9	19.4	45.3
0.750	264	8	232	55.9	14.7	97.1	16.7	46.8	40
0.800	25	265	7	247	53.3	9.2	97.4	21.9	48.2
0.850	16	266	6	256	51.8	5.9	97.8	27.3	49.0
0.900	8	270	2	264	51.1	2.9	99.3	20.0	49.4
0.950	4	272	0	268	50.7	1.5	100.0	0.0	49.6
1.000	0	272	0	272	50.0	0.0	100.0		50.0

Table 8. The number of mismatched sub-quads per transect in the model that is described in the text. The model includes the following covariates: gravels (Grvl6; 2 to 6 cm diameter), stones (Stn15), wood (Wd12; 12 in. to 3 ft; ~30 cm to 1 m), total *Cladonia* (Totcla), total *Peltigera* (Totpelt), total moss (Totmoss), litter/basal vegetation (Littrbv), grass canopy (Cangrs), forb canopy (Canfrb), and shrub canopy (Canshb). See Figure 6.

Site	Transect	Distance Away	Mismatch	Total	% Mismatched
82	A	4	4	16	0.25
82	B	6	9	16	0.56
82	A	3	6	16	0.38
84	A	20	10	16	0.63
977	A	20	9	16	0.56
977	B	0	3	16	0.19
977	C	15	10	16	0.63
977	D	4	3	16	0.19
413	A	50	8	16	0.50
413	B	35	9	16	0.56
95	A	30	13	16	0.81
95	B	15	5	16	0.31
90	A	30	9	16	0.56
90	B	50	4	16	0.25
90	C	15	8	16	0.50
69	A	7	4	16	0.25
69	B	7	11	16	0.69

Table 9. Average distance and dot products between mean values of the corrected histograms of selected negative and positive quads for the three color bands: (A) red band, (B) green band, and (C) blue band. See text for details.

A.

Red Band	Mean	Standard deviation in distance in the direction of means (dot product)	
		Positive	Negative
Negative to Positive	3150	3598	
Negative to Positive	3150		2015
Positive to Negative	3150	3598	

B.

Green Band	Mean	Standard deviation in distance in the direction of means (dot product)	
		Positive	Negative
Negative to Positive	2673	3047	

C.

Blue Band	Mean	Standard deviation in distance in the direction of means (dot product)	
		Positive	Negative
Negative to Positive	3006	3379	

Table 10. Average distance and dot products between mean values and variance of the corrected histograms of all the negative and positive quads for the three color bands: (A) red band, (B) green band, and (C) blue band.

A.

Red Band	Mean	Standard deviation in distance in the direction of means (dot product)	
		Positive	Negative
Negative to Positive	1227	3950	
Negative to Positive	1227		2614
Positive to Negative	1227	3950	
Positive to Negative	1227		2614

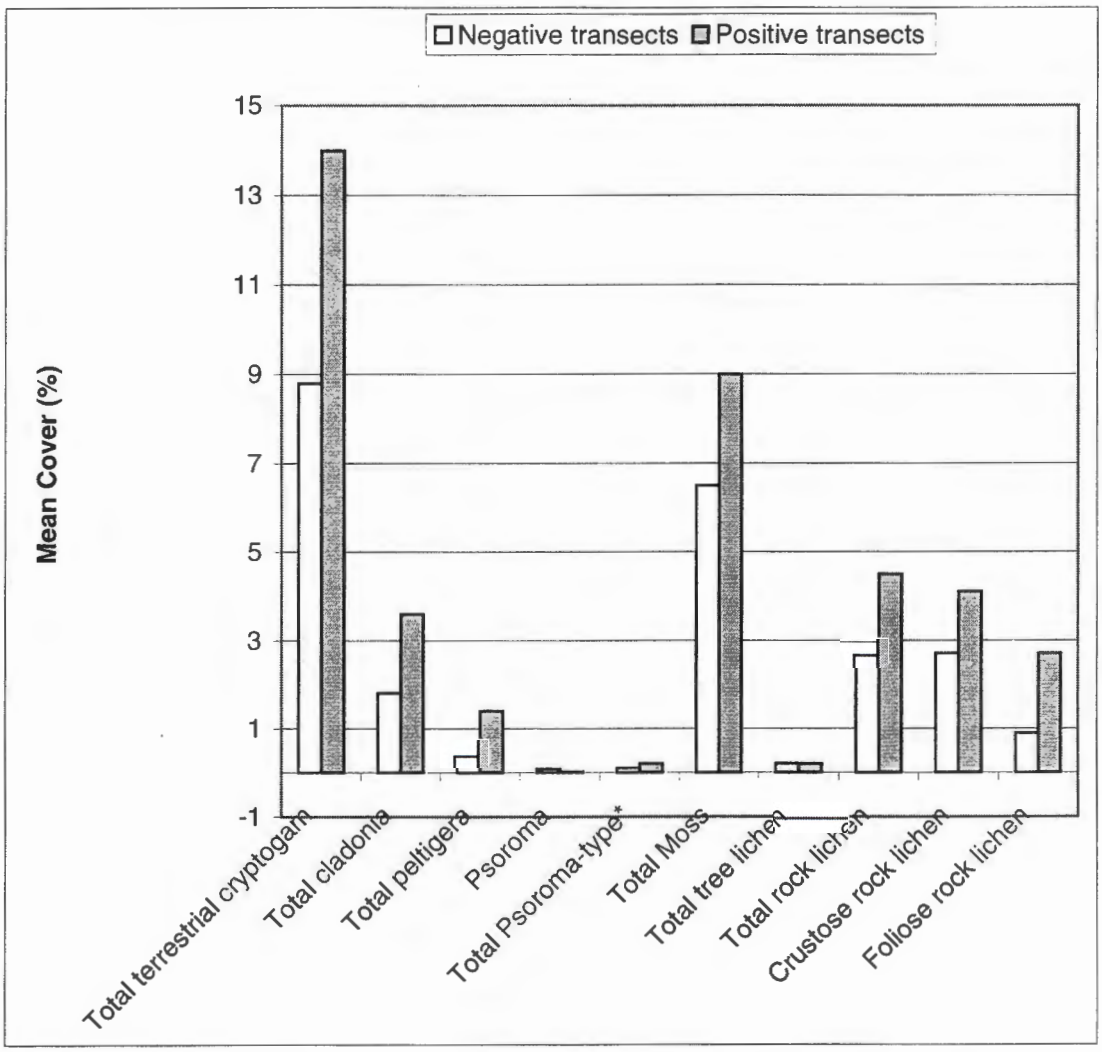
B.

Green Band	Mean	Standard deviation in distance in the direction of means (dot product)	
		Positive	Negative
Negative to Positive	1046	3413	
Negative to Positive	1046		2733
Positive to Negative	1046	3413	
Positive to Negative	1046		2733

C.

Blue Band	Mean	Standard deviation in distance in the direction of means (dot product)	
		Positive	Negative
Negative to Positive	1639	3974	
Negative to Positive	1639		3220
Positive to Negative	0	0	
Positive to Negative	1639		3220

Figure 1. The average difference in cryptogam cover on the salamander-positive and salamander-negative transects.



	Percent cover	
Values in the graph	**Negative transects**	**Positive transects**
Total terrestrial cryptogam	8.8	14
Total *Cladonia*	1.8	3.6
Total *Peltigera*	0.4	1.4
Psoroma	0.08	0.02
Total *Psoroma*-type*	0.1	0.2
Total Moss	6.5	9
Total tree lichen	0.2	0.2
Total rock lichen	2.7	4.5
Crustose rock lichen	2.7	4.1
Foliose rock lichen	0.9	2.7

*Total *Psoroma*-type lacked the prominent apothecia but resembled *Psoroma* otherwise.

Figure 2. Means and results of the Kruskal-Wallis test for differences in selected moss and crustose lichen cover on salamander-positive (1) and salamander-negative (0) transects.

```
Moss A
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level        N      Mean     StDev  ---------+---------+---------+-------
0          272      4.68      8.99   (--------*--------)
1          272      7.15     14.16                     (---------*--------)
                                     ---------+---------+---------+-------
Pooled StDev =     11.86                     4.5       6.0       7.5
Kruskal-Wallis Test on Moss A
H = 2.33  DF = 1  P = 0.127
H = 2.81  DF = 1  P = 0.094 (adjusted for ties)

Moss B
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level        N      Mean     StDev  -+---------+---------+---------+-----
0          272     1.036     3.858                     (--------*-------)
1          272     0.306     1.263  (--------*-------)
                                     -+---------+---------+---------+-----
Pooled StDev =     2.871           0.00      0.40      0.80      1.20
Kruskal-Wallis Test on Moss B
H = 0.84  DF = 1  P = 0.360
H = 2.71  DF = 1  P = 0.100 (adjusted for ties)

Black crustose lichen
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level        N      Mean     StDev  -----+---------+---------+---------+-
0          272     0.342     1.749     (--------------*--------------)
1          272     0.307     2.035  (--------------*-------------)
                                     -----+---------+---------+---------+-
Pooled StDev =     1.897                0.15      0.30      0.45      0.60
Kruskal-Wallis Test on Crusblk
H = 1.52  DF = 1  P = 0.217
H = 4.68  DF = 1  P = 0.030 (adjusted for ties)

Green crustose lichen
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level        N      Mean     StDev  -------+---------+---------+---------
0          272     0.288     1.656                     (--------*---------)
1          272     0.036     0.201  (--------*---------)
                                     -------+---------+---------+---------
Pooled StDev =     1.180                 0.00      0.15      0.30
Kruskal-Wallis Test on Green crustose lichen
H =  3.19  DF = 1  P = 0.074
H = 13.20  DF = 1  P = 0.000 (adjusted for ties)
```

Figure 3. The tree canopy cover over transects that were positive and negative for salamander presence.

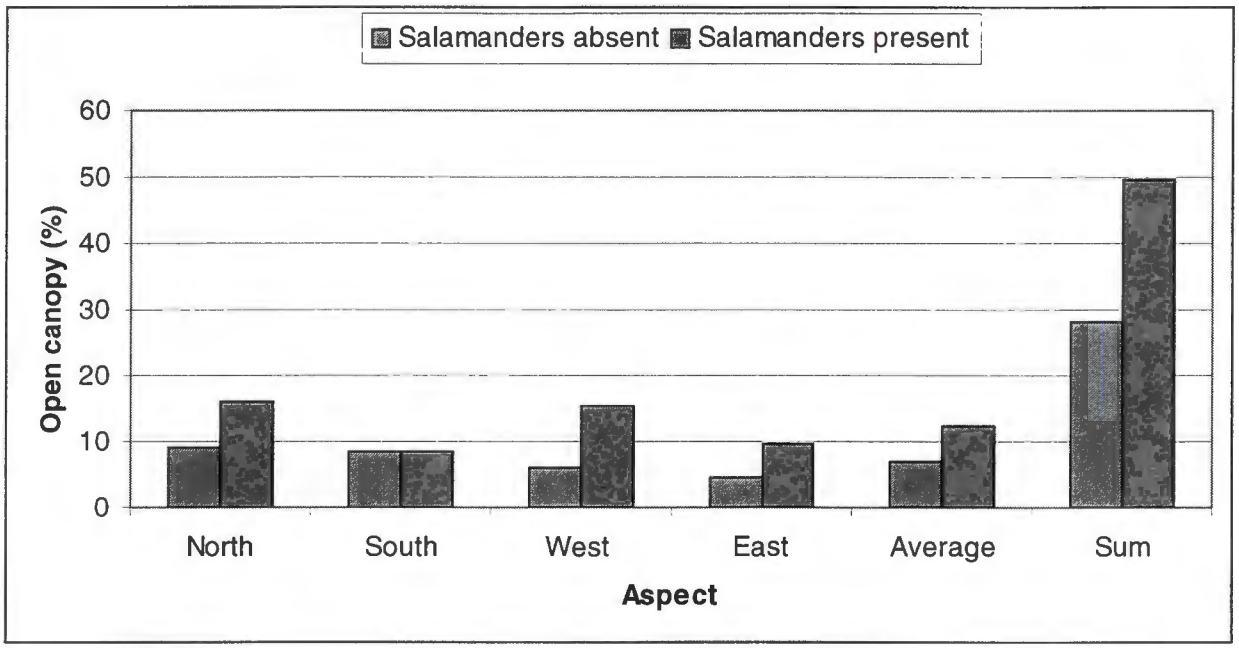


Figure 4. The average slope of the hillsides on which salamanders were found.

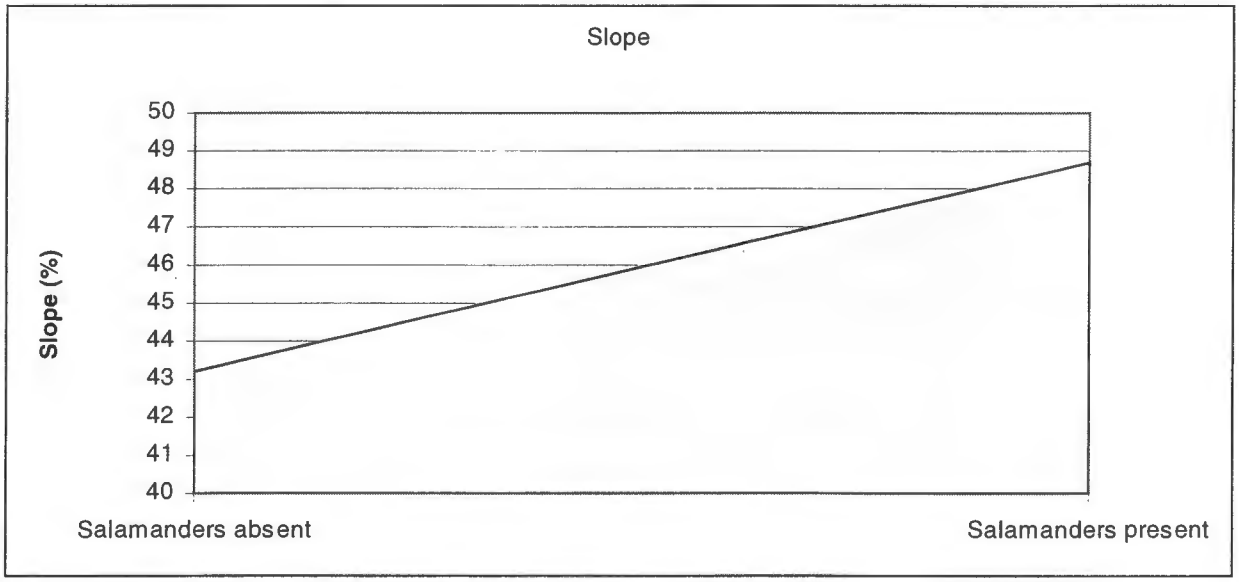


Figure 5. The average aspect of the salamander-positive and salamander-negative transects. Distance from the Y axis in the chart is not significant.

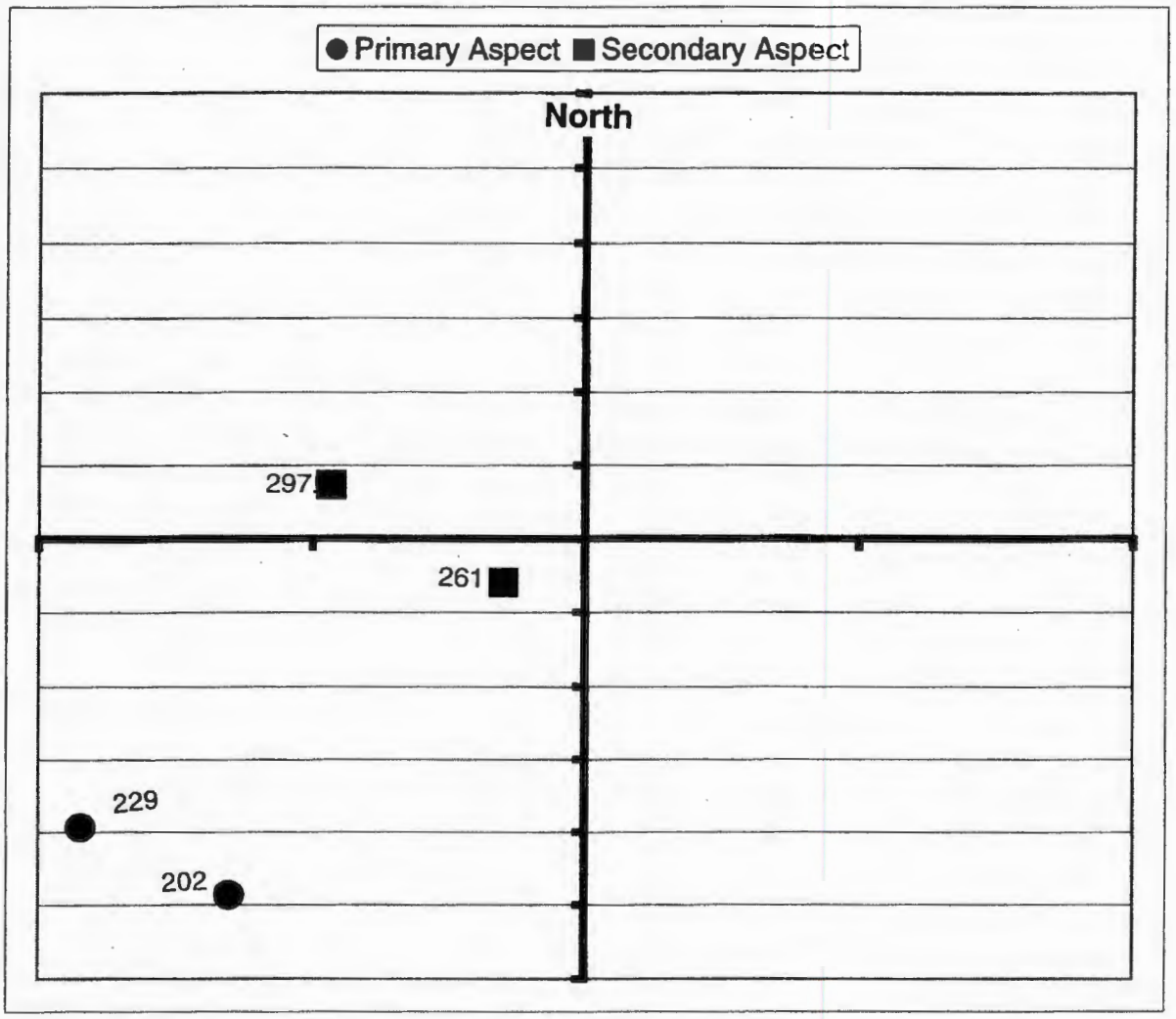
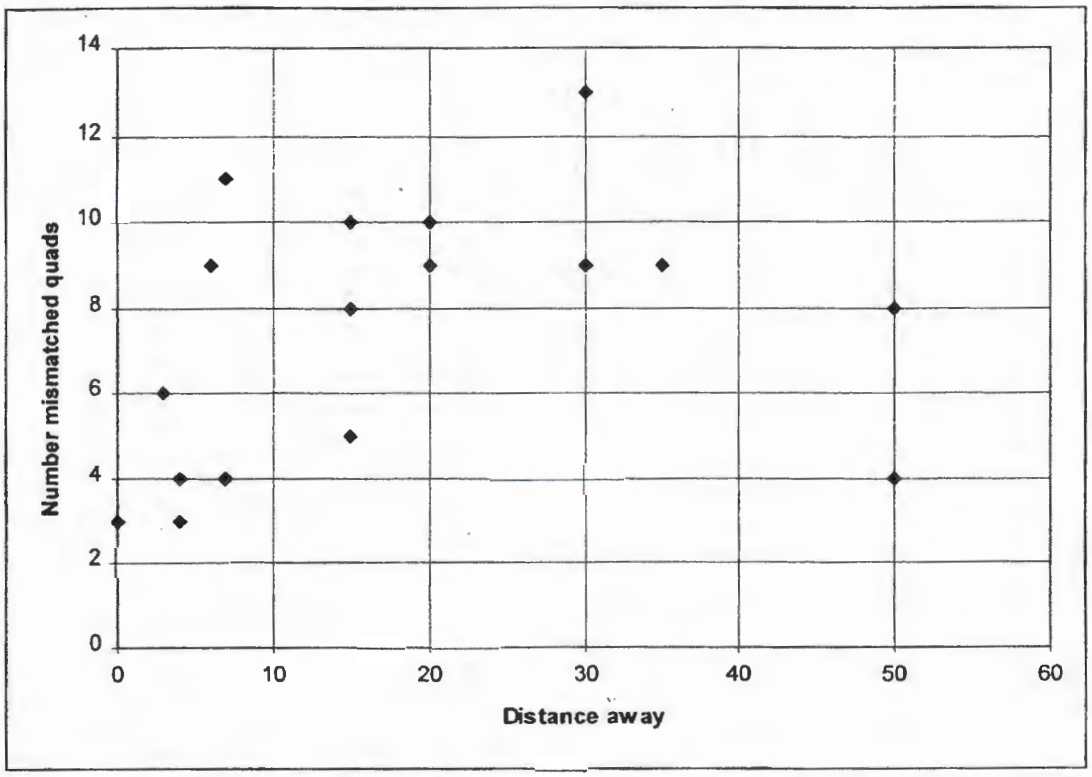


Figure 6. The number of mismatched sub-quads per transect from the model described in the text plotted against the distance the transect was from the nearest salamander. See Table 7.



Polynomial regression – The line fits R-Sq = 0.476
Y = 3.54553 + 0.468341X - 8.36E-03X**2

Figure 7a. **Graph showing the total number of plant species associated with the transects grouped according to whether they were positive (1) or negative (0) for salamanders.**

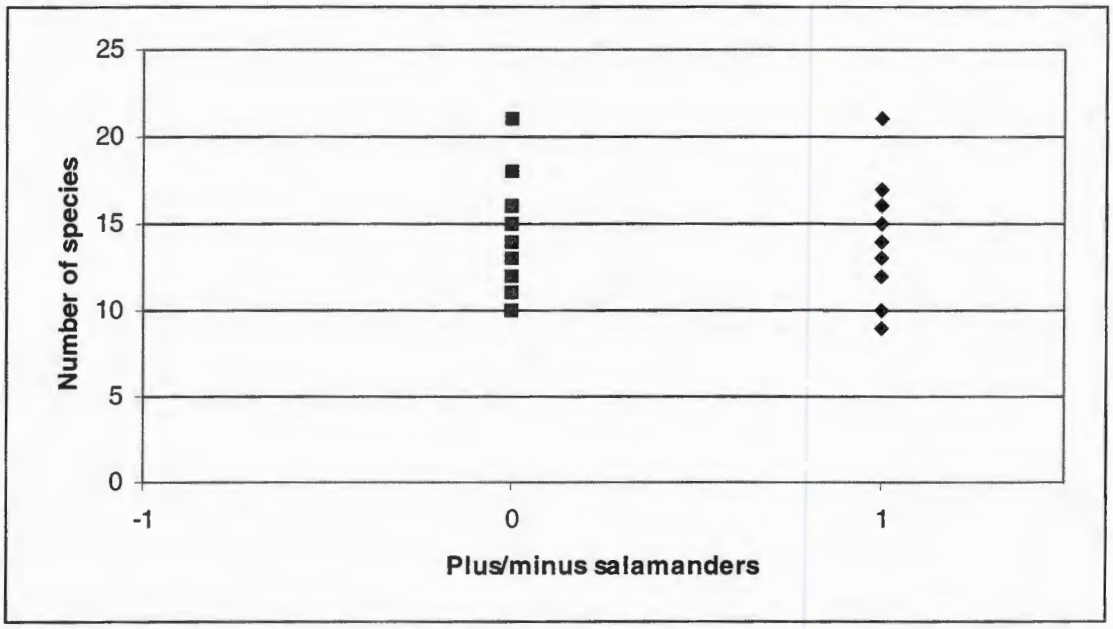


Figure 7b. **Graph showing the relationship between the total number of plant species found on each transect and the distance salamanders were found from each transect. 100 ft is for graphing purposes and denotes a salamander-negative site.**

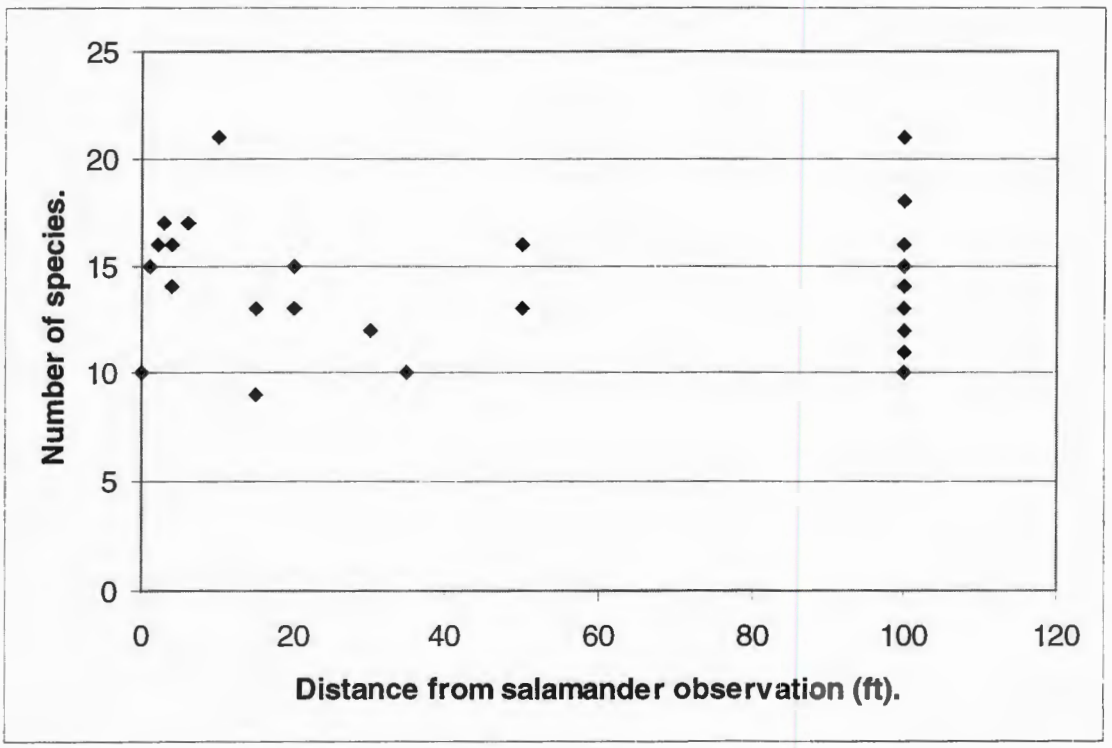


Figure 8a. Graph showing the number of vascular plant species associated with the transects grouped according to whether they were positive (1) or negative (0) for salamanders.

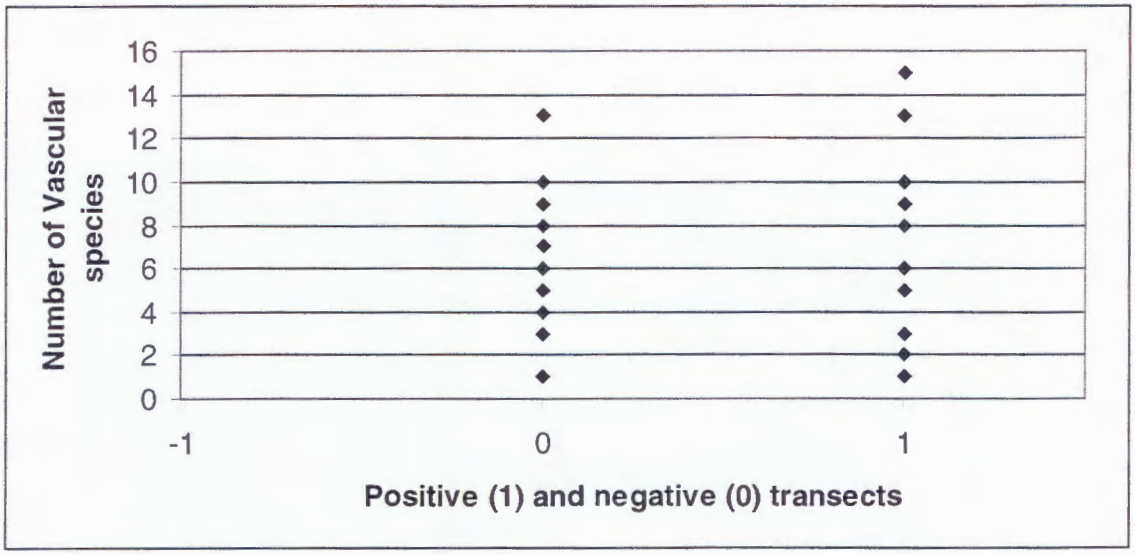


Figure 8b. Graph showing the relationship between the number of vascular plant species found on each transect and the distance salamanders were found from each transect. 100 m is for graphing purposes and denotes a salamander-negative site.

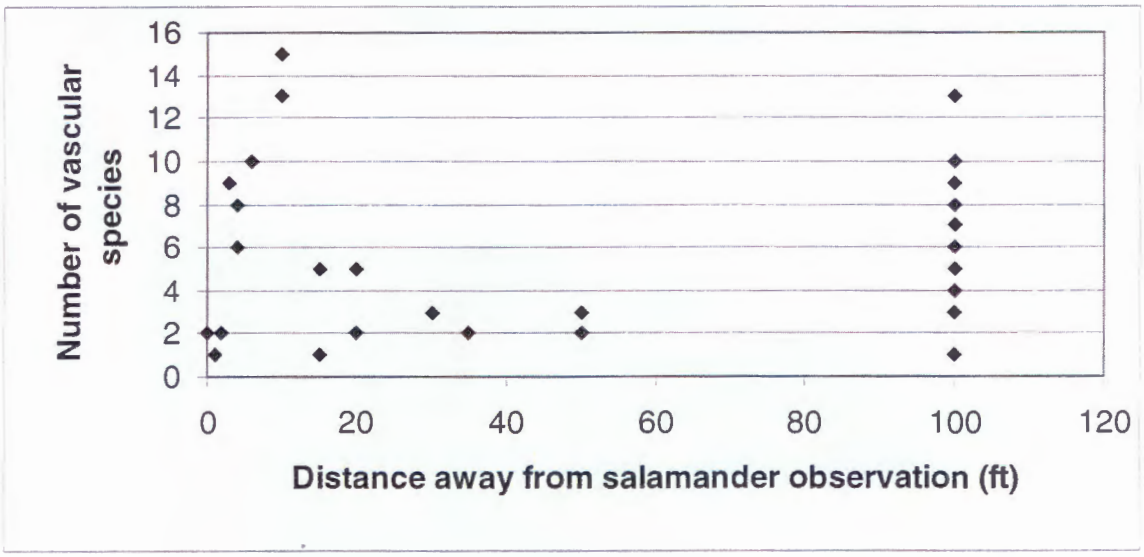


Figure 9. The top photograph shows the quad as the picture was taken on the hillside. The bottom photograph shows the image after it was cropped for processing using "Adobe Photoshop." The photographs are sub-quads 9–12 on transect A at site 977. The influence of the sun flecks is discussed in text.

A

B

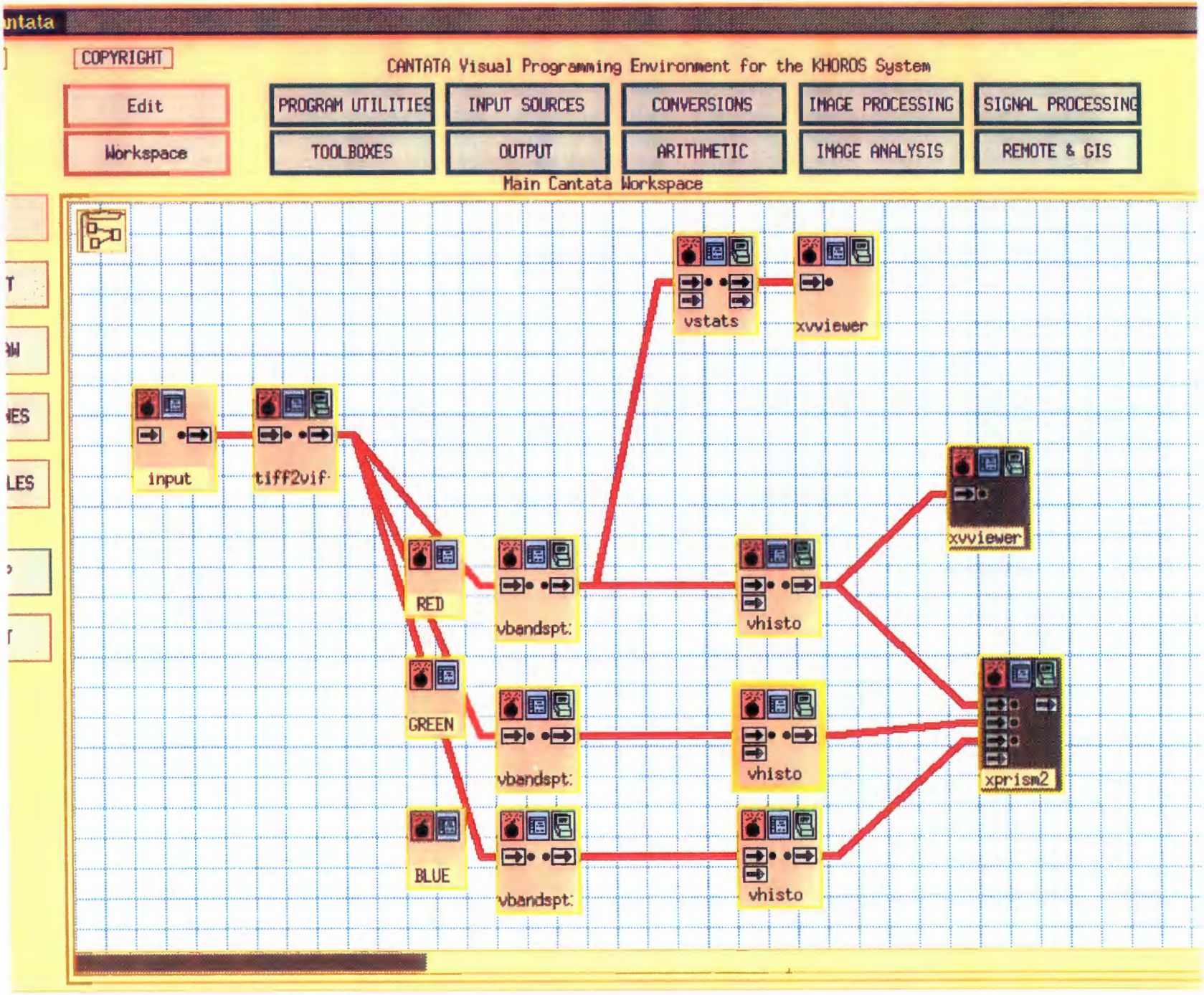


Figure 10. The original program that generated the individual color band histograms of the cropped quad images.

Figure 11. The modified programs that generated (A) the smoothed (median filtered) individual color band histograms of the cropped quad images and (B) the zero padded histograms that were corrected for intensity shifts caused by processing and environment.

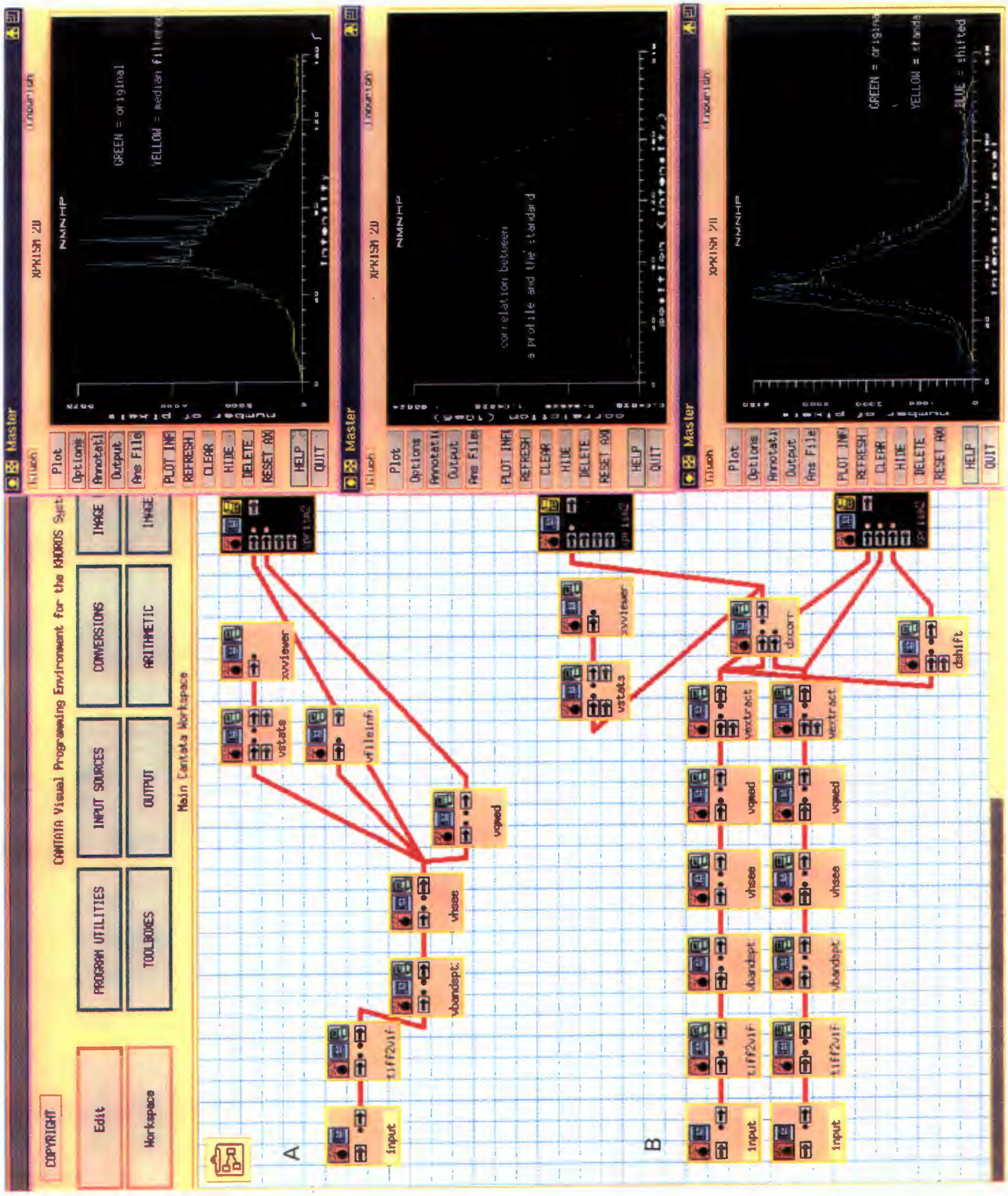


Figure 12. A portion of the histogram showing the original "spiky" histogram (teal-colored line) and the median filtered histograms: yellow (median of three pixels), purple (median of five pixels), and blue (median of seven pixels).

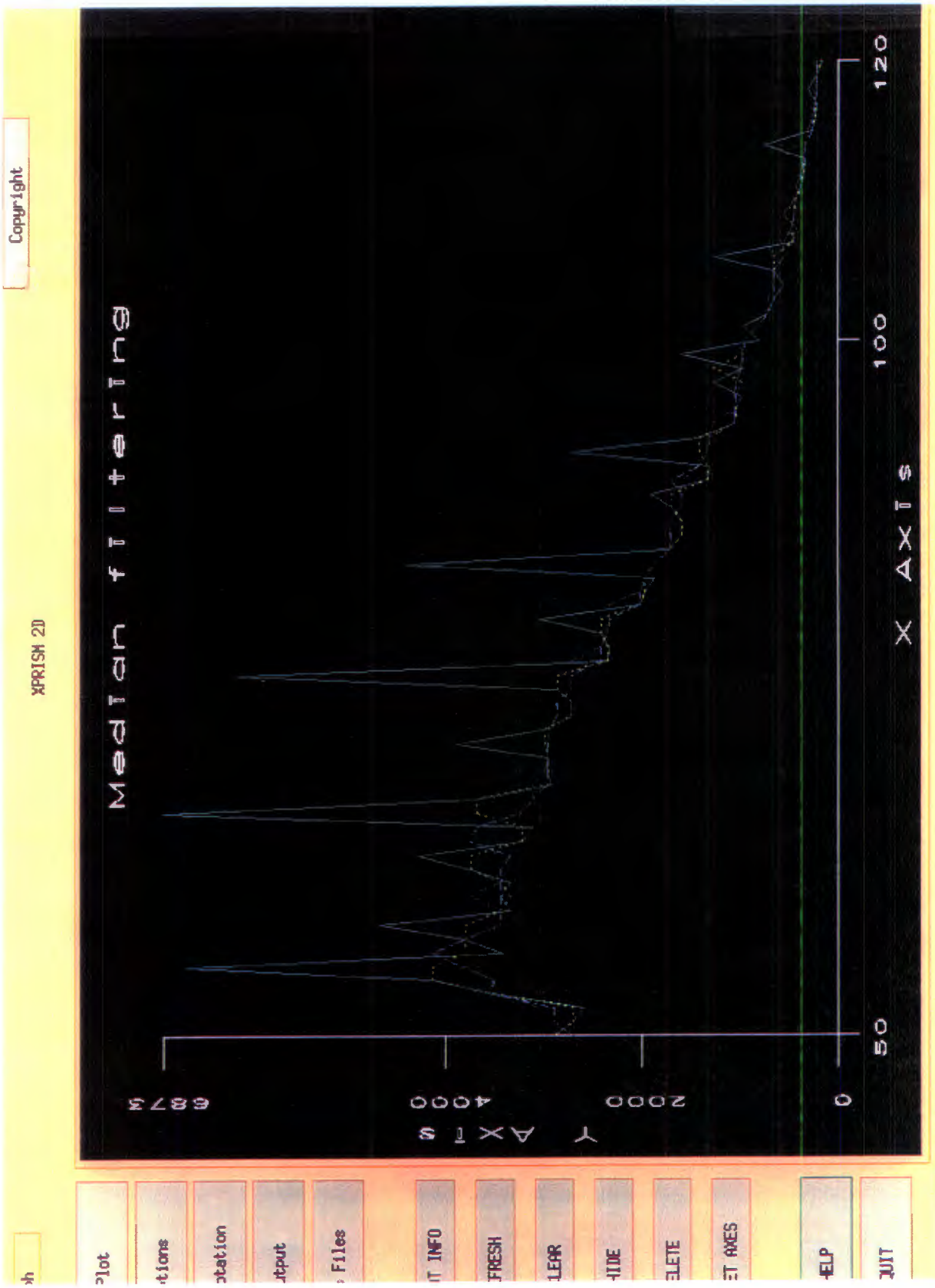


Figure 13. Photographs of sub-quads 5–8 on transect C at site 412. The photograph (A) was the original scan. The second (B) was made using a scanner that was locally available. One byte was allocated to each color band, and the scanner auto intensity setting was used.

A.

B.

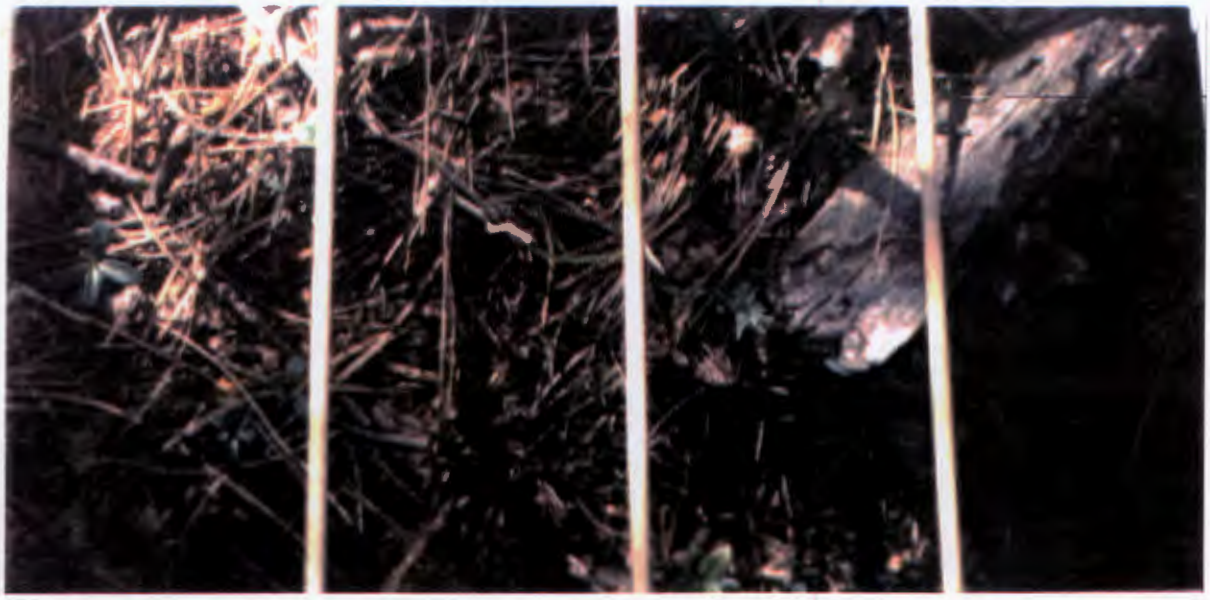


Figure 14. Photographs of sub-quads 1–4 on transect A at site 84. The first photograph (A) was the original scan. The second (B) was made using a scanner that was locally available. One byte was allocated to each color band, and the scanner auto intensity setting was used.

A.

B.

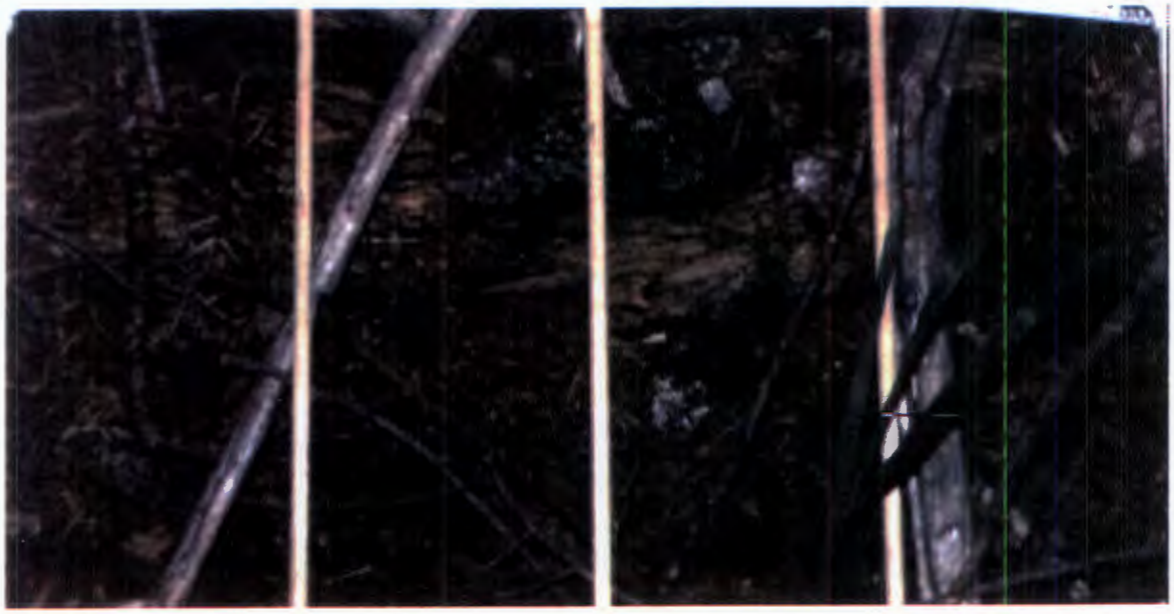
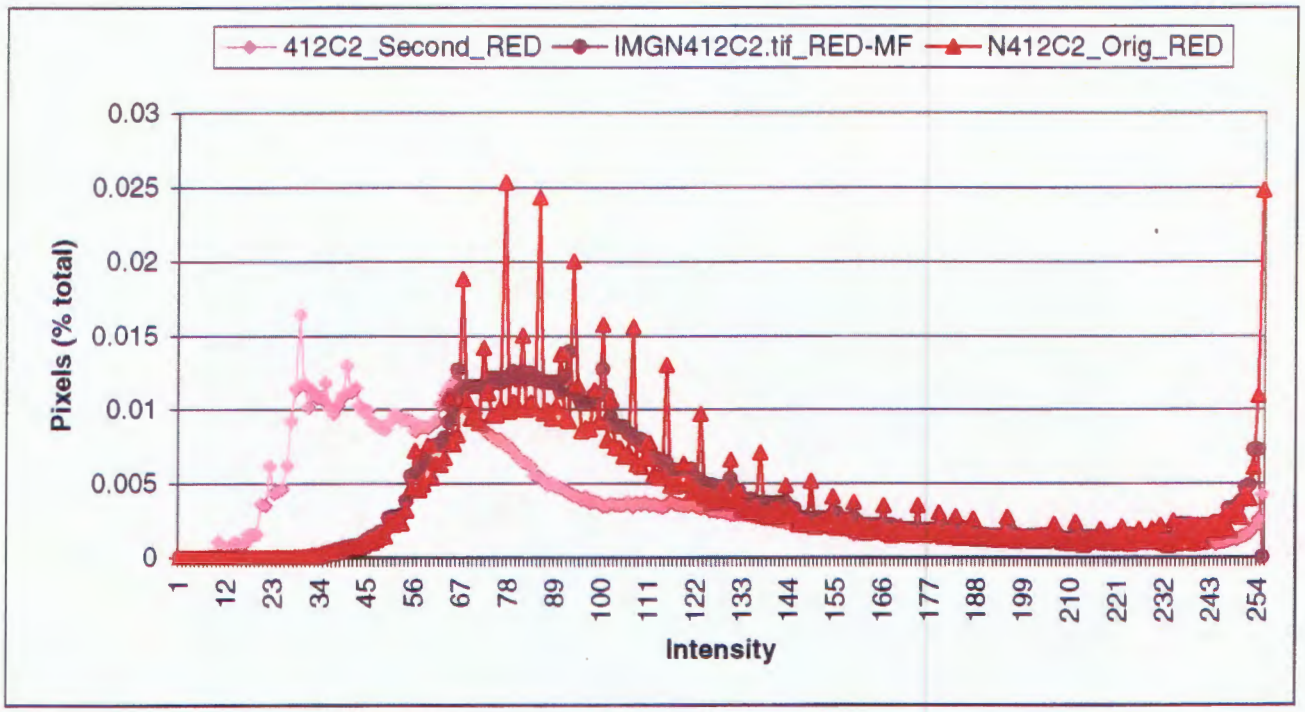


Figure 15. Histogram of the color bands for the different slide scans. ". . . _Second_ . . ." refers to the second scan of the photograph using a different scanner. ". . . _Orig_ . . ." refers to the original scan without median filtering. ". . . -MF . . ." refers to the histogram after median filtering is applied.



B. Green Band - subquads 5-8 on transect C at site 412

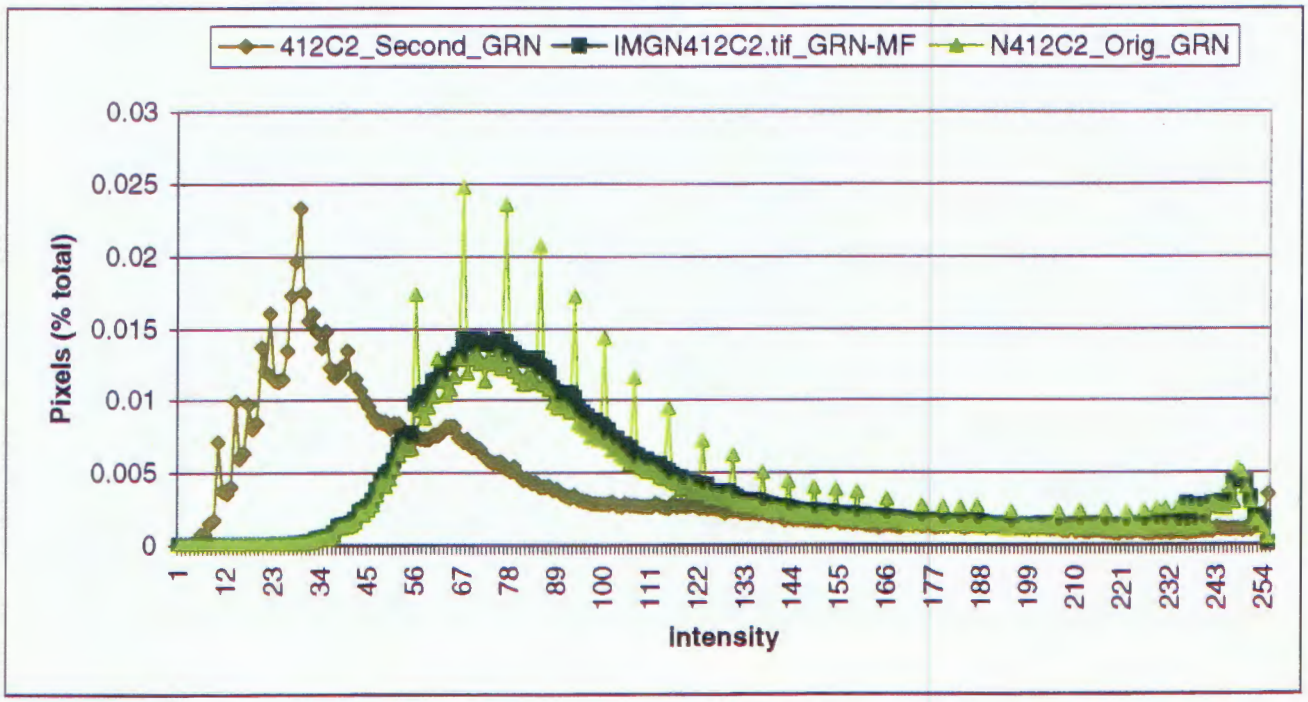


Figure 15(C). Histogram of the color bands for the different slide scans. ". . . _Second_ . . ." refers to the second scan of the photograph using a different scanner. ". . . _Orig_ . . ." refers to the original scan without median filtering. ". . . -MF . . ." refers to the histogram after median filtering is applied.

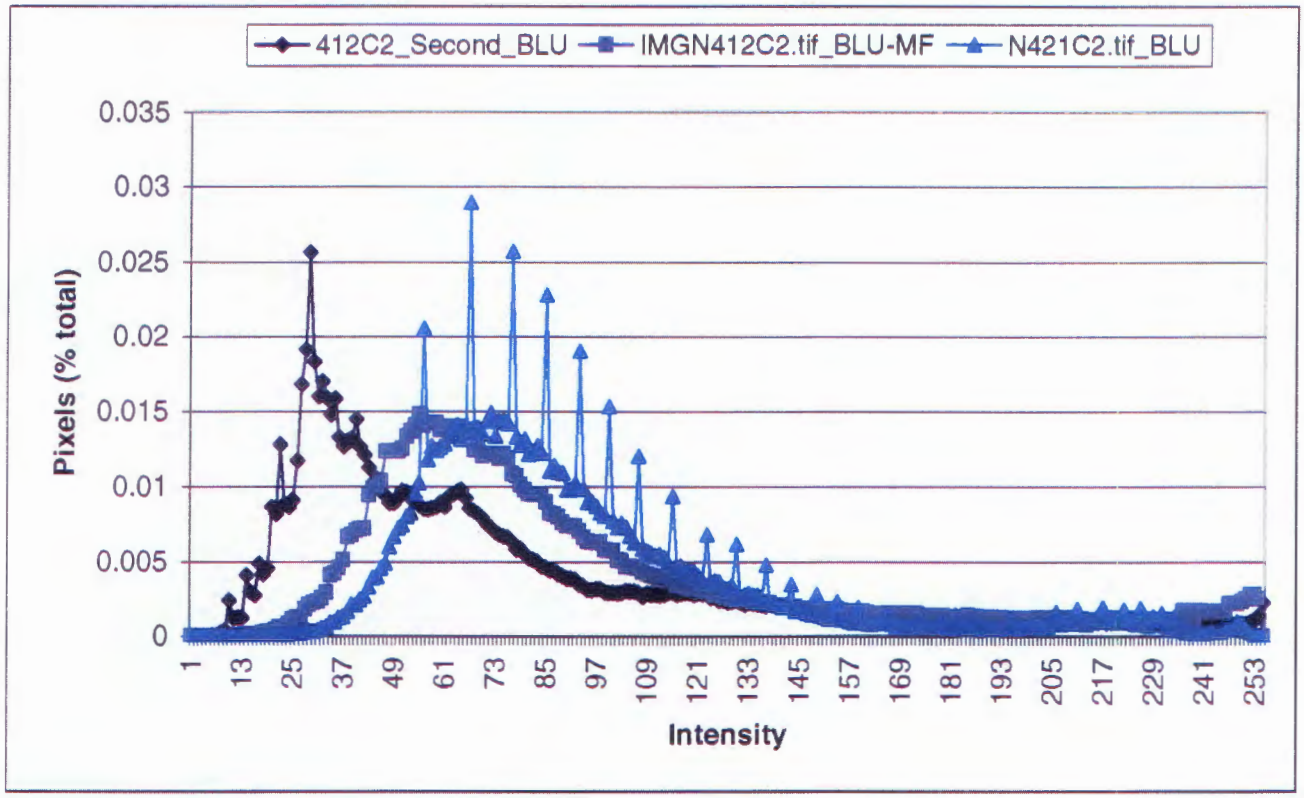
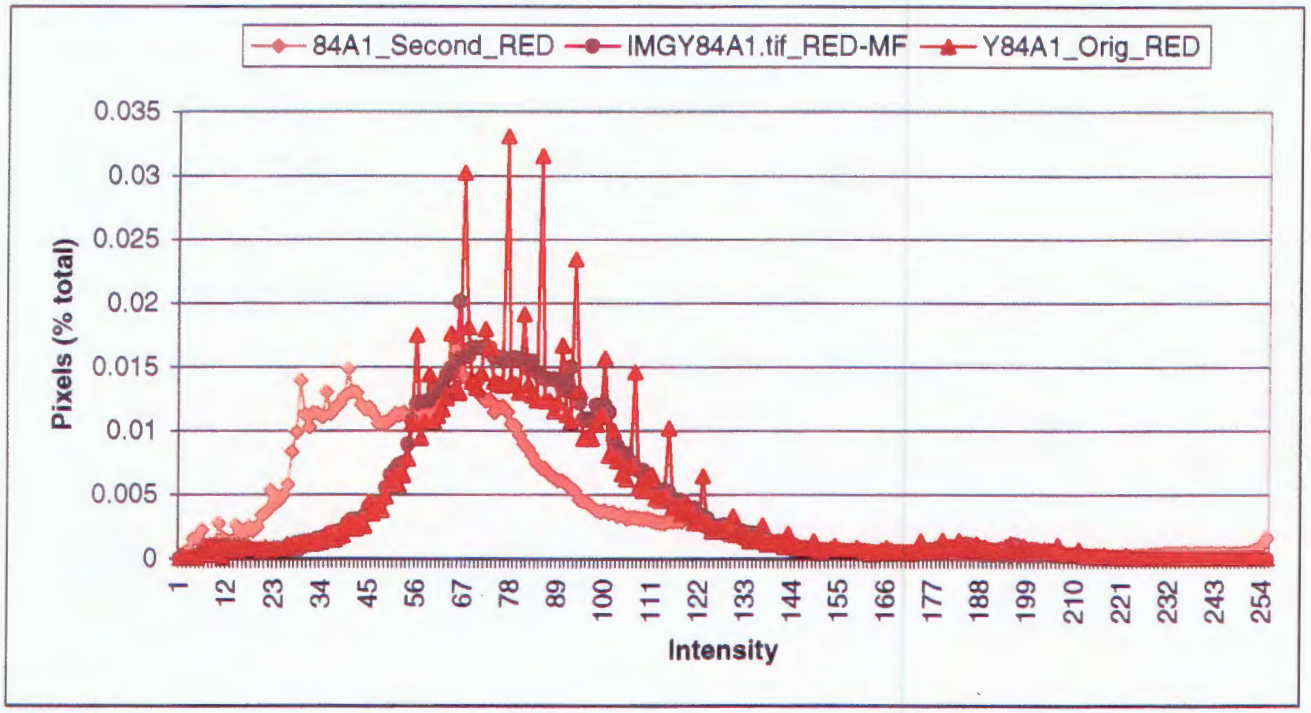


Figure 16. Histogram of the color bands for the different slide scans. ". . . _Second_ . . ." refers to the second scan of the photograph using a different scanner. ". . . _Orig_ . . ." refers to the original scan without median filtering. ". . . -MF . . ." refers to the histogram after median filtering is applied.

A. Red Band - subquads 1-4 on transect A at site 84



B. Green Band - subquads 1-4 on transect A at site 84

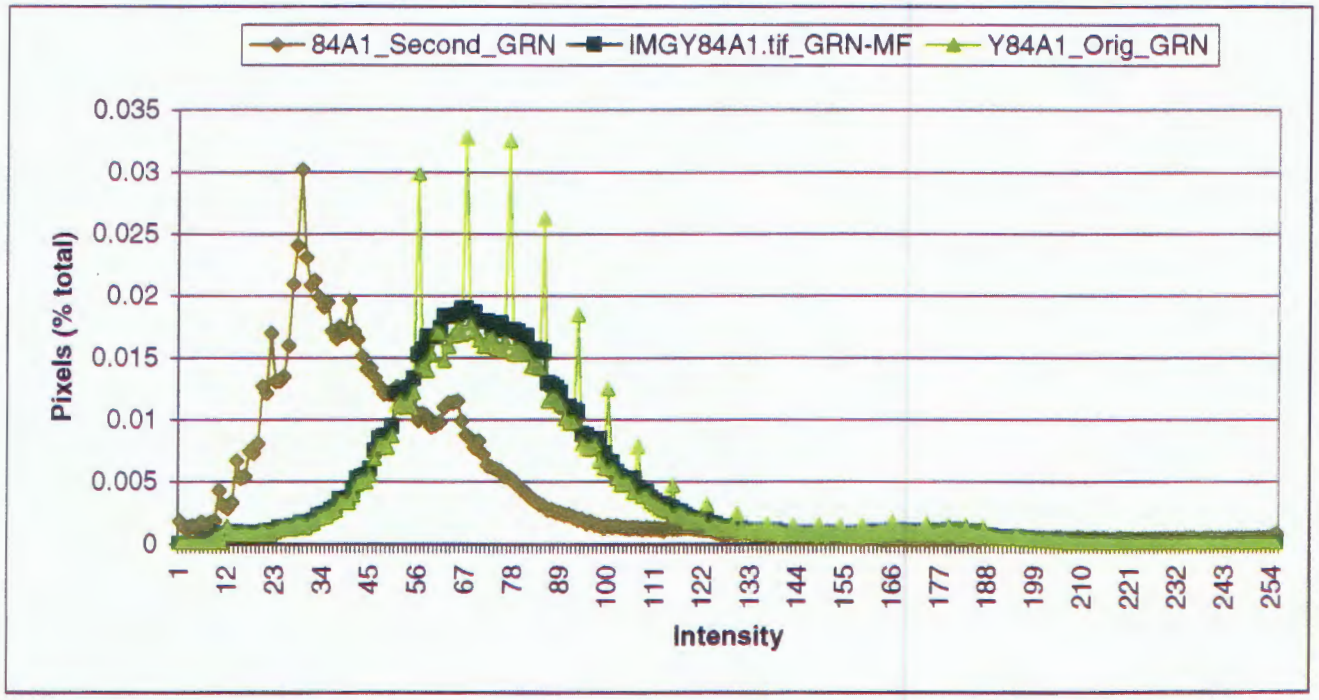


Figure 16(C). Histogram of the color bands for the different slide scans. ". . . _Second_ . . ." refers to the second scan of the photograph using a different scanner. ". . . _Orig_ . . ." refers to the original scan without median filtering. ". . . -MF . . ." refers to the histogram after median filtering is applied.

C. Blue Band - subquads 1-4 on transect A at site 84

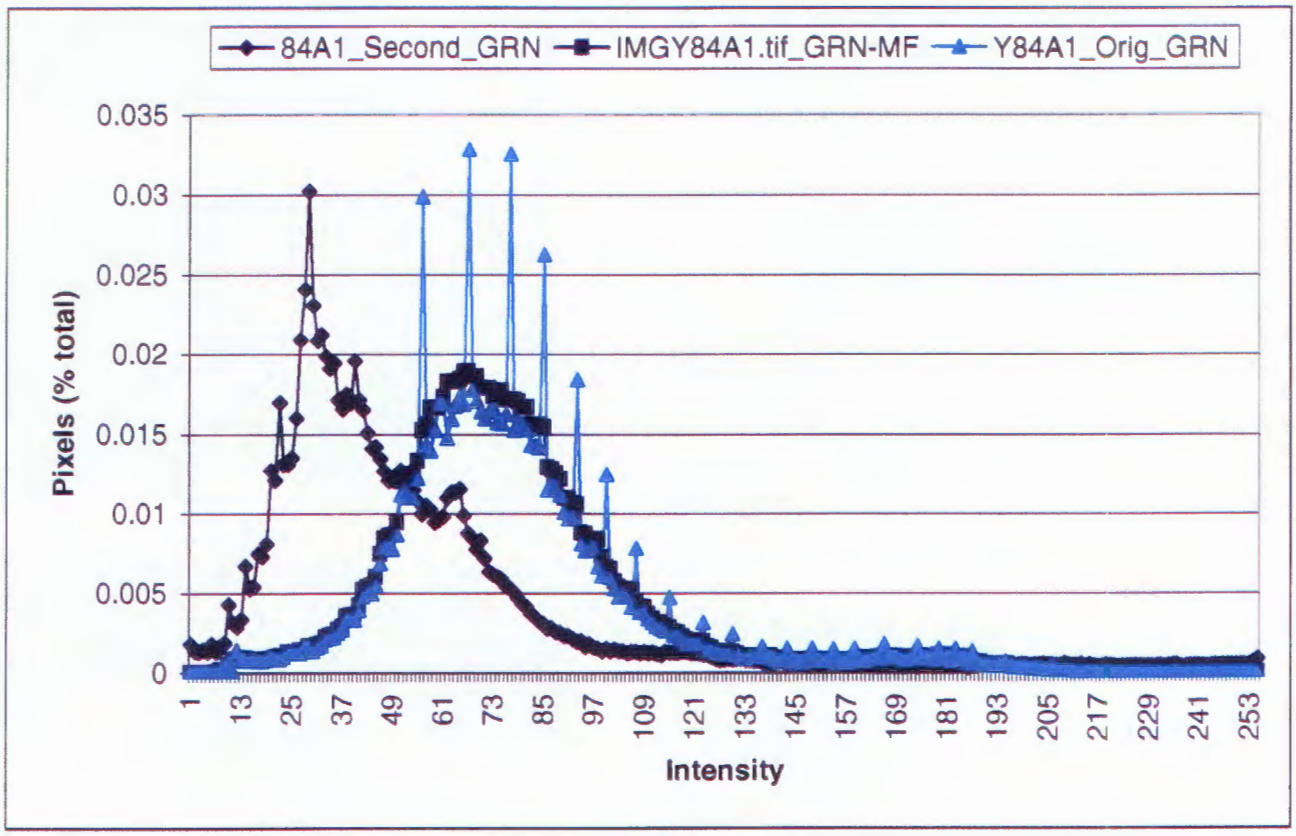
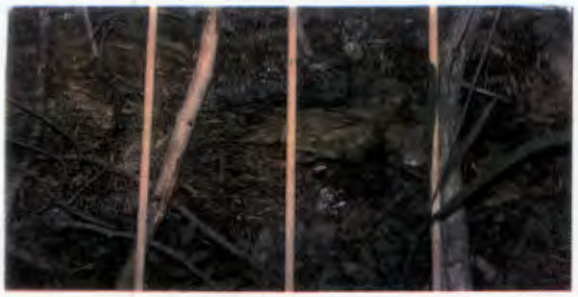


Figure 17. Site 84 on the Guaje Trail, transect A.

Before rain - June 30 1997.

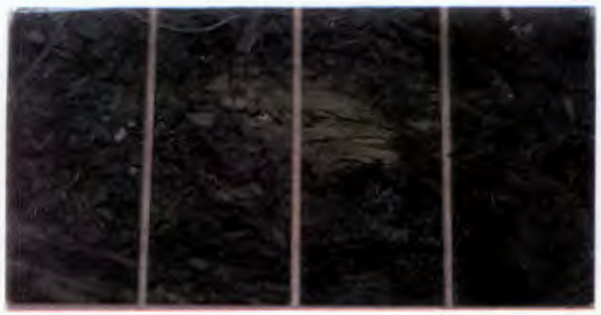
After rain - July 10 1997.

Quads 1 - 4



Quads 5 - 8.

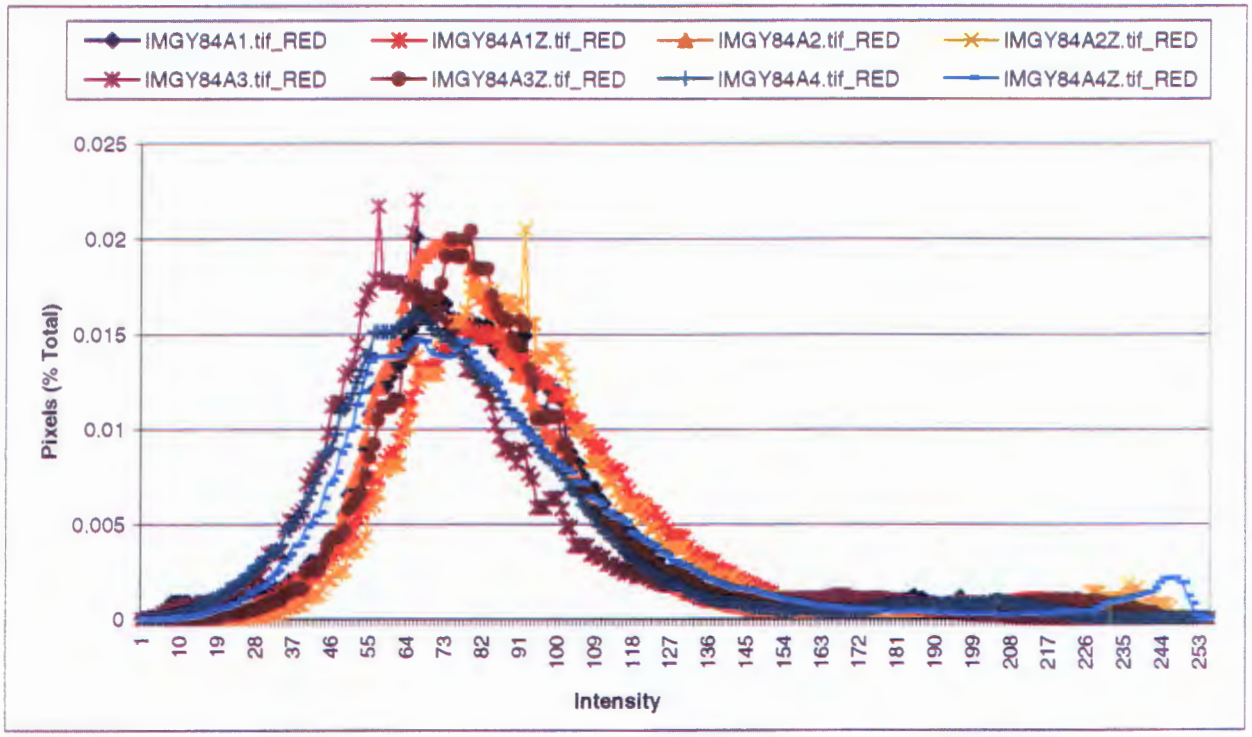
Quads 9 - 12.



Quads 13 - 16.

Figure 18. Graphs showing the histogram profiles of quads on transect A at site 84 photographed on June 30 and July 10 (denoted by "Z" in the legend). A = red band, B = blue band, C = green band.

A.



B.

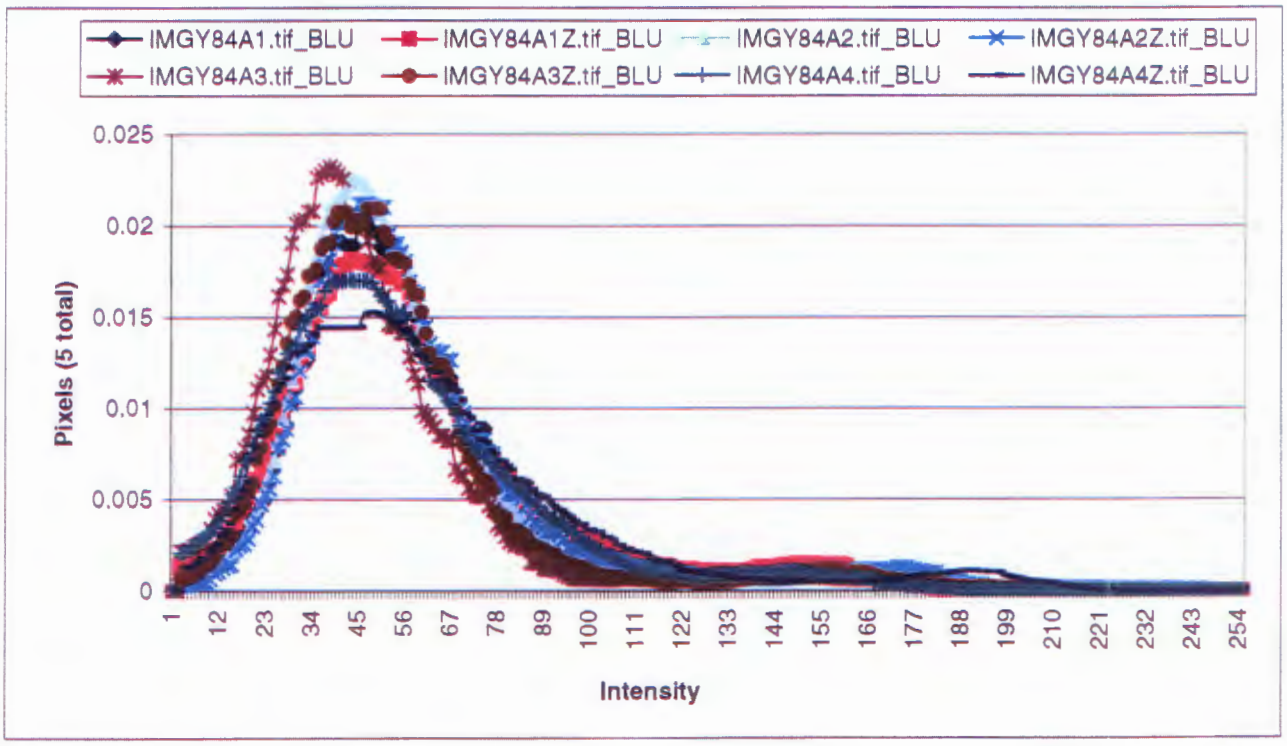


Figure 18(C). Graphs showing the green band histogram profiles of quads on transect A at site 84 photographed on June 30 and July 10 (denoted by "Z" in the legend).

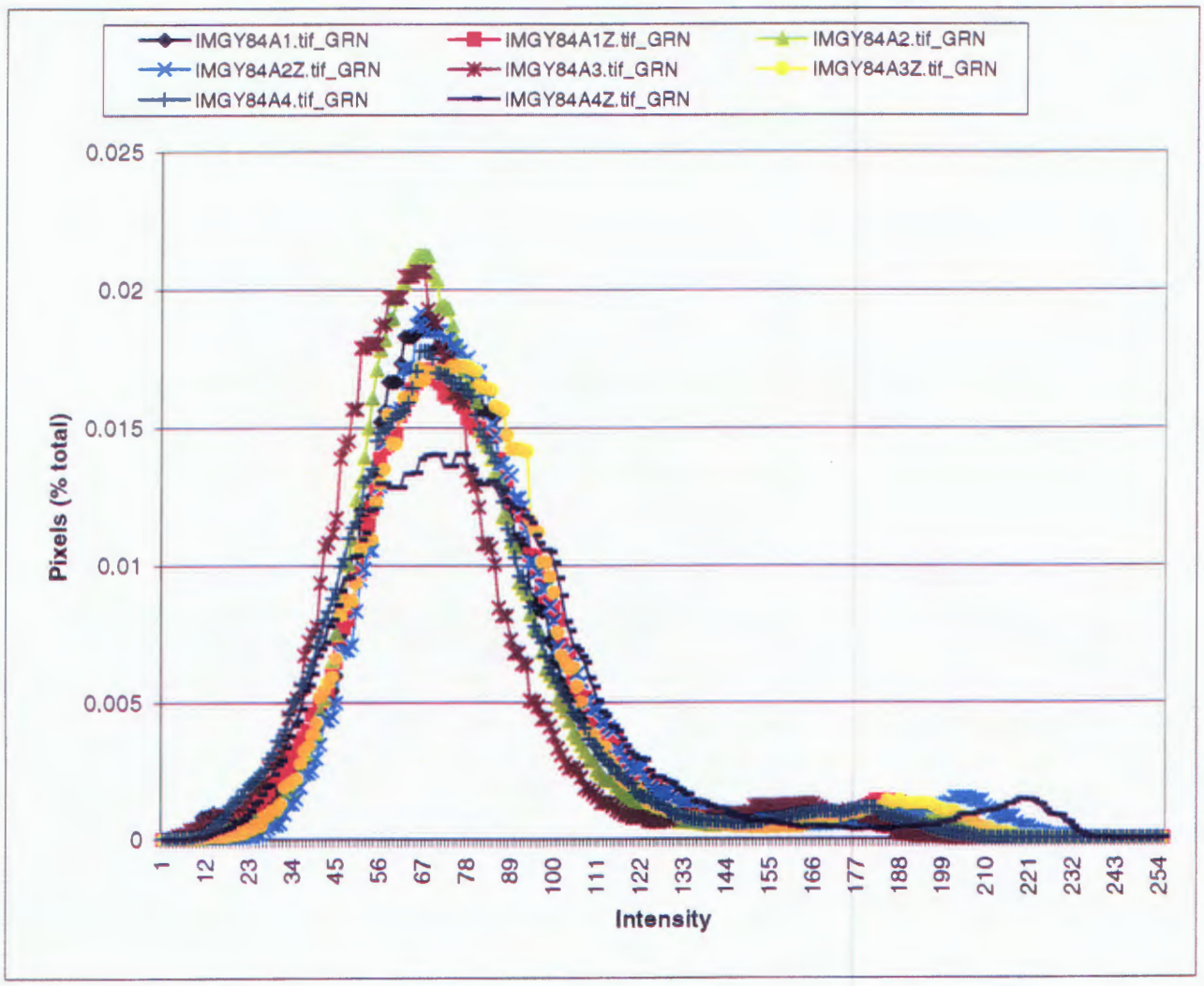


Figure 19. Site 412, transect B, sub-quads 1–4 (A). The natural lighting made the spectral information contained in the first sub-quad misleading (see Figure 20) and, therefore, it may become more appropriate to perform the analyses only on sub-quads 2–4 as shown in photograph B.

A.

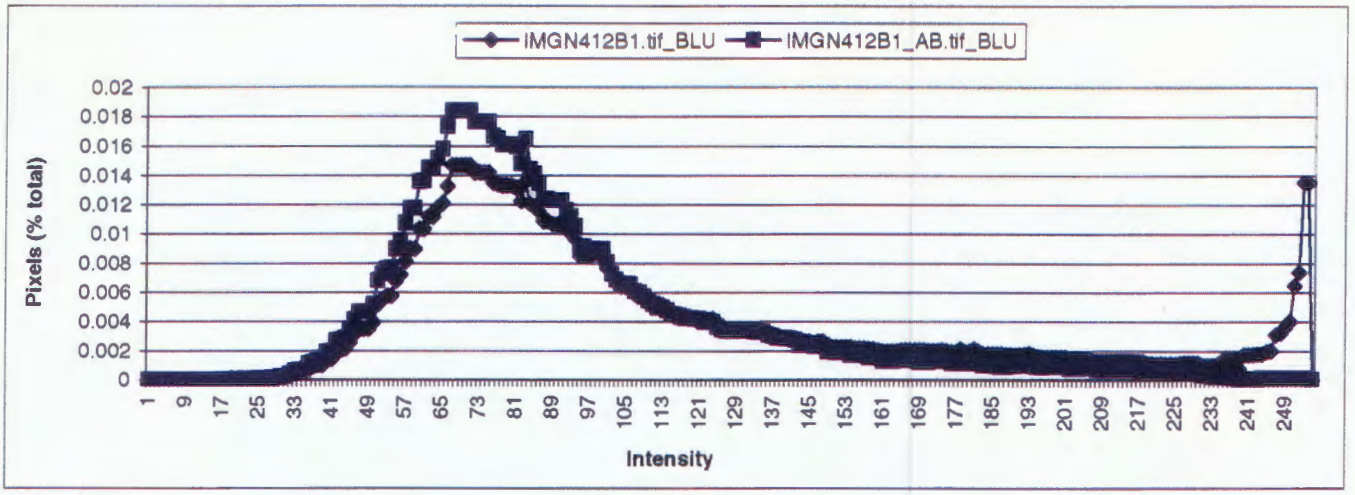
Site 412, Transect B, sub-quads 1-4

B.

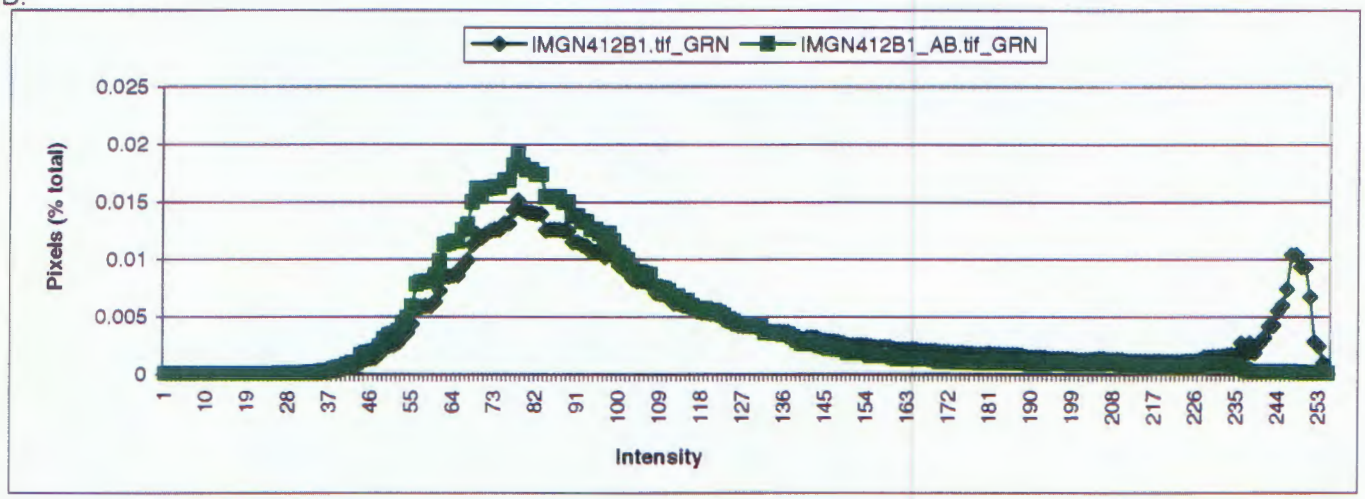
Site 412, Transect B, sub-quads 2-4

Figure 20. Histograms of the blue (A), red (B), and green (C) bands of sub-quads 1–4 and sub-quads 2–4 (denoted by ". . . _AB . . .") of transect A on site 412. By eliminating sub-quad 1, we also eliminated the high-intensity peaks (see Figure 19).

A.



B.



C.

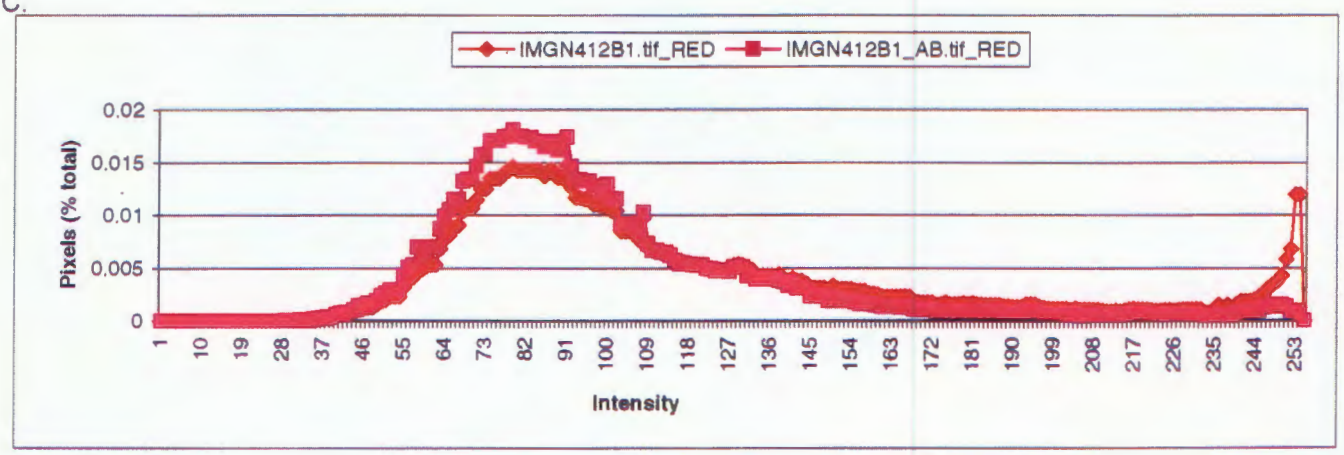


Figure 21. Histograms for the blue, red, and green bands of sub-quads 9–12 on transect A at site 977. The peaks at the highest intensities are ascribed to the sun flecks that can be seen in Figure 9.

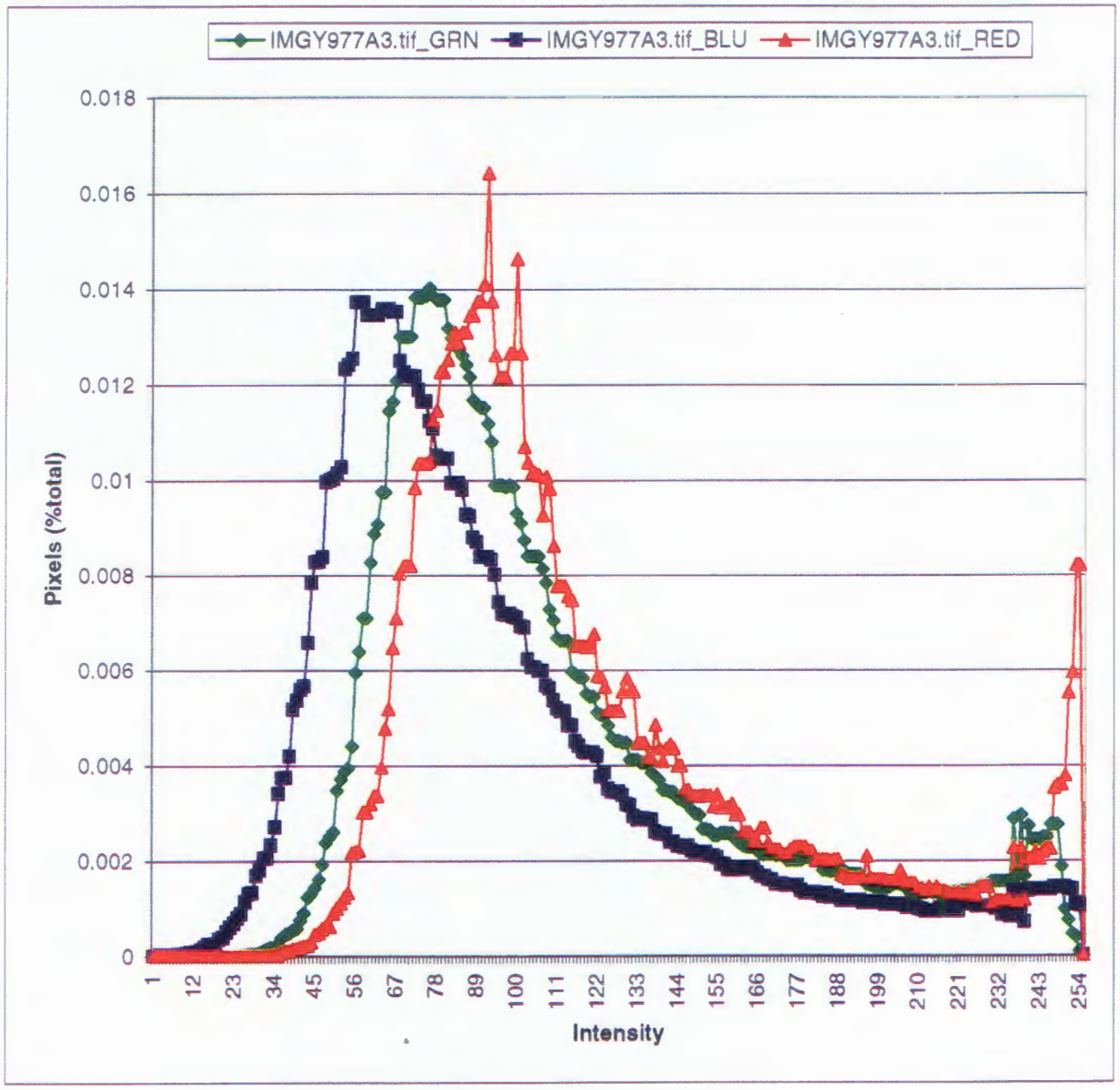
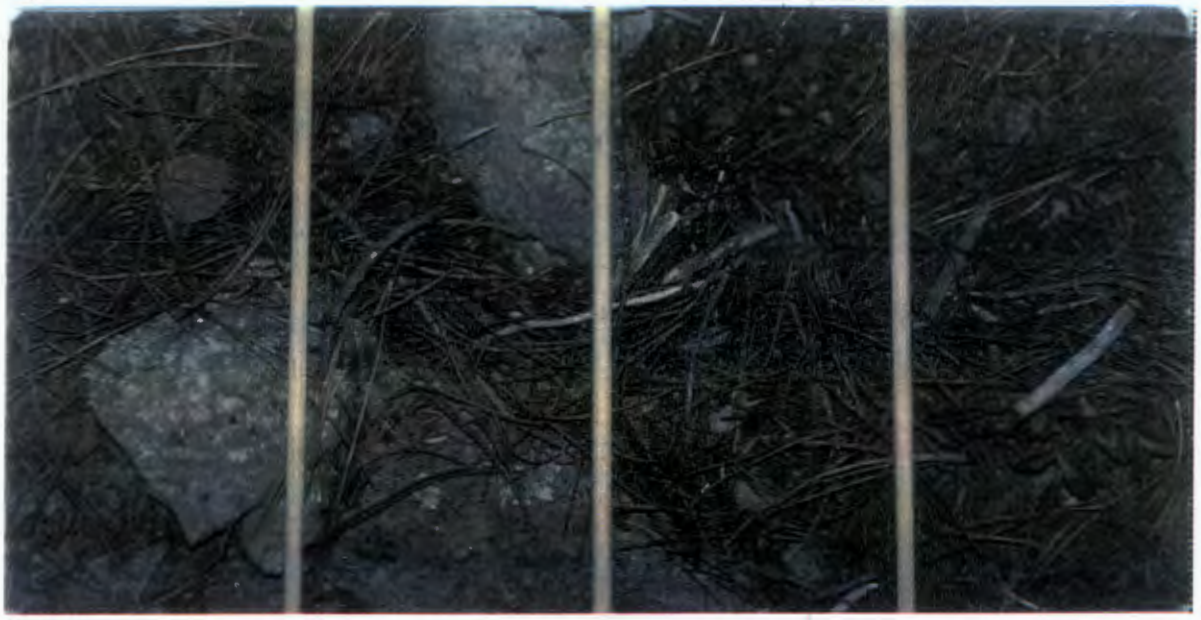


Figure 22. Photographs of sub-quads 13–16 on transect A at site 412 taken without (A) and with (B) a camera flash.

A



Site 412, Quads 13-16, Transect A

B

Site 412, Quads 13-16, Transect A

Figure 23. Photographs of sub-quads 13–16 on transect B at site 82 taken with (A) and without (B) a camera flash. See Figure 25 for color band histograms.

A.

B.

Figure 24. Histograms of the color bands of sub-quads 13–16 on transect A at site 412 taken with (". . . _dup . . .") and without a camera flash.

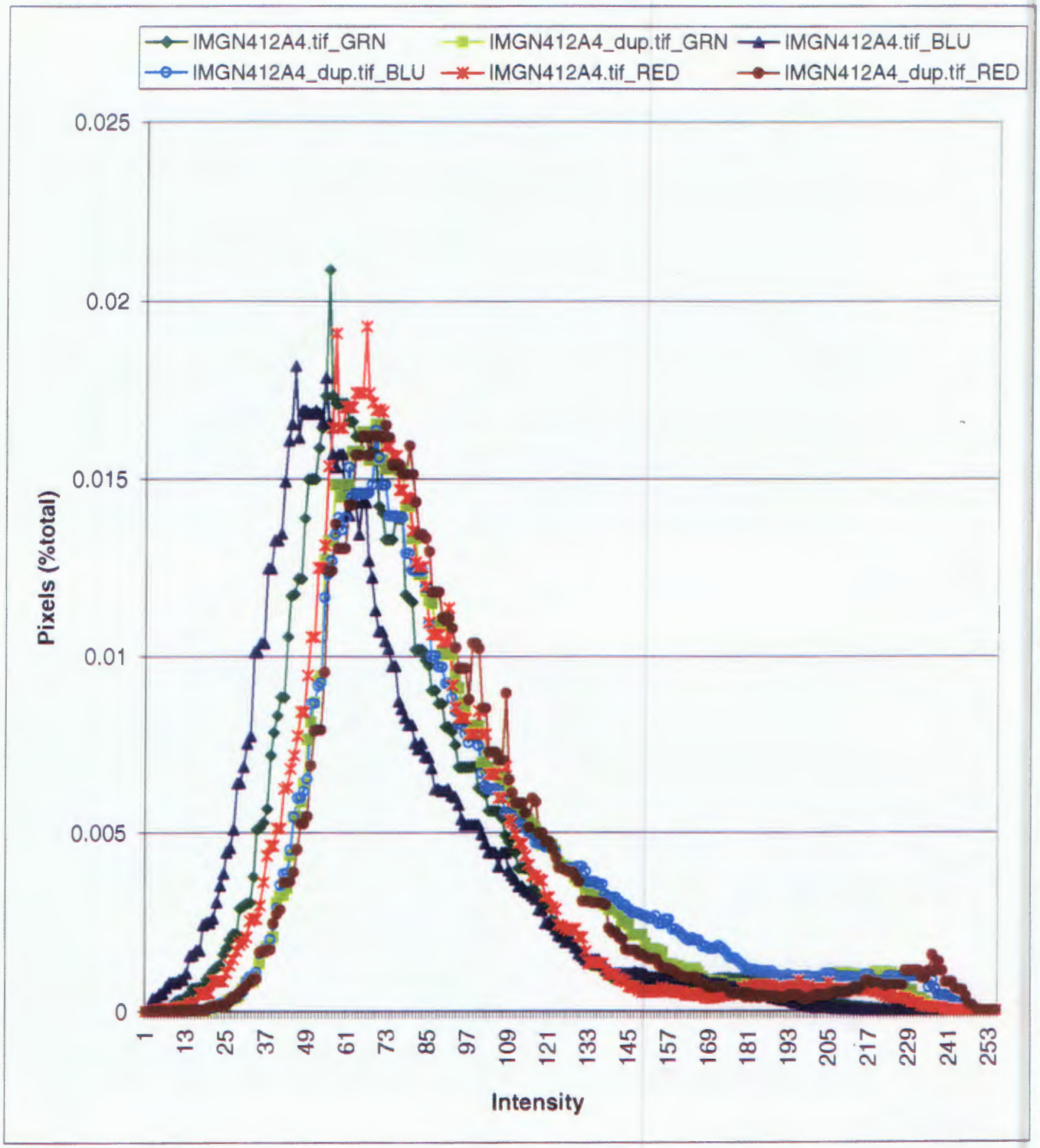


Figure 25. Histograms of the color bands of sub-quads 13–16 on transect B at site 82 taken with (". . . _DUP . . .") and without a camera flash.

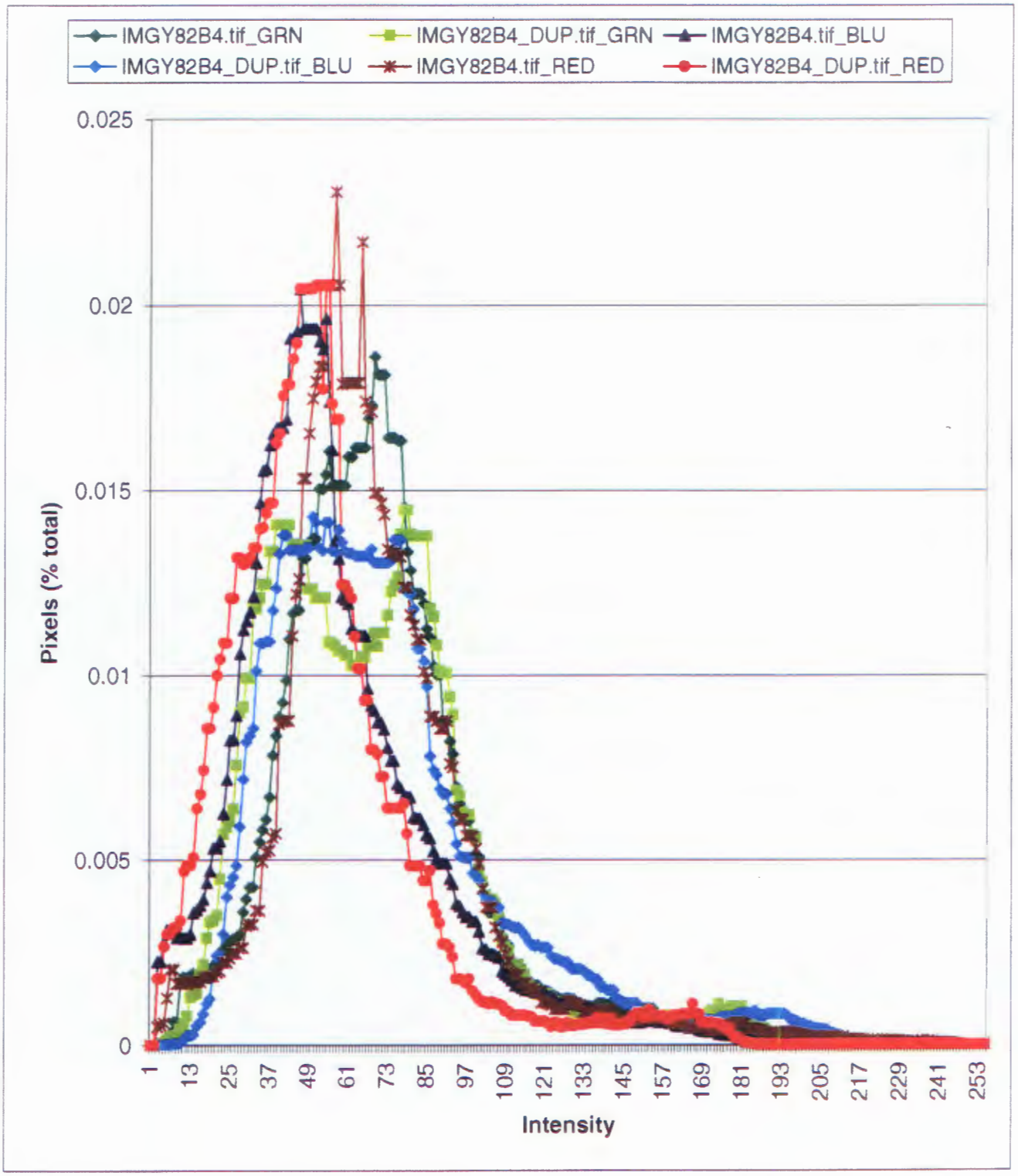


Figure 26. The color band histograms for the cropped image are shown in Figure 28 and labeled MC1.equ.

Area cropped from the 4th sub quad of transect A on site 82 (Posos).

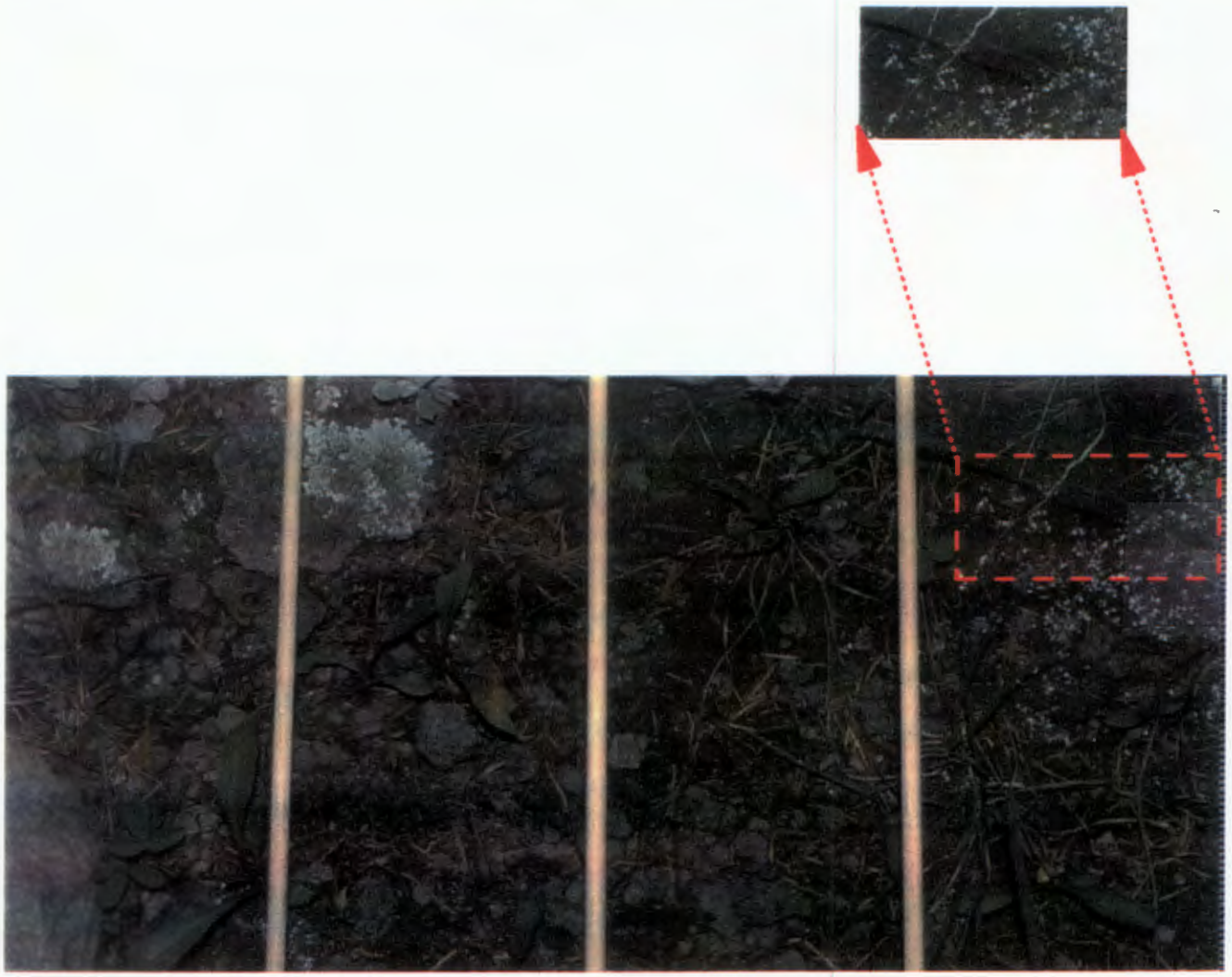


Figure 27. The color band histograms for the cropped image are shown in Figure 28 and labeled MC15.equ.

Area cropped from the 4th sub quad of transect A on site 82 (Posos).

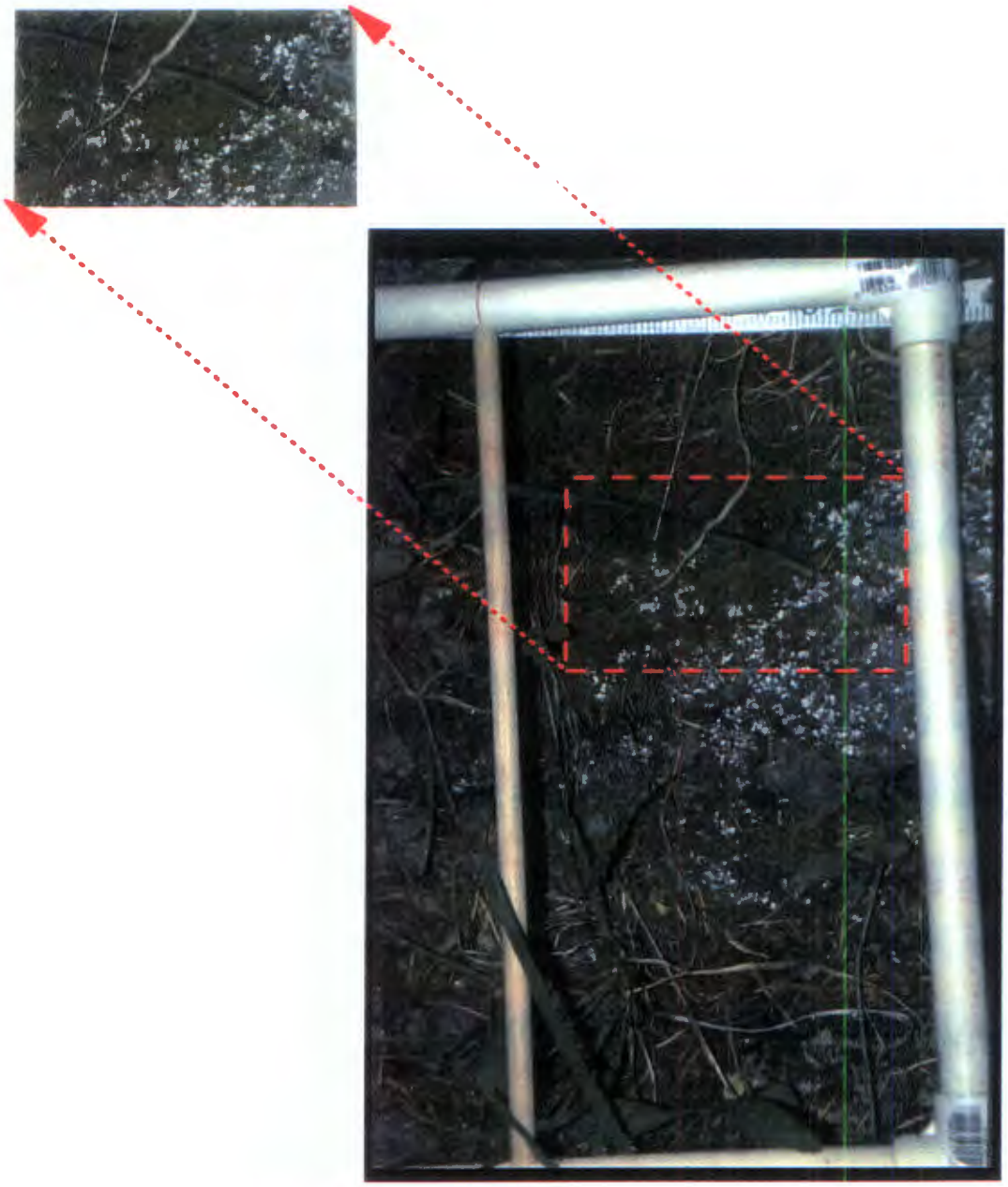
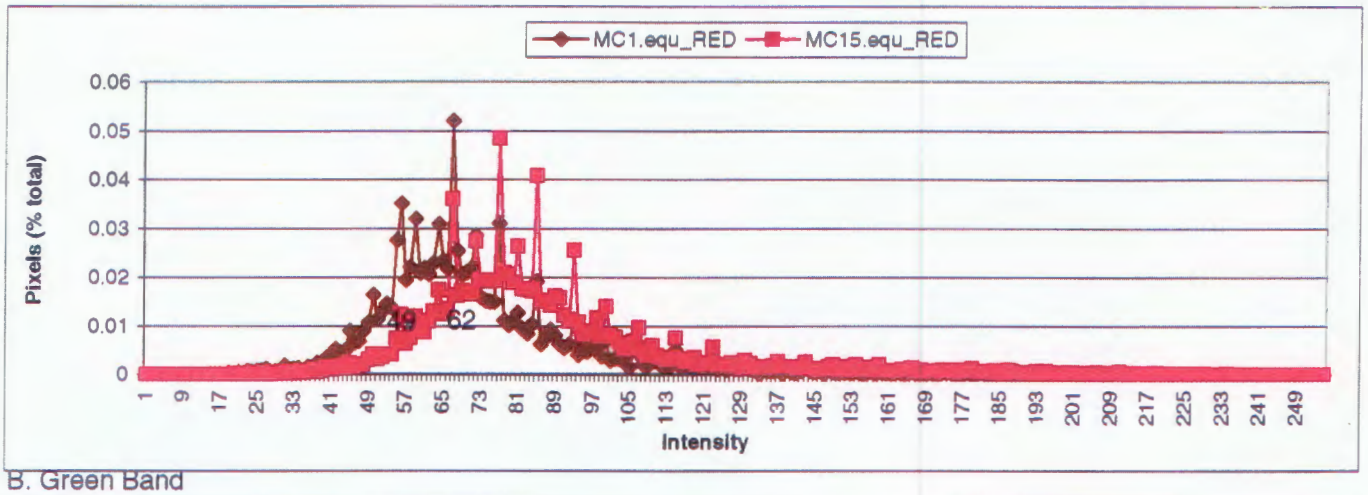
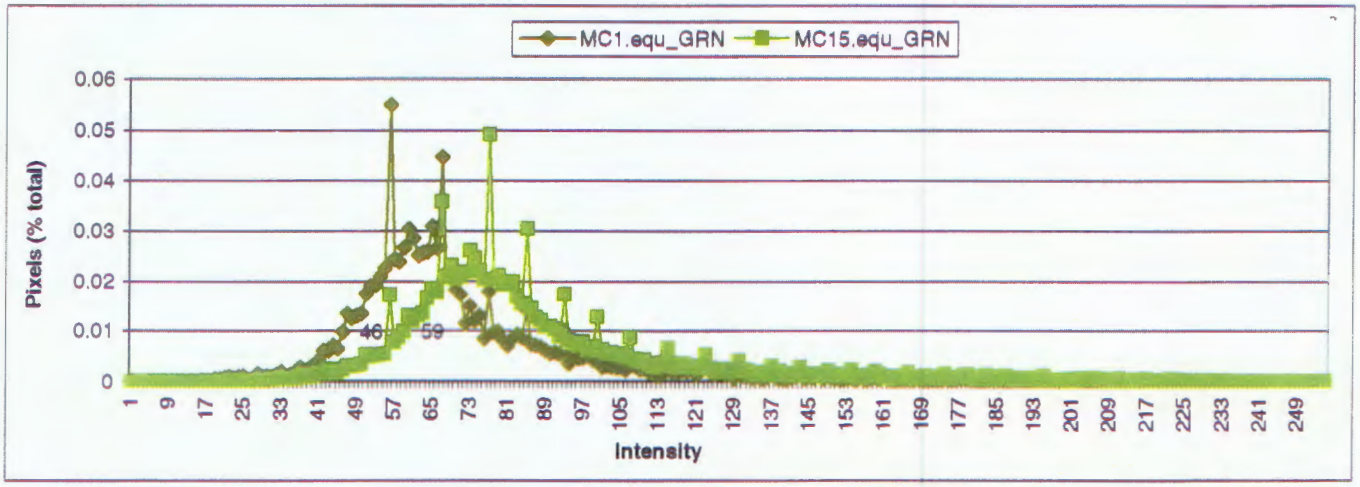


Figure 28. An equivalent portion of a patch of moss and Cladonia cropped from the same quad (sub-quad 4, transect A, site 82). However, the sub-quad was photographed at two different magnifications (Figures 26 and 27). Median filtering has not been applied.

A. Red band



B. Green Band



C. Blue Band

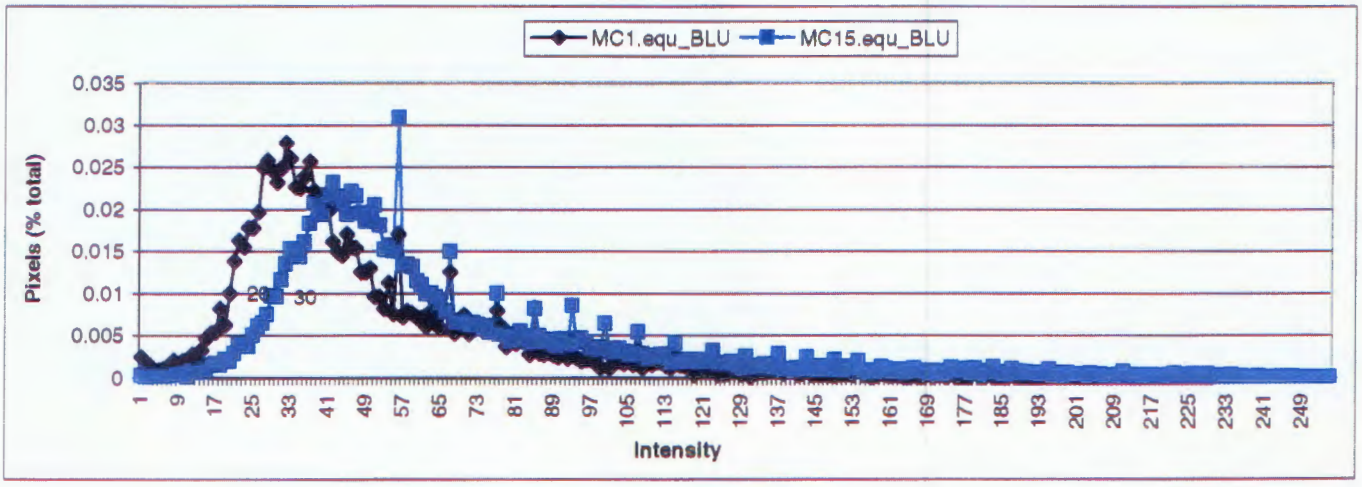


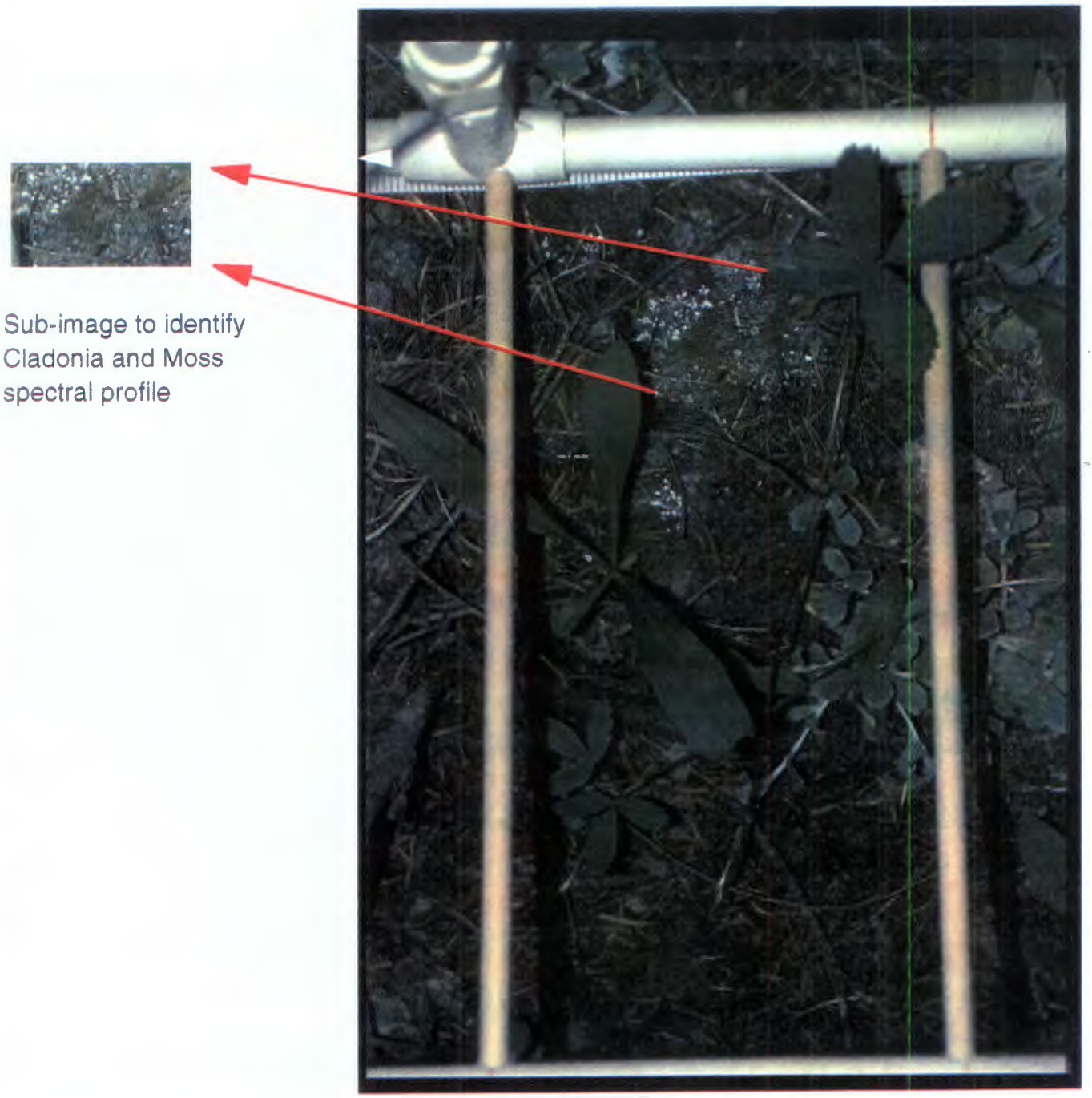
Figure 29. Photographs of sub-quads 1–4 on transect A at site 82.

Figure 30. Photograph of sub-quad 4 on transect A at site 82.

Sub-image to identify Cladonia and Moss spectral profile

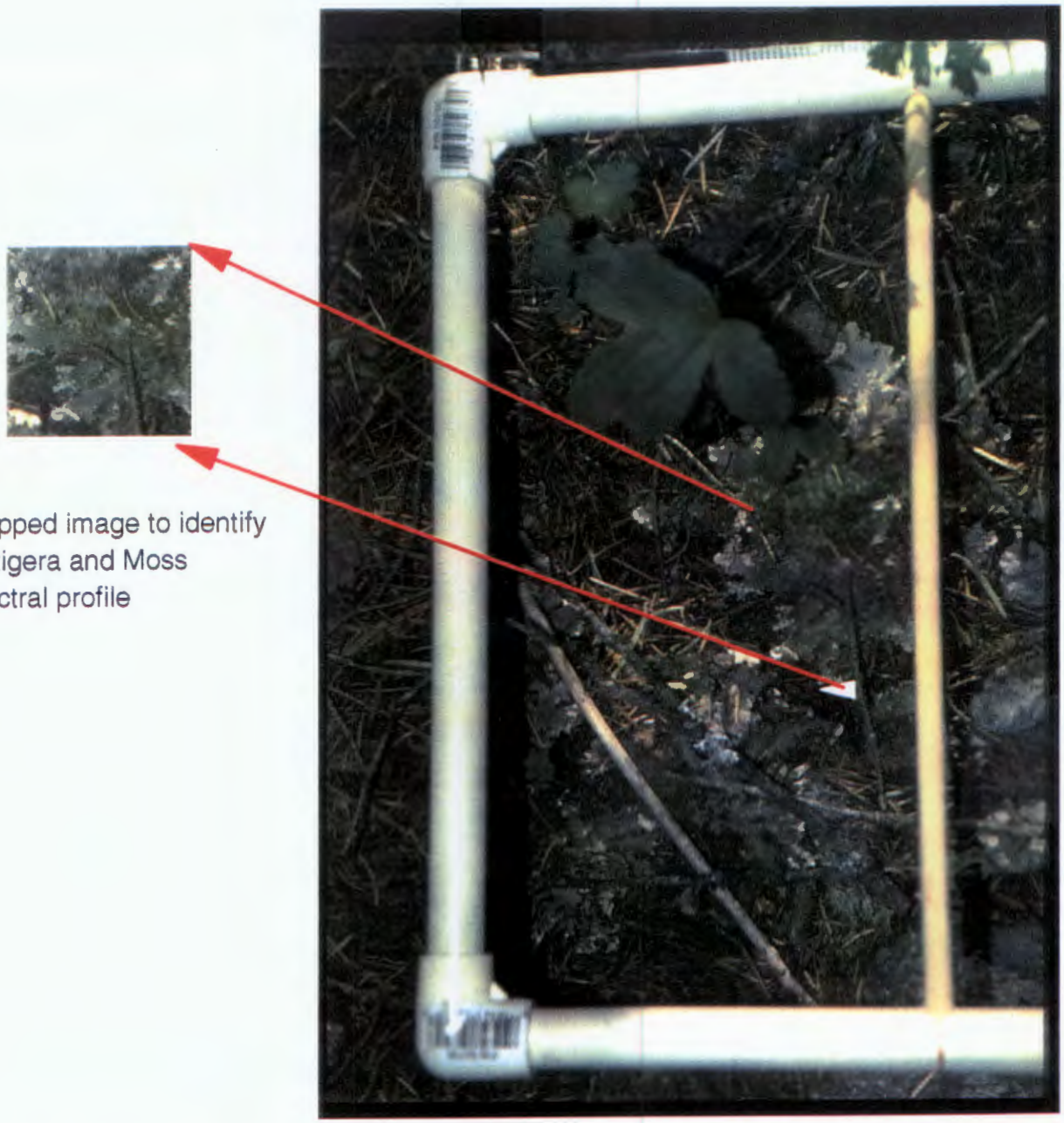
Quad 4 on Transect A at site 82 (Posos)

Figure 31. Photograph of sub-quad 7 on transect A at site 82.



Quad 7 on Transect A at site 82 (Posos)

Figure 32. Photograph of sub-quad 1 on transect C at site 82.

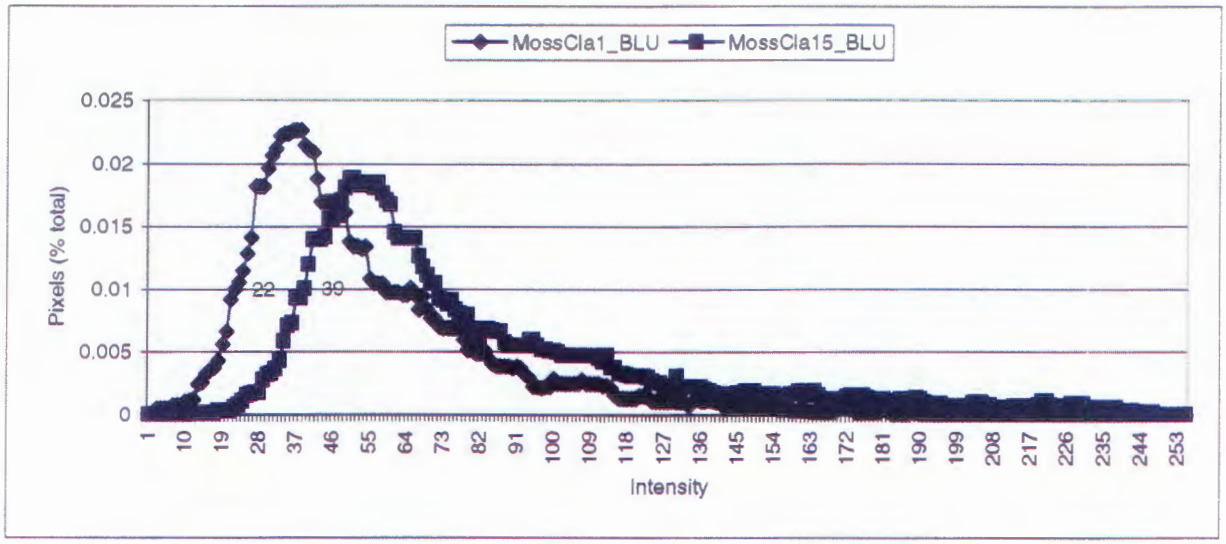


Cropped image to identify Peltigera and Moss spectral profile

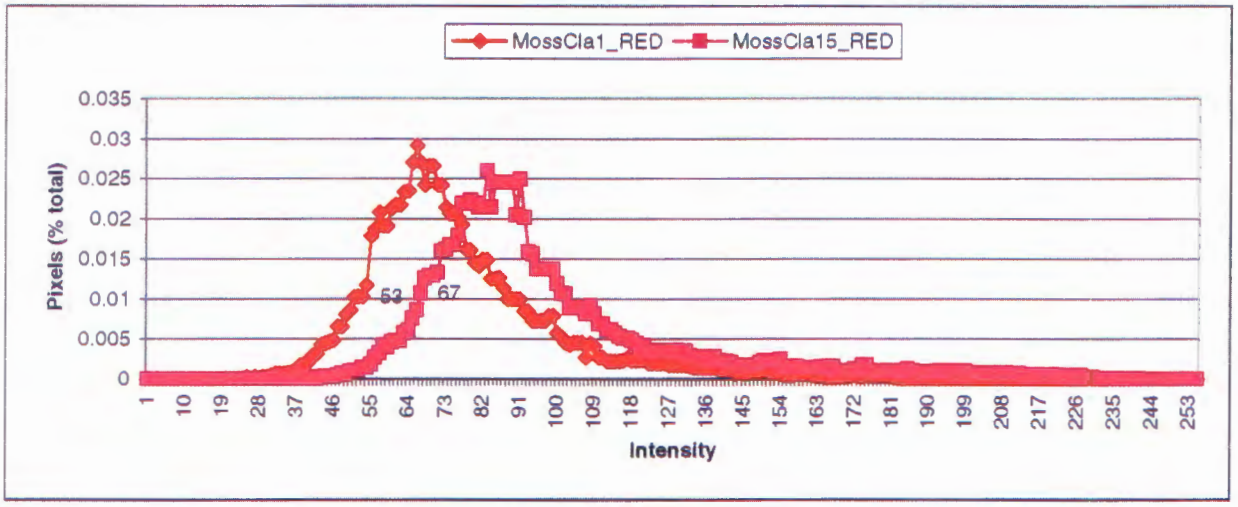
Sub-quad 1 on transect C at site 82 (Posos)

Figure 33. Histograms of the color bands derived from the cropped images in Figures 29 and 30. Values on the graph indicate the x-value at the intersection with y = 0.01%.

A.



B.



C.

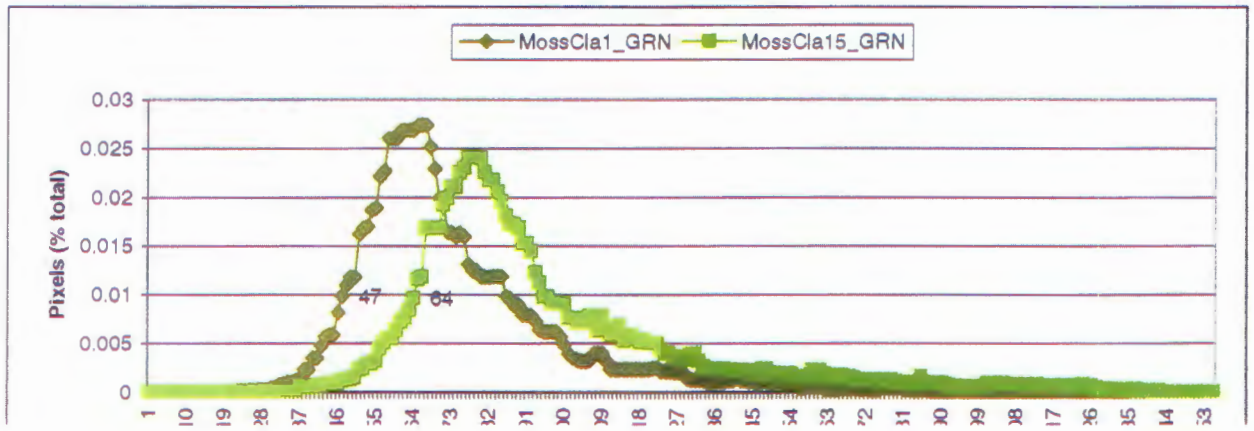


Figure 34. Histograms of the color bands of the cropped cryptogam images. MossCla18 is shown in Figure 31, and MossPel14 is shown in Figure 32.

A. Blue band

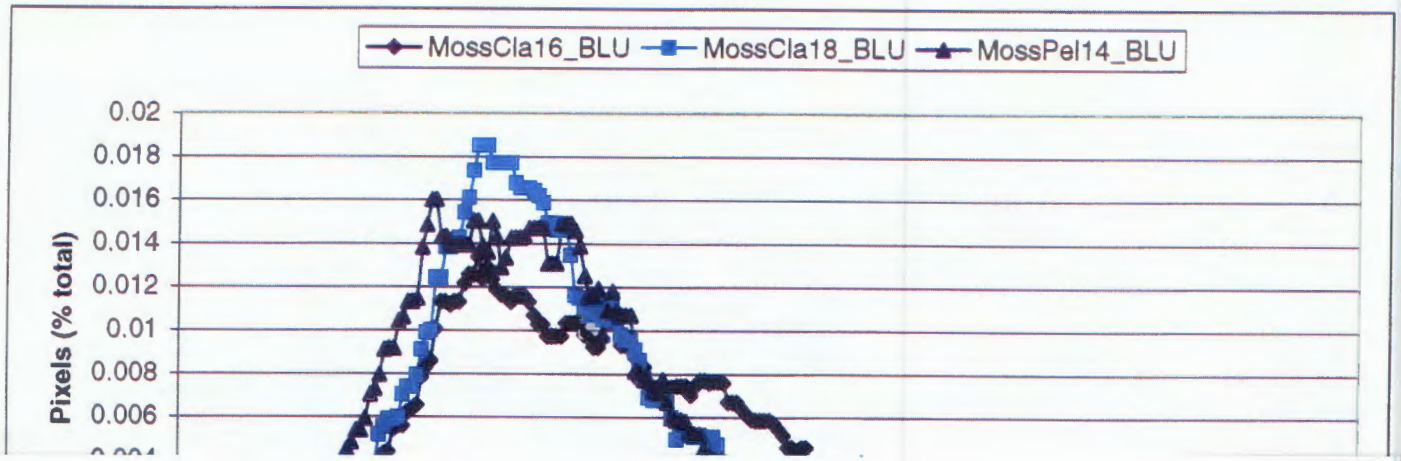


Figure 35. The bar chart shows the distribution of the positive and negative quads among clusters according to the green color band histograms. Zero padding was applied and intensity levels 220-255 were eliminated. See text for details. There were 70 quads in cluster 1, and 72 in cluster 2. Hierarchical cluster analysis used the correlation coefficient distance and complete linkage.

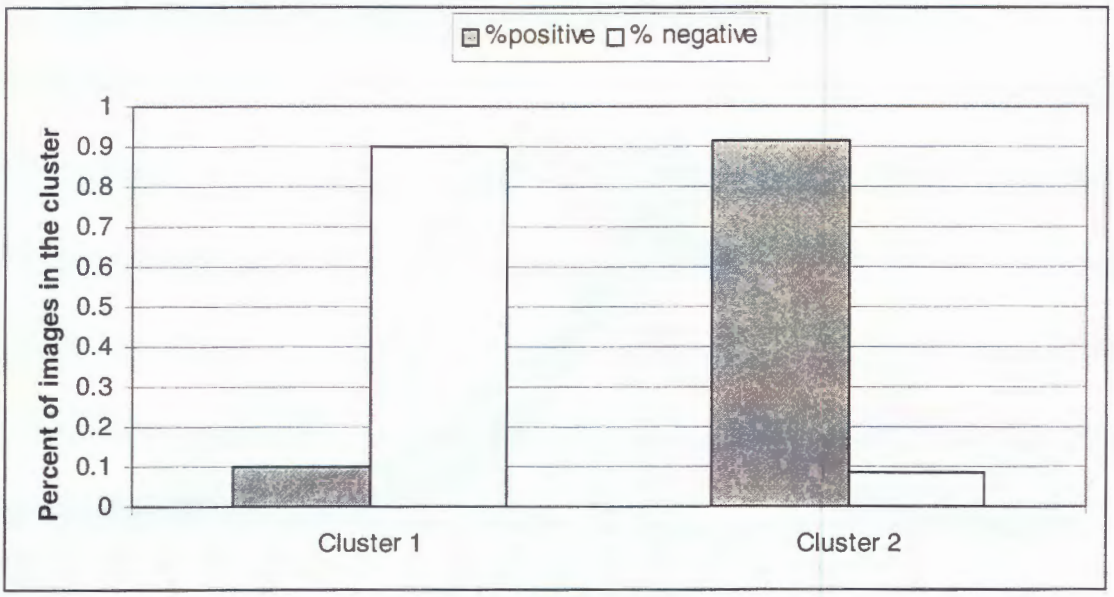
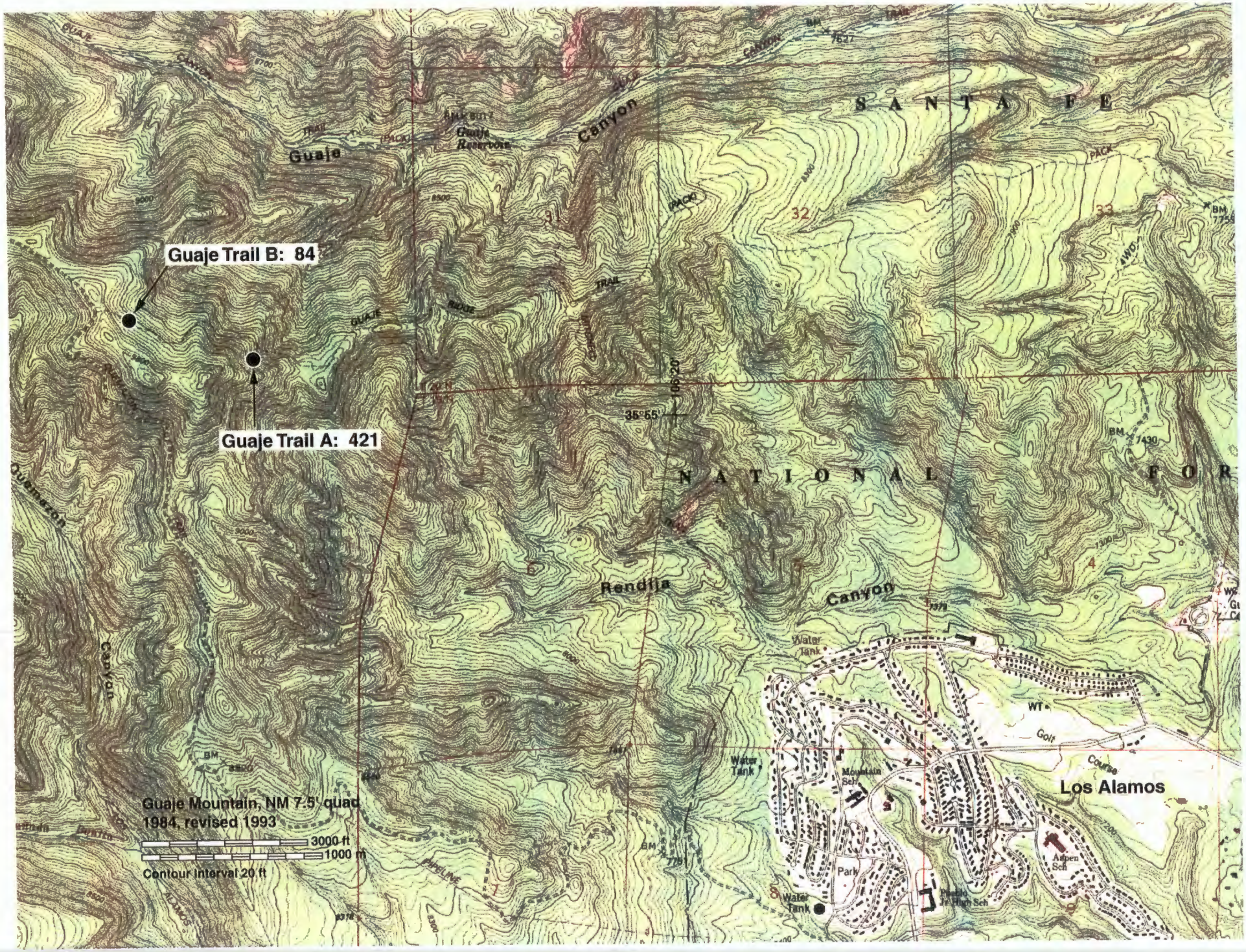
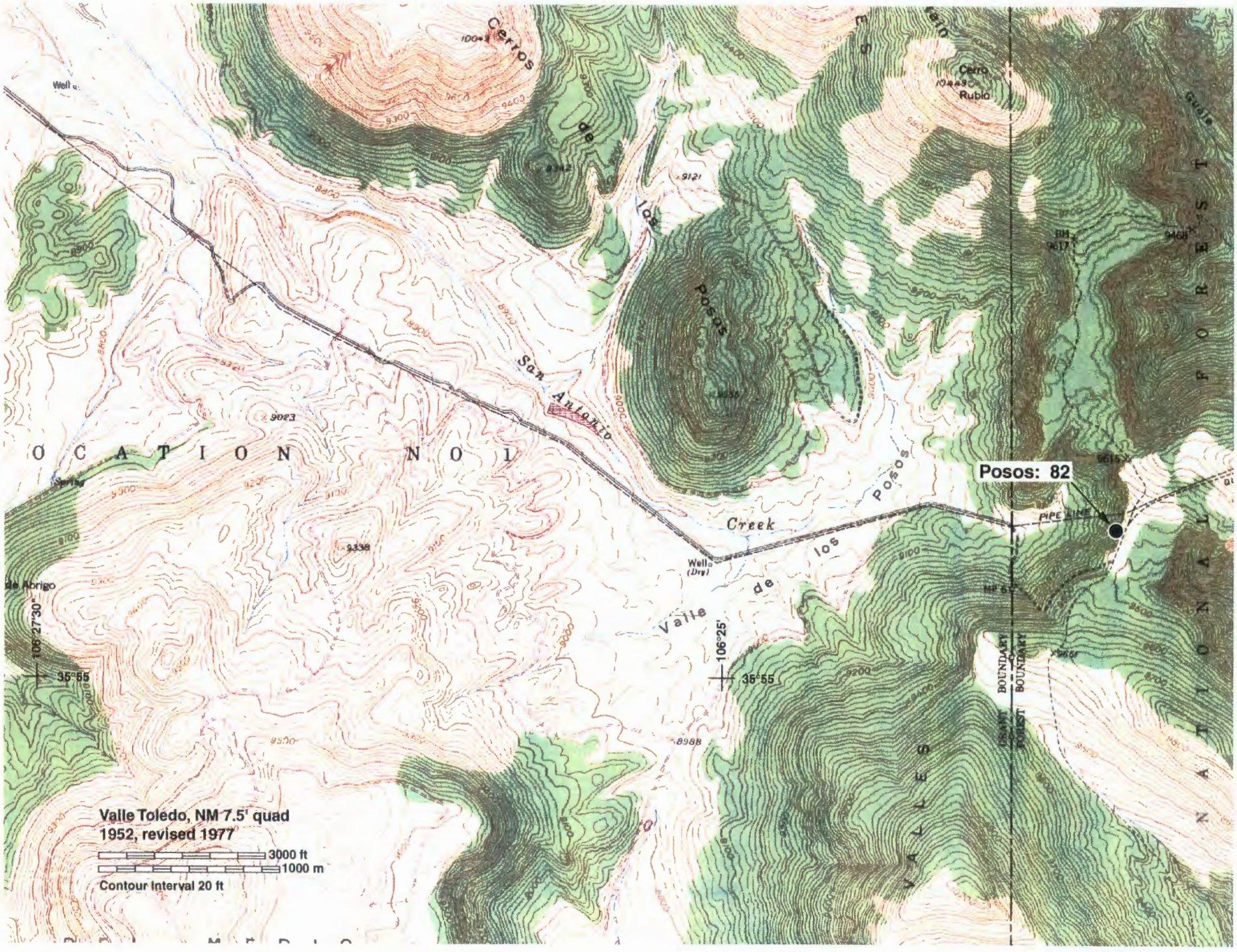


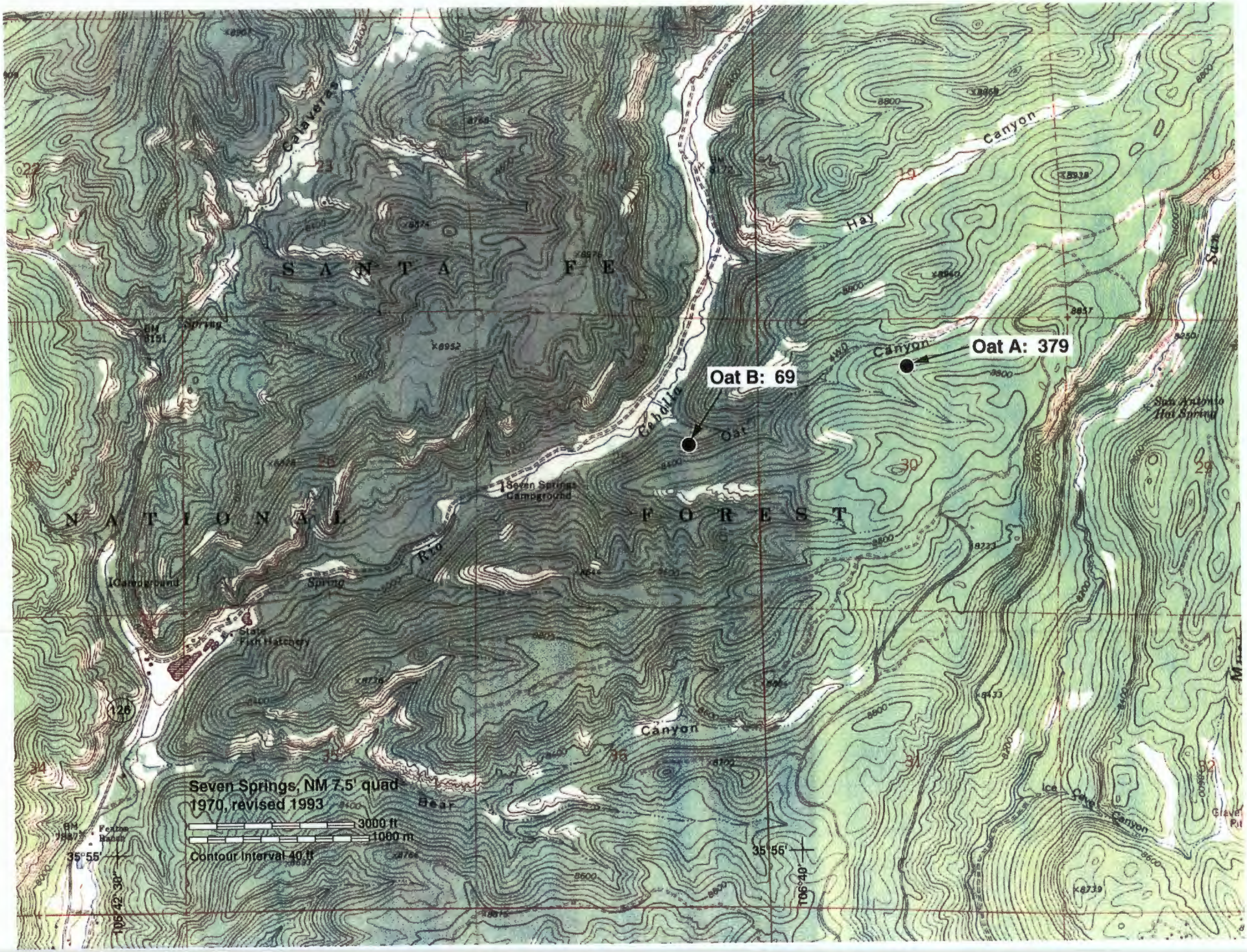
Figure 36. The bar chart shows the distribution of the positive and negative quads among clusters according to the blue color band histograms. Zero padding was applied and intensity levels 220-255 were eliminated. See text for details. There were 68 quads in cluster 1, and 74 in cluster 2. Hierarchical cluster analysis used the correlation coefficient distance and complete linkage.

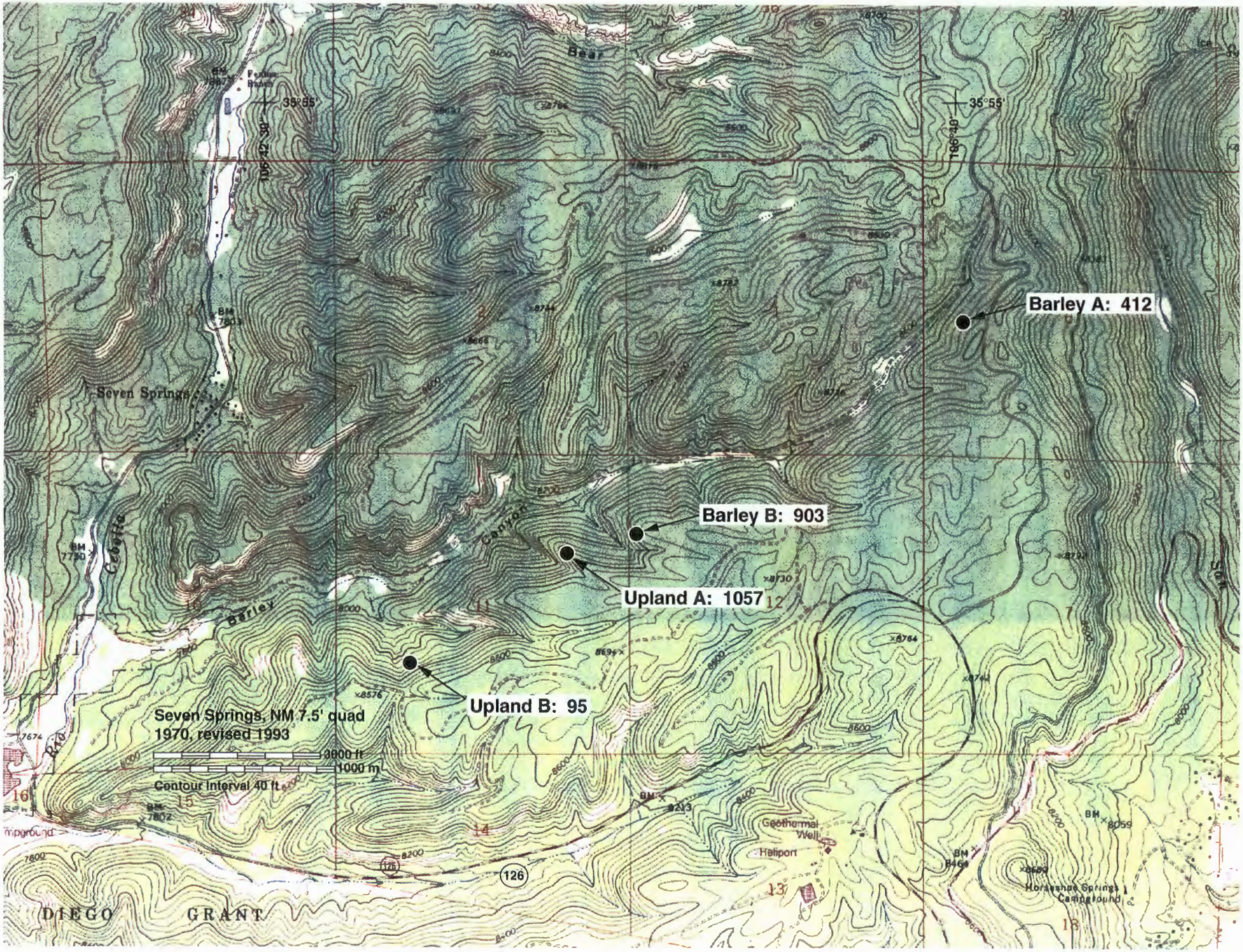
Appendix A.

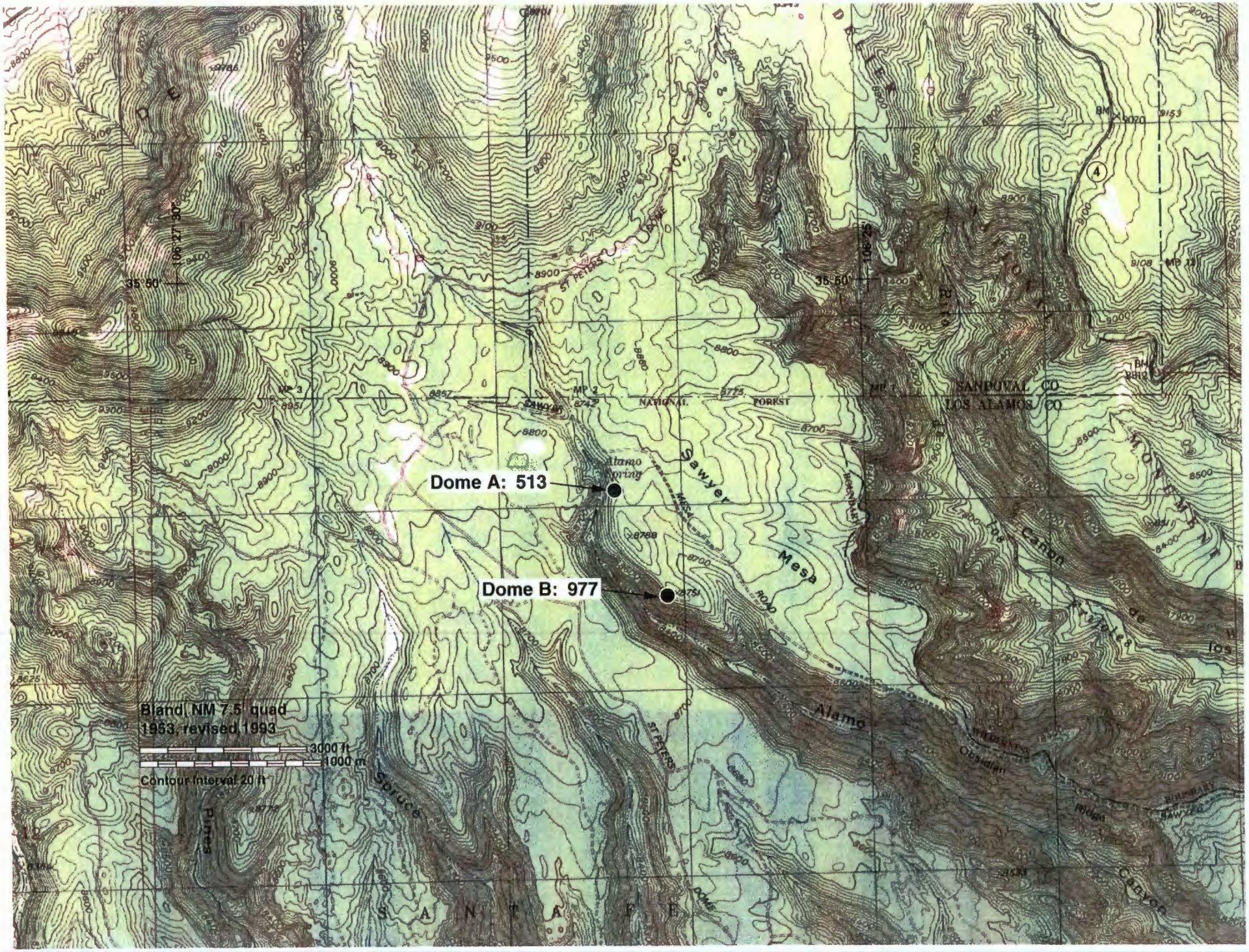
Maps showing the locations of the various sites.


Guaje Trail B: 84
Guaje Trail A: 421
Guaje Canyon
Rendija Canyon
Los Alamos
Guaje Mountain, NM 7.5' quad
1984, revised 1993
3000 ft
1000 m
Contour Interval 20 ft


Posos: 82
Valle Toledo, NM 7.5' quad
1952, revised 1977
3000 ft
1000 m
Contour Interval 20 ft
Cerros de los Posos
San Antonio Creek
Valle de los Posos
Cerro Rubio
Well (Dry)
PIPE LINE
BOUNDARY
FOREST
106°27'30"
35°55'
106°25'
35°55'
9023
9338
8988
9121
9300
9400
9500
9600
9700
9800
9900
10000
10049


Oat A: 379
Oat B: 69
Seven Springs, NM 7.5' quad
1970, revised 1993
3000 ft
1000 m
Contour Interval 40 ft
S A N T A F E
N A T I O N A L F O R E S T
Calaveras
Canyon
Hay
Canyon
Cabolla
Oat
Canyon
Seven Springs Campground
Spring
Rio
Campground
State Fish Hatchery
Canyon
Bear
Canyon
Ice
San Antonio Hot Spring
35°55'
106°42'30"
106°40'
126


Barley A: 412
Barley B: 903
Upland A: 1057
Upland B: 95
Seven Springs, NM 7.5' quad
1970, revised 1993
3000 ft
1000 m
Contour Interval 40 ft
Seven Springs
Bear
Canyon
Barley
Geothermal Well
Heliport
Horseshoe Springs Campground
DIEGO
GRANT
126
35°55'
106°40'
106°42'30"


Dome A: 513
Dome B: 977
Bland, NM 7.5' quad
1953, revised 1993
3000 ft
1000 m
Contour Interval 20 ft
Sawyer Mesa
Alamo Canyon
Spruce
Pines
Alamo
Obsidian
Ridge
Canyon
SANDOVAL CO
LOS ALAMOS CO
NATIONAL FOREST
ST PETERS
35°50'
106°27'30"
106°25'

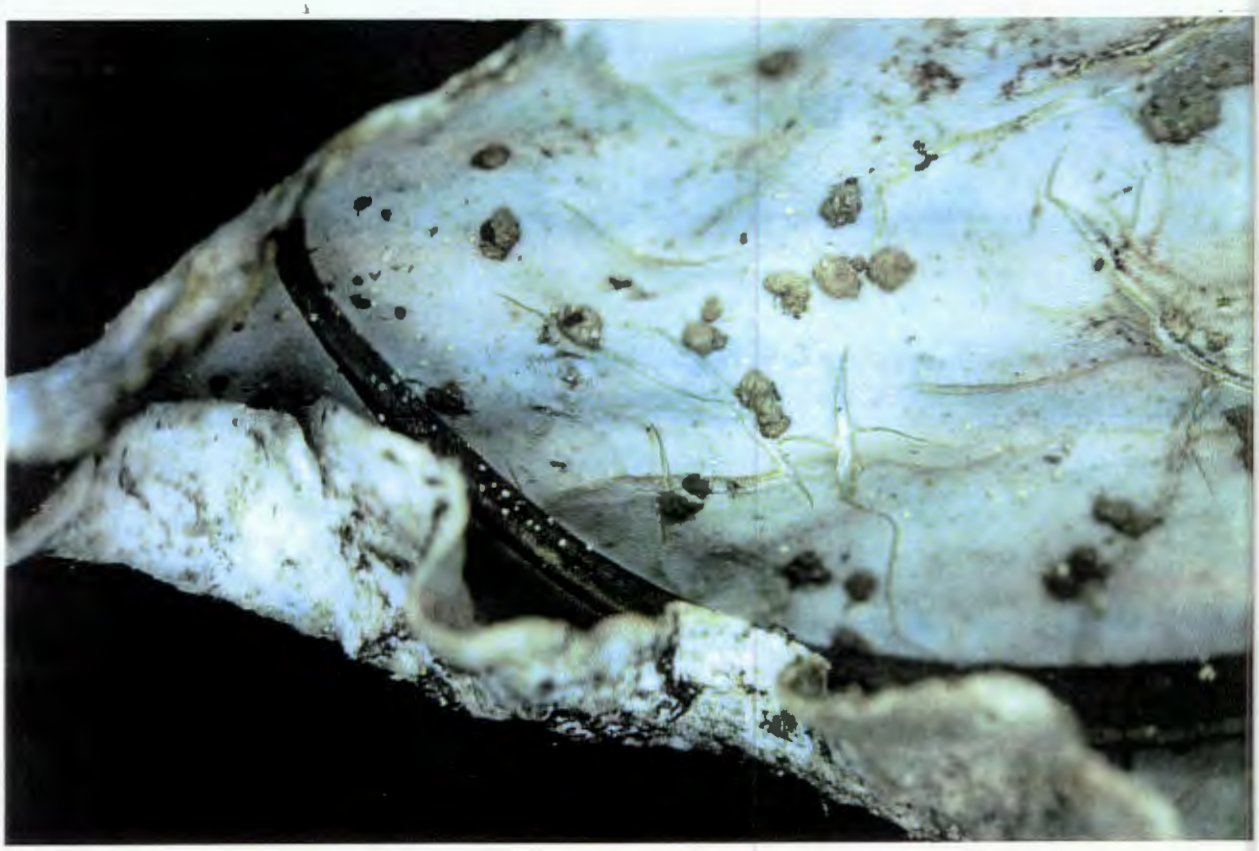
Appendix B.

Photographs of some of the cryptogam species found on the transects.

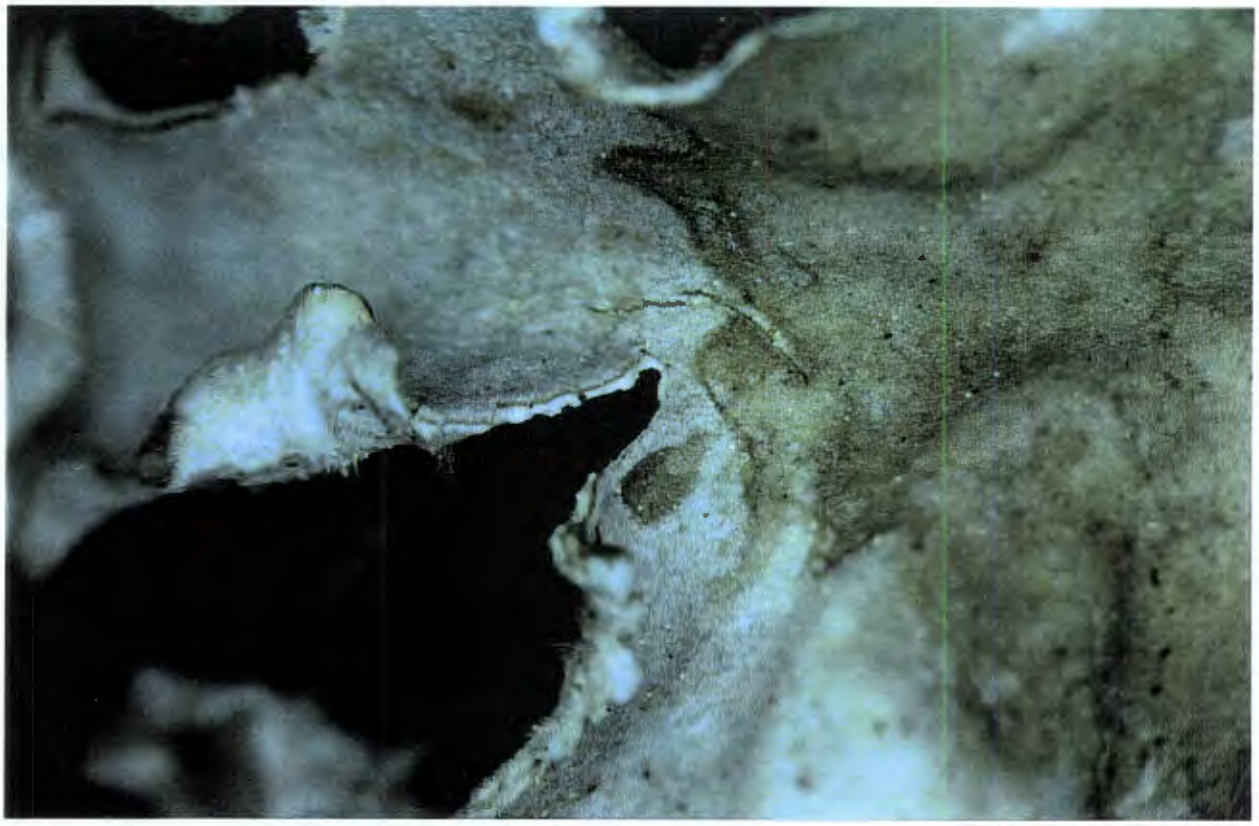
Micrograph of Hypnum revolutum

Micrograph of Dicranum rhabdocarpum

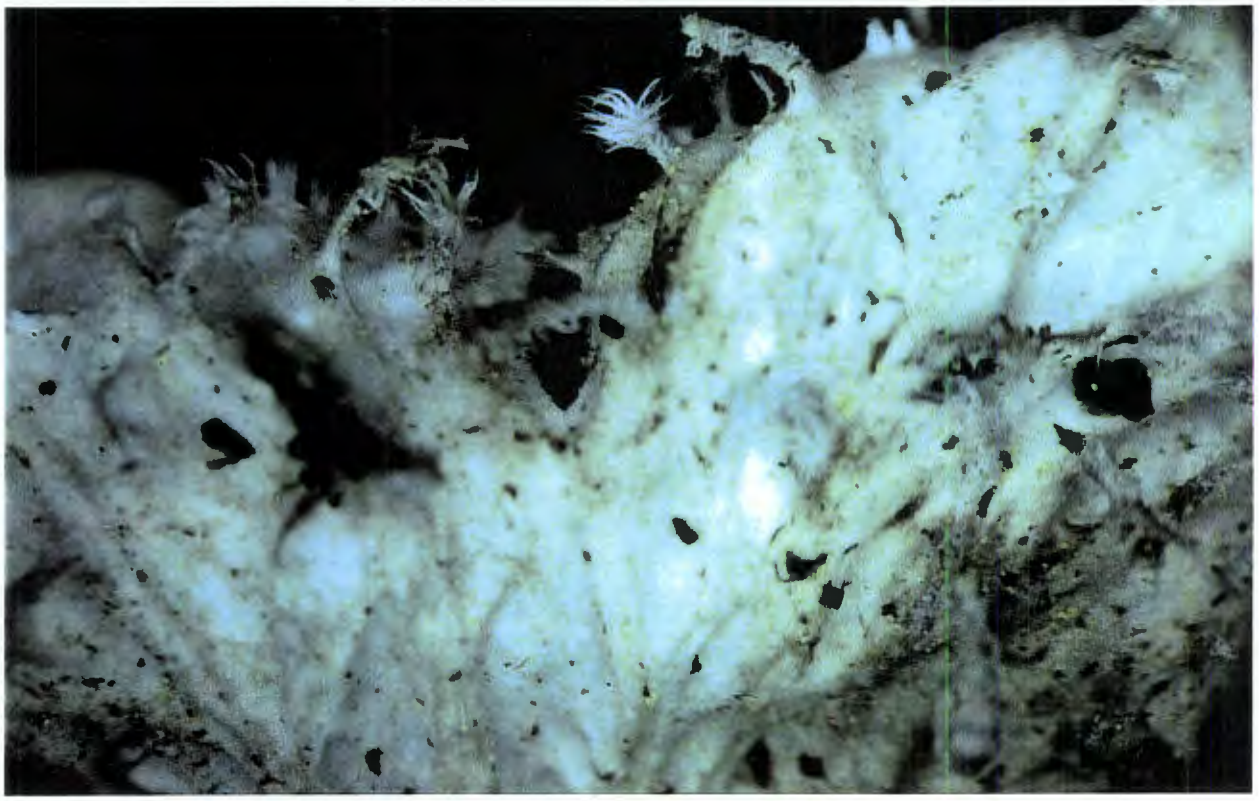
Micrograph of *Peltigera aphthosa*:
The lichen is wet.



Micrograph of *Peltigera aphthosa*:
The lichen is dry.



Micrograph of *Peltigera canina*:
View of the top surface.



Micrograph of *Peltigera canina*:
View of the underside surface that is in contact with the ground. The rhizines are clearly visible.

Micrograph of Peltigera horizontalis

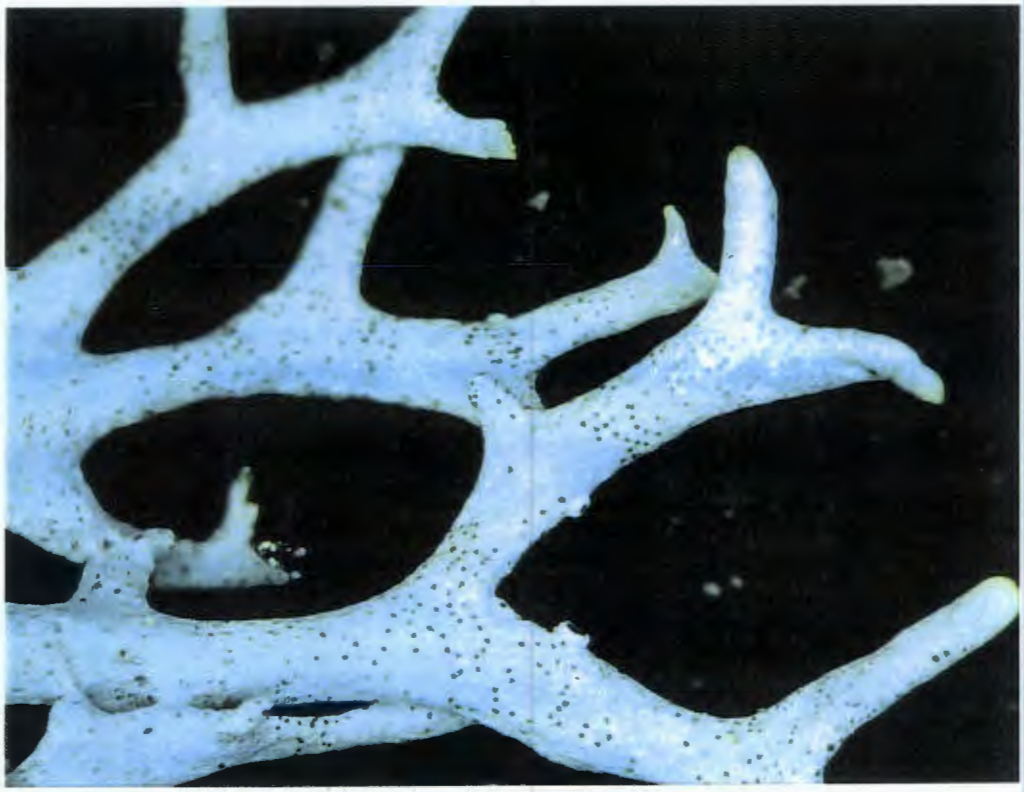
Micrograph of *Cladonia chlorophaea:*
View from above.

Micrograph of *Cladonia chlorophaea:*
Note the characteristic cup of *Cladonia* species.

Micrograph of *Cladonia coniocraea*

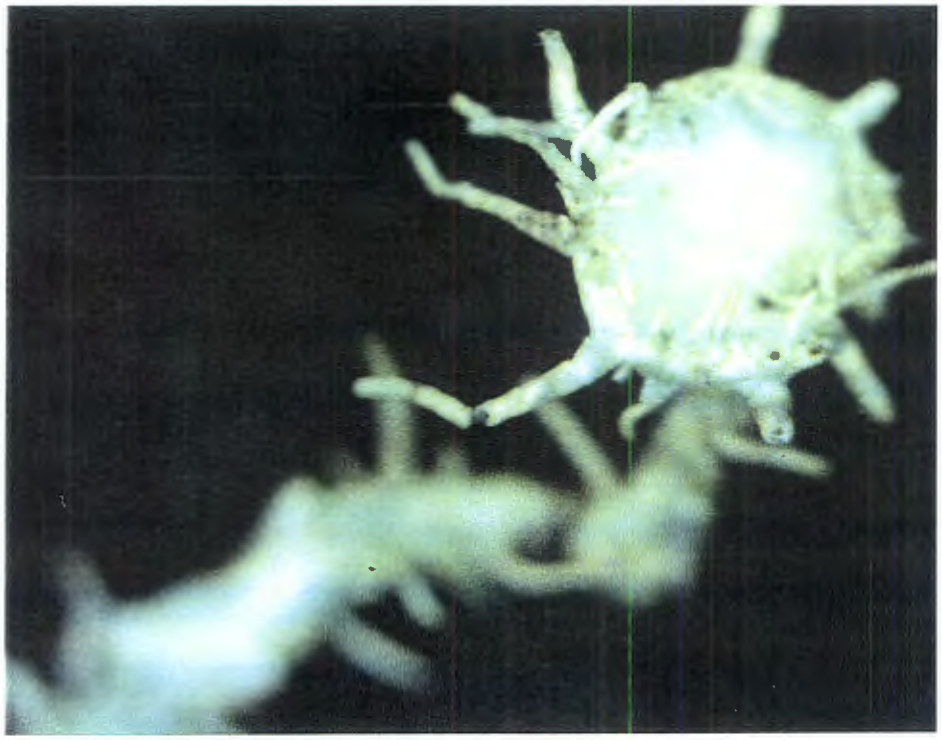
Micrograph of *Cladonia cariosa:*
Note the yellow basal area that indicates that this lichen is K^+ after reaction with concentrated potassium hydroxide (KOH). Such chemical tests are important for species identification.

Micrograph of *Psoroma hypnorum*



Micrograph of *Pseudevernia intensa*:
View of the top side of the thallus.

Micrograph of *Pseudevernia intensa*:
View of the characteristic ridged underside of the thallus.



Micrograph of *Usnea arizonica*:
View of the thallus and large apothecia.

Micrograph of *Usnea arizonica*:
View of the characteristic dense central cord of many of the *Usneas.*

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