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Strategic Environmental Research and Development Program
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NNSA
National Nuclear Security Administration

Bechtel Nevada

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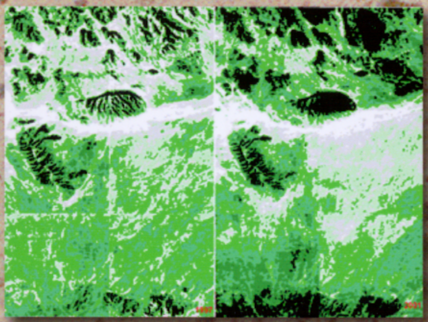
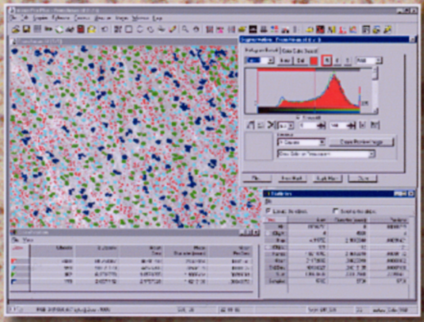
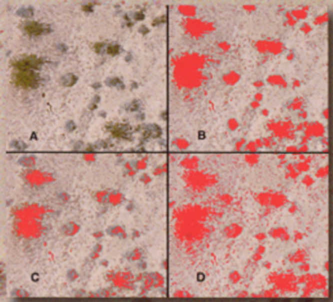
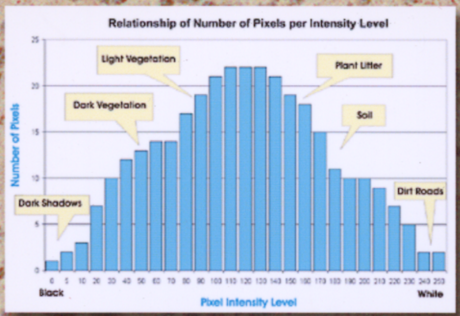
VEGETATION CHANGE ANALYSES USER'S MANUAL









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Vegetation Change Analysis USER'S MANUAL

October 1, 2002

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The Technical Advisory Team was comprised of Dr. Cyrus McKell, President of Applied Ecological Services in Salt Lake City, Utah, who served as chairman and six other specialists in the areas of remote sensing, reclamation, and arid-land ecology: Dr. Merrill Ridd from the University of Utah, Salt Lake City, Utah; Dr. Charles Hutchinson from the University of Arizona's Office of Arid Land Studies, Tucson, Arizona; Dr. Kathryn Thomas from the University of Northern Arizona, Flagstaff, Arizona; Dr. Von Winkel (formerly with Science Applications International) from the Las Vegas Valley Water District, Las Vegas, Nevada; Dr. Steven Monsen, from the U.S. Forest Service Shrub Science Laboratory, Provo, Utah; Dr. Richard Gebhardt from the USACERL, Champaign, Illinois.

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Fort Hunter Liggett in California; the Orchard Training Area, Idaho Army National Guard in Idaho; and the Idaho National Engineering and Environmental Laboratory in Idaho.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ASA	American Standards Association
BMP	Blimp Aerial Photography
BN	Bechtel Nevada
CD	Compact disks
cm	centimeter
CMYK	Cyan, Magenta, and Yellow and blacK
CIR	Color Infrared
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
dpi	disintegrations per inch
ENVI	Environment for Visualizing Images
ESRI	Environmental Systems Research Institute
FAA	Federal Aviation Administration
ft^3	cubic feet
GIS	Geographic Information System
GPS	Global Positioning System
IT	ImageTool
ITAM	Integrated Training Area Management
JPG	Joint Photographic Experts Group
KAP	Kite Aerial Photography
lbs	pounds
LCTA	Land Condition Trend Analysis
m^2	square meters
m^3	cubic meters
MB	megabyte
mm	millimeter
MrSID	Multiresolution Seamless Image Database
NASA	National Aeronautics and Space Administration
NTS	Nevada Test Site
PDF	Portable Document Format
RGB	Red, Green, and Blue

SAE	Society of Automotive Engineers
SERDP	Strategic Environmental Research and Development Program
TIFF	Tagged Image File Format
TMSES	Terrain Modeling and Soil Erosion Simulation
USACERL	U.S. Army Construction Engineers Research Laboratory
USAEC	U.S. Army Environmental Center
UTHSCSA	University of Texas Health Science Center, San Antonio
UTM	Universal Transverse Mercators

ABSTRACT

Approximately 70 percent of all U.S. military training lands are located in arid and semi-arid areas. Training activities in such areas frequently adversely affect vegetation, damaging plants and reducing the resilience of vegetation to recover once disturbed. Fugitive dust resulting from a loss of vegetation creates additional problems for human health, increasing accidents due to decreased visibility, and increasing maintenance costs for roads, vehicles, and equipment. Diagnostic techniques are needed to identify thresholds of sustainable military use. A cooperative effort among U.S. Department of Energy, U.S. Department of Defense, and selected university scientists was undertaken to focus on developing new techniques for monitoring and mitigating military impacts in arid lands. This manual focuses on the development of new monitoring techniques that have been implemented at Fort Irwin, California. New mitigation techniques are described in a separate companion manual.

This User's Manual is designed to address diagnostic capabilities needed to distinguish between various degrees of sustainable and nonsustainable impacts due to military training and testing and habitat-disturbing activities in desert ecosystems. Techniques described here focus on the use of high-resolution imagery and the application of image-processing techniques developed primarily for medical research.

A discussion is provided about the measurement of plant biomass and shrub canopy cover in arid lands using conventional methods. Both semiquantitative methods and quantitative methods are discussed and reference to current literature is provided. A background about the use of digital imagery to measure vegetation is presented.

Image-capturing techniques using cameras mounted on tripods and hand-held poles, kites, blimps and balloons, helicopters, fixed-wing aircraft, and satellites are discussed. The pros and cons of using various types of cameras and lenses, films, and digital recording media are reviewed and evaluated.

Image processing using various approaches are described in detail with links to useful Web sites including the use of commercial image-processing software. Screen captures of key procedures of selected software are shown and described. Digital image formats are discussed. Classes of image-processing software include: (1) image editing and enhancing (e.g., Picture Window Pro® and Adobe Photoshop®), and (2) georeferencing software (e.g., MrSID®, DIME®). The historical background of measuring plant cover by digital techniques is presented. Several types of image-processing software are described. These include ImageTool, Sigma Scan Pro®, and Image Pro Plus®. A detailed description of the steps required to successfully measure shrub canopy cover is provided, including tips from experienced users, user precautions, and alternate approaches.

A discussion is also provided about image-mapping software such as Surfer® gridding and mapping software. An image conversion program written for this project is described and provided to users to convert TIF (tagged image file) images to Surfer® XYZ tabular grid files. Procedures are described to assist users in exporting maps to rectified shapefiles that can be used in geographic information systems for the purpose of shrub-cover change detection and the

presentation of areas at various thresholds of use. Using these thematic layers permits managers to estimate cost for mitigation and establish priorities for future mitigation efforts.

Additionally an appendix is provided that describes (1) application of techniques used at the U.S. Army's National Training Center at Fort Irwin, California, to evaluate changes in vegetative cover using the new techniques described in this report; (2) a plant-damage assessment technique for evaluating military vehicular impacts to vegetation in the Mojave Desert; and (3) pertinent Internet Web sites and links to other related SERDP projects and government sites that focus on remote-sensing techniques for monitoring and mitigating training impacts.

1.0 INTRODUCTION

This user's manual describes new remote sensing tools that use high or very high-resolution imagery for the purposes of measuring changes in plant canopy cover. Techniques developed during the preparation of this manual provide users with the means of bridging the gap between deficiencies common to remote sensing using satellite imagery and the high cost and time associated with detailed ground surveys. Innovative technologies described in this manual will provide valuable tools to ensure continuation of military testing and training which is currently threatened at many arid-land installations by deteriorating site conditions and will significantly reduce collection costs and time, while increasing data quality and reliability.

1.1 BACKGROUND

Approximately 70 percent of all U.S. military training lands are located in arid and semi-arid areas. Training activities may adversely affect vegetation, damaging plants and reducing the resilience of vegetation to recover once disturbed. The cumulative impacts result in a loss of plant cover, species diversity, plant reproduction, and soil resources such as organic matter and soil microorganisms needed to recycle soil nutrients. Fugitive dust resulting from a loss of vegetation creates additional problems for human health, increasing accidents due to decreased visibility and increasing maintenance costs for roads, vehicles, and equipment.

It is difficult to detect and monitor impacts to vegetation from military training in desert areas using conventional remote sensing techniques that rely on low-resolution satellite imagery. This is because the pixel sizes of satellite images are large (e.g., 10 to 30 square meters per pixel) while the shrub sizes are small (0.25 to 3 square meters in area). Vegetation cover in arid landscapes varies substantially with seasonal changes in climate. Cover is normally low, usually less than 25 percent in undisturbed areas and frequently less than 5 percent in heavily used areas. Sun light reflecting from soils in these desert areas frequently masks the smaller amount and quality of light that is reflected by vegetation making it impossible to accurately measure changes in vegetation cover. New diagnostic techniques are needed to identify thresholds of sustainable military use, and to accurately measure plant canopy cover in arid-land environments.

In 1999, a cooperative effort among U.S. Department of Energy (DOE), U.S. Department of Defense (DoD), and selected university scientists was undertaken to focus on mitigating military impacts in arid lands. Bechtel Nevada (BN) assembled a team of scientists to address these problems in arid lands. The research team included researchers and advisors from government, universities, and private industry. Collaborators include DOE National Nuclear Security Administration Nevada Operations Office (formerly known as DOE Nevada Operations Office [DOE/NV]) BN; DoD–Fort Irwin, Center for Ecological Management of Military Lands at Colorado State University; U.S. Army Construction Engineers Research Laboratory (USACERL), California State University–Dominguez Hills; and Weber State University–Applied Ecological Services, Inc. Fort Irwin, the Army's National Training Center (NTC) located near Barstow, California, in the Mojave Desert, was selected as the primary test site for development of new technologies. The approach focuses on specific problems at the NTC, but is suitable for other DoD and DOE facilities located in arid and semiarid areas. Diagnostic tools developed by this program may also be applicable to wetter areas of the United States.

1.2 GOALS AND OBJECTIVES

This manual is designed to address current gaps in diagnostic capabilities needed to distinguish between various degrees of sustainable and nonsustainable impacts due to military training and testing or earth-disturbing activities in desert ecosystems. These diagnostic tools will enable management to maximize utilization of limited training environs and thus increase operational readiness. Specific objectives of this manual include:

- Discuss the measurement of plant canopy cover in the Mojave Desert
- Describe the limitation and variability of conventional ground sampling techniques
- Evaluate image-capturing techniques for obtaining large-scale aerial imagery
- Evaluate image-processing software and techniques for measuring shrub cover
- Summarize findings and describe recommendations for new diagnostic techniques

1.3 USERS MANUALS

The technologies evaluated and tested are divided into two principal areas: (1) diagnostics and (2) restoration techniques. Technologies are described in two separate user's manuals:

Vegetation Change Analysis User's Manual. Dennis J. Hansen and W. Kent Ostler. 2002. DOE/NV/11718—729, Bechtel Nevada, Ecological Services, Las Vegas, NV 89193.

New Technologies to Reclaim Arid Lands User's Manual. W. Kent Ostler, David C. Anderson, Derek Hall, and Dennis J. Hansen. 2002. DOE/NV/11718—731, Bechtel Nevada, Ecological Services, Las Vegas, NV 89193.

These manuals were distributed in a workshop held in Las Vegas, Nevada, during the fall of 2002. The purpose of the workshop was to facilitate technology transfer by presenting the new technologies and assisting scientists working at selected military installations to understand how the these technologies could assist them in managing biological resources at their sites.

1.4 RELATIONSHIP TO OTHER USER'S MANUALS AND TECHNOLOGIES

Information about remote sensing has been assembled by the National Aeronautics and Space Administration (NASA) and the U.S. Army Environmental Center in the form of a Remote Sensing Tutorial. The objective of this tutorial is to provide organized tools to help land managers take advantage of existing remote sensing technology.

Basic information about remote sensing organizations, links, conferences, publications, and sources of imagery can be located through the remote sensing Internet Virtual Library (http://www.vtt.fi/tte/research/tte1/tte14/virtual/).

The reader is also referred to a related Strategic Environmental Research and Development Program (SERDP) project that describes the effect of spatial resolution on vegetation cover, developing and testing a procedure to scale-up vegetation cover estimates, and development of procedures and models to estimate standing woody biomass in arid areas (Tweddale *et al.* 2002)

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2.0 MEASUREMENT OF PLANT BIOMASS AND COVER

An essential component of monitoring to determine the spatial extent and degree of military impact is the ability to accurately assess site changes through time as training areas undergo normal use under varying climatic conditions. Historically, monitoring techniques have been primarily limited to expensive, labor-intensive, ground collection of data such as plant canopy cover by line-point or line-intersect methods, and plant density by quadrant sampling techniques. Additionally, accessibility to the range by field biologists has been limited at some sites to only one week each month because of intensive military training exercises, making it difficult to obtain sufficient field data during narrow windows of opportunity.

Alternatives to ground-based monitoring techniques are those that focus on remote sensing. Traditionally, these techniques have used satellite imagery as a means of capturing and assessing vegetation conditions at a landscape-size area or scale. Information such as the intensity of a particular wavelength of light or ratio of wavelengths from individual area units of the satellite image (known as pixels) are then statistically correlated with data taken on the ground (e.g., canopy cover or plant density). Pixel size for most satellite images ranges from 10 meters square (m^2) to 30 m^2 (328 feet square [ft^2] to 2,953 ft^2), which further restricts the usefulness of this technique because most shrubs are often less than 1 m^2 (11 ft^2) in size. This method is useful in areas where ground cover of vegetation is relatively high (e.g., > 30 percent cover) and impacts to the vegetation result in spectral changes that are detectable in the digital images (Falkner, 1995). Such conditions are common for agricultural lands, grasslands, and forest areas, but this method is less useful in desert areas where plant canopy cover is often less than 10 percent and may be as low as 1 to 2 percent following intensive training impacts such as encampment.

Large-scale ecoregion management approaches have relied upon satellite imagery such as LANDSAT multispectral and thematic mapper, and Satellite pour L'Observation de la Terre panchromatic/multispectral images (Plumb and Pillsbury, 1986). For example, at Fort Irwin, California, the use of this approach has been successful in identifying broad disturbance patterns attributed to military training impacts over time (Lee, 1995). Fort Irwin was selected for development of new diagnostic tools because it is one of the largest military training facilities and it is where previous studies have provided a sound foundation of biological, modeling, and remote sensing information. Proposed work was designed to be built on this foundation of existing site information.

Despite the usefulness of conventional remote-sensing techniques, data deficiencies still exist in applying these techniques to assess the sustainability of training impacts. The deficiencies are associated with the inability to obtain additional levels of detail needed to determine essential characteristics of the vegetation such as shrub cover, density, and species composition. These parameters are needed to establish recovery thresholds where increasing costs and rest-rotational use patterns may restrict short-term use in order to sustain long-term testing and training.

Because training impacts are ongoing at most military training areas and precise location of these impacts are somewhat unpredictable, a method for rapidly monitoring the condition of soils and vegetation is needed to determine the condition of vegetation, assess its resiliency to training impacts, assess impact severity, and direct land maintenance activities. A method for rapid capture of field data is required. Such rapid detection methods are being developed as part of this project using aerial photography and hand-held digital cameras to record selected ground details. These techniques can utilize permanent transects or photo points to assess year-to-year trends and to be compatible with current sampling formats used in the LCTA. The focus of BN's research has been to develop techniques that bridge the gap between the labor-intensive and costly ground collection techniques and remote-sensing techniques using satellite imagery which is less expensive, yet less precise in detecting vegetation change. A discussion follows of techniques used to measure plant biomass and shrub canopy cover and how they can be used to monitor vehicle and training impacts.

2.1 PLANT BIOMASS AND COVER

Among the most important parameters used to describe vegetation are plant biomass and plant cover. These parameters are important for describing plant dominance, community structure, and wildlife habitat. They are used to estimate animal forage, protection of the soil from erosion, and ecosystem functions such as transpiration rates and water budgets or cycles. Plant cover is usually highly correlated with plant biomass and generally much easier to measure. Historically, plant cover has been considered the vertical projection of vegetation parts onto the ground or the amount of ground covered or shaded by a plant. Perturbations to the plant community or changes in the ecosystem often result in changes in plant cover; therefore, changes in vegetative cover can be thought of as an indication of perturbations or disturbance.

2.2 PLANT COVER IN THE MOJAVE DESERT

Vegetation in the Mojave Desert is often sparse and inter-plant spacings are large. Plant cover in the desert is dynamic and can change suddenly and dramatically through the growing season. Plants respond favorably to soil moisture following precipitation events by producing new leaves and branches which increase plant cover. With the loss of soil moisture by evapotranspiration plants begin to shed leaves to obtain a more favorable shoot-to-root ratio and plant cover is reduced. Shallow-rooted species are forced to adjust to drying soils before more deeply-rooted species because of the lack of available soil moisture near the soil surface. Prolonged drought up to several years in duration may result in reductions in plant cover and die back of most above-ground perennial plant biomass. It may also result in the death of many individual plants. In extreme cases perennial species may be replaced by annual species that are capable of avoiding unusually dry soil conditions for up to several decades.

2.3 CONSIDERATIONS FOR MEASURING PLANT COVER

The selection of methods used to measure plant cover is dependent on the objectives of the research effort. The measurement of lichen cover on a small rock surface responding to local air pollution may require a very different technique than the measurement of forest canopy cover losses due to clear cutting in the Amazon jungle. Often of greater initial value are qualitative or semiquantitative trends rather than absolute accuracy and precision inherent in some quantitative methods. The relative differences in cover are often far more revealing than the absolute values in evaluating trends over time. In other words, it may be more important for a manager to know in what direction a plant community is trending and the relative rate of change of those changes rather than the exact seral stage and rate of change. Thus, the level of accuracy (the extent to which a measured value approaches the true value) and precision (the level of numerical exactness) needed will vary depending on the manager's objectives, the scale of the problem, the statistical confidence level required, and the resources available to answer the question.

2.4 METHODS OF MEASURING PLANT COVER

2.4.1 Semiquantitative Methods

Measures of plant cover have included semiquantitative and quantitative methods (Bonham, 1989; Kent and Coker, 1992). Semiquantitative methods, such as those of Braun Blanquet, Daubenmire, and Domin-Krajina, include cover scales, classes, or ratings that represent a range of percent cover values (Bonham, 1989). Six to twelve cover classes or ratings permit a rapid characterization of plant cover within a plant community and often give good relative comparisons between communities or stands. The scales are usually more sensitive to lower cover values or changes in these cover values and less sensitive to higher cover values or their changes. For example, a scale value (cover rating of 1) at the low end of the scale may range from only a trace of cover up to 1 percent cover (range of 1 percent cover), while the next scale value (cover rating of 2) may be from 1 to 5 percent cover (range of 4 percent cover), while values further up the scale (cover rating of 4) may be 50 to 75 percent cover (range of 25 percent cover). In short, the interval of cover in most semiquantitative methods is unequal and often skewed at the lower end of the scale.

Most often the semiquantitative techniques have been used to describe plant cover within forests where cover is quite variable by species. Use of these semiquantitative methods is more sensitive to species with lower cover as might be needed to detect invading species or small plants infrequent in the plant community. These methods are based on that fact that precise measures of differences in percent cover (e.g., 1-5 percent) are usually not needed to describe plant communities because of the inherent variability in cover (e.g., 5-10 percent) over space and through the year (e.g., 3-5 percent) within the same plant community (Hessing, et. al., 1996).

2.4.2 Quantitative Methods

Quantitative methods for measuring percent cover have included such techniques as satellite image-processing methods, aerial photographic methods, mapping and charting using gridded quadrats or pantographs, ocular estimates of area (area-lists), intercept techniques (point intercept, grid quadrat frame, point frame, single points, cross-wire sighting, line intercept, combined line transect, and point intercept), loop methods, crown diameter and canopy closure methods, plotless methods, Bitterlich's variable-radius method, and the point-centered quarter method (Bonham, 1989; Kent and Coker, 1992). Considerable effort has been made in the past to compare methods for accuracy and to identify which techniques work best on different vegetation types. At the very heart of these efforts is the need to obtain the most accurate information for the least cost and effort. Typically, a high degree of accuracy and precision are costly, both in terms of time and expertise needed to collect such data. Selection of the right method for the right vegetation is thus imperative to achieve the desired study objectives cost-effectively.

2.5 LINE-INTERCEPT METHOD

The sparseness of vegetation in deserts makes line-intercept methods preferred over point-intercept methods where large amounts of time can be consumed recording bare ground. The line-intercept method consists of measuring the intercept of each plant under a line (Figure 2-1).

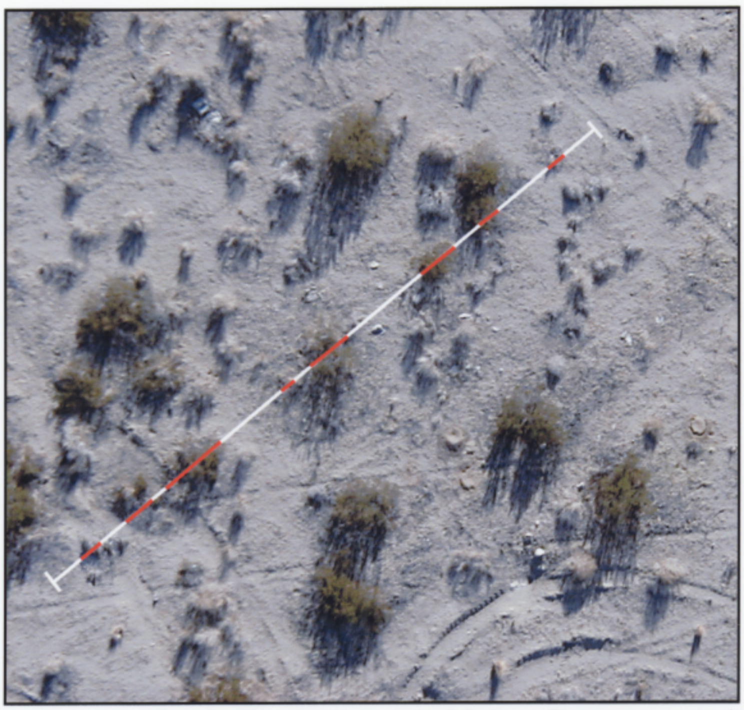

Figure 2-1. An example of a line intercept in Mojave Desert vegetation. The white line represents the measuring tape. The red lines indicate the portions of the tape that intercept shrub canopy. The percent shrub cover is the total length of the red divided by the white.

The measured intercept is the distance across from one edge of the projected plant canopy to the other edge along the line. The accuracy of the methods depends largely on the accuracy of the vertical projection along the line. Steel- or fiberglass-measuring tapes are pulled taut and anchored by steel pins driven into the ground. Parker and Savage (1944) reported statistical differences (significant at the 1 percent probability level) among lines and among observers using line intercept methods, and Bonham (1989) concluded that data were reproducible by the same observer but differed among observers. Potential sources of error or bias were in determining where the edge of the plant canopy begins and ends along the line. Estimating the edge of the canopy in dense foliage with well-defined canopies is not a problem, but estimating the edge is more problematic for sparse foliage such as occurs in desert environments, particularly in periods of drought when branches have lost many, if not most, of their leaves.

There may also be a small error factor that is associated with rounding the linear distance off to the nearest unit of measure (e.g., nearest 1 millimeter (mm), 1 centimeter (cm), or 10 cm). Despite these sources of error, the measurement of plant cover using the line intercept method still provides one of the best methods to estimate cover in desert vegetation. Disadvantages of using the line-intercept method are that it is time consuming, generally requires two workers, and measures only a small portion of the total area being assessed.

In order to statistically estimate how many meters of line intercept are needed to adequately sample the mean shrub canopy cover of a Mojave Desert plant community at different confidence levels, 30, 10-meter-long line intercepts were randomly located along the north-south and east-west axis of a square plot. The transects were located within a relatively homogeneous, undisturbed plant community at the Nevada Test Site (NTS) according to methods described by Chambers and Brown (1983) and Bonham (1989). The community was dominated by creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) with occasional Joshua trees (*Yucca brevifolia*).

The mean shrub canopy cover was estimated to be 29 $\pm$ 1.5 percent with a standard deviation of 8.398 and a sample number of 30, 10-meter transects. The number of 10-meter transects required to achieve a 90 percent, 95 percent, and 99 percent confidence level was 24, 34, and 62, respectively. It is estimated by Bonham (1989) that it requires approximately 30 seconds per meter per person for a two-person team to read and record the tape. To meet the minimal sampling at the 90 percent level this would require 24, 10-meter transects and require a team of two people approximately 2.0 hours to complete (i.e., 4.0 person hours). This estimate is based on an average of 30 seconds per meter per person for the line-intercept technique and does not take into account time required traveling to and from the site and preparing the tape for the measurements. Also, these estimates are based on undisturbed site conditions. In disturbed plant communities, the variability increases dramatically requiring more meters of transect to achieve a given level of statistical confidence. Experience by the authors at the NTS suggest that two trained technicians can complete no more than approximately 30, 10-meter transects per day, suggesting that Bonham's estimates should be considered low for vegetation in the Mojave Desert.

2.5.1 Application of Aerial Photographs for Line Intercepts

Attempts to reduce the amount of field time needed to conduct line-intercept measurements have been made by photographing the vegetation at various scales (usually aerial photographs) during periods of optimal cover (e.g., during the spring when cover is near maximum and species identification is facilitated) and then overlaying measuring rulers or tapes to measure the intercept on the photograph or a 35-mm slide projected onto a wall or screen (Chambers and Brown, 1983). This provided the additional advantage of being able to measure more than one intercept line within a community and makes validation of prior measurements possible.

2.5.1.1 Photographic Scale for Aerial Photographs

Photographic scales used for analyses of aerial photographs for plant cover vary, but generally range between 1:2000 (1 horizontal unit on the photo equals 2,000 horizontal units on the ground) for shrublands to 1:16000 for woodlands, although Uuttera (Uuttera et al., 1998) concluded that at least a photo scale of 1:5000 was needed to determine spatial pattern of trees in forest stands in Finland. Photo scales less than 1:2000 (e.g., 1:1000) may be required for working in grasslands and may require modifications in the aircraft (helicopter vs. fixed wing), lens (telephoto lens vs. normal lens), or film speed (faster vs. slower speed films). Their use at these scales may be restricted to areas that are flat. The reason for this is that the aircraft goes so fast so close to the ground that blurring due to aircraft speed and safety become issues. The minimal altitude for a fix-wing aircraft is about 1,000 feet. Commercial aerial photographic services can usually accommodate these higher resolution needs with advanced planning. Forward motion compensation drives on newer cameras move the film to adjust for the speed of the aircraft to reduce blurring. Photographic scales larger than 1:16000 (e.g., 1:24000) are restricted to forested lands with large shrubs (e.g., mesquite [*Prosopis* spp.]) and study objectives where there is no need to differentiate between similar species (e.g., pinyon [*Pinus monophylla*] vs. Utah juniper [*Juniperus osteosperma*]) or individual plants of a species (e.g., oak [*Quercus* spp.] or willows [*Salix* spp.]).

2.5.1.2 Optimal Scale for Aerial Photographs

The optimal (film) scale for line-intercept analyses is generally that scale where photographic details permit the clear differentiation between species and their canopy edges. The optimal scale varies depending on the plant species in the community, the time of year, the time of day (sun angle >30 from the horizon or about 3 hours after sunrise to 3 hours before sunset) (Falkner, 1995), and the quality of the photographic lens (e.g., faster lenses like *f* 1:1.7 reduce blurring due to aircraft forward motion and coated lenses reduce slight color shifts bent by the glass lens elements, and film type (e.g., Kodak® Royal Gold has an extremely fine grain size and a very high resolution). Colored prints are preferred over color infrared (CIR) positive film or black and white prints. Because of the false red color of vegetation in CIR film, they are harder to interpret than normal color prints in desert environments with sparse vegetation. Photographic films may be enlarged on print paper by a factor 2 to 4 without sacrificing quality; however, greater enlargement merely enlarges film graininess, scratches, dust, or lint on the film; it does not compensate for lack of original lens sharpness. Printing to paper using an antivignette filter can enhance the quality of a picture by removing the normal darkening of the image at the edges of the photographs created by the lens elements. Alternatively, using just the center of the photographs can also help minimize the effects of vignetting (a normal overlap of photo coverage is about 60 percent end lap and 30 percent side lap).

A good method for determining the optimal scale is to select a flight line that crosses several plant communities of interest where the need to differentiate between species is greatest. Select several altitudes to fly resulting in multiple scale photos, for example: 1:2000 scale, 1:4000 scale, 1:8000 scale, 1:16000 scale, and 1:32000 scale. Film positives, negatives, or printed photographs can be analyzed for photo details and the optimal scale selected. Once the optimal scale is determined, a second flight can be made to record the areas of interest. Registration marks can be laid out on the ground using white cloth or plastic (e.g., ½ meter wide and 2-4 meters in length in the shape of a cross pointing to the cardinal directions of north, south, east and west). The marks help guide the pilot and can be used to properly orient the photo for georectification in a Geographic Information System (GIS). If funding limits the overflight to just one flight, then it is best to obtain the largest scale (1:2000 to 1:4000) that you can afford. The smaller scale photos (1:16000 to 1:24000) can often be used to provide image backgrounds for GIS displays.

In the Mojave Desert, scientists at BN have determined that 1:2000 scale photographs were adequate for distinguishing between cover of Joshua tree, creosote bush, white bursage, and generic grass cover. A photo scale of 1:4000 could also be used, but was less capable of distinguishing grass cover. A photo scale of 1:8000 had difficulty in distinguishing small shrubs, but was good for distinguishing cover of medium to large shrubs of creosote bush from Joshua tree. A photo scale of 1:16000 could only distinguish larger creosote bushes. Photo scales of 1:24000 or smaller (1:32000) were limited in use and scientists could only distinguish very large creosote or generic trees in pinyon-juniper habitat from sites located in the Great Basin Desert on the NTS.

2.6 DIGITAL TECHNIQUES FOR THE MEASUREMENT OF PLANT COVER

2.6.1 Digital Imagery and Software

The measurement of plant cover using software to evaluate digital images provides an even more efficient means of rapidly measuring image parameters than merely measuring intercepted plant cover on photographs or projected images by hand. With the availability and relatively low-cost digital scanners, cameras, and relatively fast personal computers, new approaches are being developed to measure plant canopy cover and to automate the calculation of percent coverage. Most of these techniques, however, are still in their infancy.

Previous applications and software development have been primarily used in the fields of medicinal, industrial, and GIS. They include such tools as fluorescence imaging, microscopic analysis, cell analysis, criminal forensics, industrial materials testing, and supervised/unsupervised classification. There has also been considerable development in image-processing software for manipulation of remote sensing satellite and aerial photography at relatively small scales (pixel sizes ranges from 30 m^2 to 1 m^2 with the newest IKONOS satellite imagery). These software include applications in GIS (e.g., ERDAS Imagine®, and ESRI's ArcView Image Analysis® extension for ArcView, and Geomatica®). However, most of the medical and industrial software has focused on microscopic images (magnification levels of 10X to 100X), while GIS software has focused on satellite imagery for small-scale aerial photography not large-scale photography. There have been few applications of software packages to imagery of intermediate scales (1:1000 to 1:10000).

With the introduction of the personal computer, high-resolution digital printers, and the need to publish digital images on the Internet, a wealth of sophisticated image manipulation software tools, such as Adobe Photoshop®, Corel Photo Paint®, and Microsoft Paint®, have also recently been developed. These permit the use of filters, sharpening techniques, histogram stretching, and other image-editing capabilities.

2.6.2 Background for Digital Imagery

While a review of the intricacies of image types and scanning techniques is beyond the scope of this manual and is presented elsewhere (Fulton, 2000; Koren 2002), a basic understanding of color theory and terminology can help one understand the use of these new tools for the purpose of measuring plant cover. Three basic color models are used in today's personal computing hardware and software: the **R**ed, **G**reen, and **B**lue (RGB) model; the **C**yan, **M**agenta, and **Y**ellow and blac**K** (CMYK) (the K is used instead of B to avoid confusion with blue) model; and the gray-scale model.

The RGB model is used to communicate colors through light-generating devices such as a video or camera monitor. The three colors red, green, and blue are used to create up to 16.7 million color combinations. Each of these three-color bands has a pixel range (luminosity) from 0 (black) to 255 (white). When the values are all equal, the results are a shade of gray; 256 shades of gray are possible. When the values of all components are 255, the result is pure white; when the values are 0, the result is pure black. The three-channel image contains 24 (8 × 3) bits per pixel. Images that are taken with a digital camera or flatbed scanner are usually recorded using this RGB model. The frequency of all pixels in an image by luminosity level can be shown in a histogram table and is unique for each image. This model is most frequently used for image processing, although the ability to convert to the CMYK model is shared by most recent software packages.

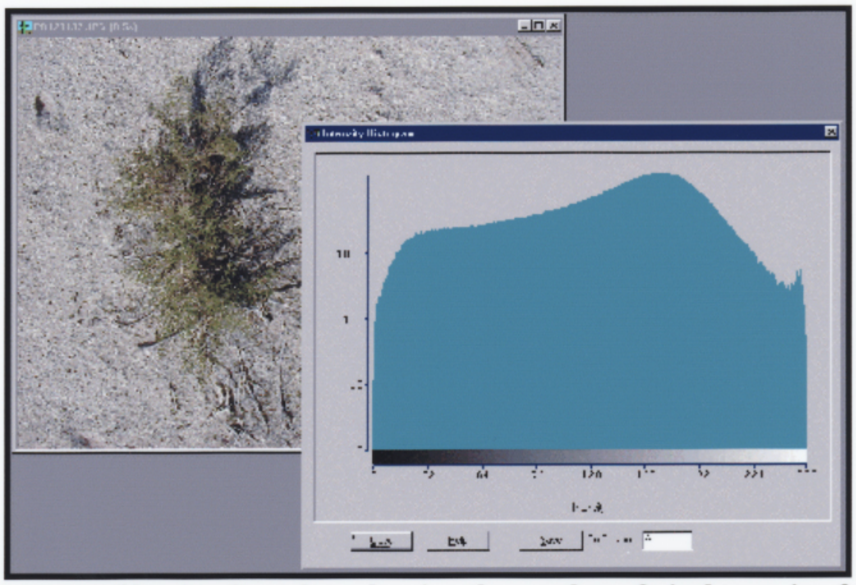

Figure 2-2. Histogram of luminosity values showing the number of pixels ranging from 0 to 255 for the digital image of the shrub and soil on the upper left.

The CMYK model is based on the light-absorbing quality of ink printed on paper. When white light strikes translucent inks, part of the spectrum is absorbed and part is reflected back to the human eye. Colors are expressed as a percentage from 0 to 100 percent. White is generated when all four components have values of 0 percent. Pure cyan, magenta, and yellow pigments should combine to absorb all colors and produce black. Because of ink impurities, they actually produce a muddy brown and must be combined with black ink to produce true black. The four-channel image contains 32 (8 × 4) bits per pixel. Printers use this model for creating inkjet color copies. It may also be used to create color separations for professional printers. Edited images from the image-processing software frequently use this model to print their final images. Subtle differences in color may occur between the image viewed on a monitor and the image viewed from the printer. Additional software to calibrate the monitor (e.g., gamma or whiteness level) and printers are available (e.g., PANTONE® Personal Color Calibrator).

The gray-scale model is a simplified black and white model from the RGB color model in which the channel values are combined into only one channel with 8 bits per pixel. There are 256 possible values for a pixel using this model with pixel values ranging from 0 (black) to 255 (white). Information for certain shades may be lost because the colors and their gray-scale counterparts are weighted, that is certain colors are weighted more than others to more closely match what the human eye perceives or to achieve a desired effect (e.g., darkening or lightening skies, soil, or vegetation). Most conversion software allows one to alter the weighting factors which has the effect of lightening or darkening the midtones. This may be helpful to accentuate the greens in vegetation or bleach out color from the reddish or brownish soil for better contrast between vegetation and soil. When the image to be analyzed is lacking in color information because of enlarging or because the film failed to capture differences in color as may happen with variations in exposure speed, chemical processing, or subdued lighting, then gray-scale images may convey all the information needed for measurements of plant cover. The file size of images converted to gray scales are about 1/3 the file size of RGB files or 1/4 the files size of CMYK files and can, therefore, conserve hard disk space or other storage space.

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3.0 IMAGE-CAPTURING TECHNIQUES

Many image-capturing techniques have been developed to provide imagery at a variety of scales and on different types of film and media. Digital recording equipment has been developed recently that provides images that equal or surpass the quality of many films and prints. Advances in film and flat-bed scanners also provide a means of converting images from film or prints to digital images. A discussion follows of the types of platforms for capturing images, cameras and lenses, and films and recording media.

3.1 TYPES OF PLATFORMS FOR CAPTURING IMAGES

The scale of the image is frequently determined by the camera lens and how close to the subject the camera is placed. Except for ground-based tripods or hand-held poles, most of the platforms for securing and positioning the camera are mounted on some sort of aircraft. There are pros and cons to all of the platforms described here. A comparison of platforms for capturing images is shown in Table 3-1. They range from relatively inexpensive to very expensive. The level of sophistication also varies significantly between platforms. Availability of imagery varies through the year based on availability of range time for the aircraft. The scale of the imagery is also highly determined by altitude, which in turn is federally regulated.

3.1.1 Tripods and Hand-Held Poles

When it is necessary to record panorama scenes or document large rectangular research plots, an oblique-angle (i.e., not a right angle) photo can be taken by standing on top of a vehicle (e.g., cab of a pickup truck) or from an elevated position such as a stepladder. An oblique-angle photo may also be used to capture silhouettes of shrubs for the purposes of measuring foliage density. The best color and contrast are obtained when the picture is taken in full sun with the sun angle at the back of the person taking the picture (i.e., facing away from the sun rather than looking into the sun where sunbursts and other reflections on the camera lens may obscure details and color).

It may also be desirable to capture images that are nadir (i.e., pointed directly down or at a right angle to the ground). This is helpful when attempting to document the details of vegetation in small plots from above (e.g., germinating seedlings in 1-2 m^2 plots). The support pole is hand-held such as the one shown in Figure 3-1. Pictures can be taken using the self-timer feature (e.g., as when taking self-portraits). Digital cameras work best because they are lighter and permit viewing immediately following the exposure. If the picture alignment is not proper, the camera can be repositioned and the picture retaken before moving from the site. When photographing nadir pictures with film, use a wide-angle lens, a slow-speed film (enhances details), and crop the image to the plot boundaries. Mounting hardware is readily available at most stores and consists of a ¼ inch SAE (Society of Automotive Engineers)-thread type (which is the same as a tripod-thread type) with rubber (for friction) and metal (for support) washers to secure the pole to the camera. The camera angle can be adjusted by rotating (tightening or loosening) the camera on the mounting bolt. Telescoping aluminum poles work well as extensions (e.g., those used for painting, window washing, or skimming debris from swimming pools). Duct tape can be used to wrap around smaller poles to secure a snug fit.

Table 3-1. Comparison of platforms for capturing aerial images.

Platform	Height Range (meters)	Resolution Quality	Representative Pixel Size	Advantages	Disadvantages	Best Application
Tripods & Handheld Poles	1-7	Very High	1 cm	Inexpensive and can be operated by one person	Field of view is relatively small with limits on height of the tripod or pole due to unstable wobbling	Small plots of very high resolution and shrub silhouettes or foliar density
Kites	20-150	Medium	1 dm - 1 m	Relatively inexpensive	Equipment not readily available commercially, camera weight is a problem, requires a slow steady wind--does not work without wind or in high winds; limited to below 500 feet; hard to position.	Medium-to-high resolution landscape images that do not have to be aligned with ground plots
Tethered Balloons & Blimps	10-150	Medium	1 dm - 1 m	More steady platform for pictures than balloons	Equipment not readily available commercially, requires calm conditions; limited to below 500 feet; requires two people and a closed trailer to move from site to site.	Medium-to-high resolution landscape images that do not have to be aligned with ground plots
Ultralite	100-300	Medium	1 dm - 1 m	Greater height and maneuverability than kites or balloons.	Requires more expensive equipment; may be hard to maneuver on small sites; motion blurring common; limited in height and acceptable weather, pilot training required, and carries greater risk in flying.	Medium resolution landscape shots that do not have to be aligned with plot dimensions
Helicopter	50-500	High	3 cm - 25 cm	Greatest maneuverability-can hover over site; can be guided by GPS to individual sites	Difficult to shoot in nadir position; vibrations may create auto-focus problems; wind from rotor creates dust and motion problems; is costly to operate; requires two people to operate.	Small areas that do not require much mosaicing of individual images or georeferencing
Fixed-wing Aircraft (amateur)	500-2,000	High	5 cm - 1 m	Relatively easy to maneuver, greater freedom in choosing sites	May be expensive to maintain and may be limited in altitude and rough terrain; usually requires two people to operate; vignetting common; georeferencing required.	Small linear areas at medium resolution that do not require much mosaicing of individual images or georeferencing
Fixed-wing Aircraft (professional)	500-12,000	Very High	2 cm - 3 m	Greater quality of imagery when professional equipment is used; can operate at greater heights	More costly, reduced control over logistics--must be well planned; vignetting common; georeferencing required.	Large areas at medium-to-high resolutions that may require mosaicing, color correction, and georeferencing
Satellite	644-805 (km)	Low	1 m - 30 m	Greater availability of data as there are no flight restrictions or range time required; better georeferencing	Lowest resolution, most expensive for coverage of large areas at high resolutions that are georeferenced	Large areas at low resolutions that may require mosaicing, color correction, and georeferencing

Figure 3-1. Example of hardware mounting bolts and hand-held swimming-pool skimming pole for taking aerial pictures.

The camera can also be mounted 2 to 3 meters above the ground on a leveled multi-legged frame (e.g., a four-legged frame leveled with a carpenter's level). The frame is often moved from one sampling location to another in the back of a pickup truck, or designed to collapse or disassemble for shipping. The permanent frame works well when many pictures are needed of small rectangular or square plots. The hand-held pole works best for infrequent nadir shots of individual shrubs. In some cases, 35-mm cameras capable of capturing stereoscopic images with wide-angle lenses are used to establish vertical distances with an accuracy of about 3 mm (Warner and Kværner, 1998). Such imagery can be used for measuring plant height and degree of soil erosion.

3.1.2 Kites

Kite aerial photography (KAP) is supported by a variety of enthusiasts who promote the use of kites to obtain aerial photography. Of notable mention is Dr. Charles C. Benton, Professor of Architecture at the University of California at Berkeley (Benton, 2002).

KAP is best suited to those who want oblique aerial photographs of the landscape that do not require alignment with rectangular plots on the ground or have to be repeated at exactly the same location over time. The disadvantages of using kites as a means of obtaining aerial photographs are that it requires a relatively high skill level in flying large kites (much more sophisticated than small recreational kites) and a need to secure, assemble, and operate electronic remote control camera equipment. It also requires proper wind conditions (e.g., 4 to 20 miles per hour (mph)) and a good deal of patience in fine-tuning the technique. Calm weather makes kite flying impossible, although low to medium wind speeds can be accommodated by selecting kites of different sizes (e.g., smaller kites for higher wind speeds and larger kites for lower wind speeds). In order to properly operate the system, it is helpful to have two people--one to secure the kite and one to walk the kite down. Because of the high tension on the line (250-pound test line), it is not recommended that the kite be pulled to the ground by winding the line on a reel (i.e., this may split or collapse the reel from the tension).

Due to U.S. Federal Aviation Administration (FAA) regulations, the maximum kite altitude that can be legally flown is 500 feet (higher altitudes, if permissible, have to be cleared with the FAA). These regulations require that visible flags be placed at spaced intervals on the kite string above 150 feet. It is a good idea to clear all kite flying on military training ranges as these ranges are frequently used by military helicopters. The flying angle of the line ranges from 50° to 70° (approximately 730 to 822 feet, respectively, of line at 500 feet altitude) depending on the type of kite.

Camera weight is critical, however, the development of new miniature video camcorders and transmitters (e.g., less than 1.5 inches × 1.5 inches × 1.5 inches) and digital cameras will make the future of KAP more promising. The choice of camera is usually (a) an inexpensive one because the kite can crash unexpectedly and (b) one with a fast, wide-angle lens (e.g., f/2 and 28 mm) which gives a wider angle of view and faster shutter speed to reduce motion blur. An ultraviolet filter is recommended to protect the camera lens. Film usually consists of a 24-exposure roll with a medium-to-high speed (e.g., Kodak Royal Gold with an American Standards Association [ASA] of 200 to 400). A photo is frequently taken with every 100 feet of line let out (marked by black pen on the line). The focus is set at infinity so there is no need for auto-focusing cameras that actually hinder proper focusing due to the kite motion.

The cost to purchase a KAP system will range from $500 to $1,000 for a kite, camera, and remote controls. More advanced systems are rarely available from a single source and require the user to shop for parts from a variety of suppliers. Additionally, labor to put the system together and test and operate it should be factored in. This option is not recommended for the novice, but rather for those willing to learn a new sophisticated skill.

3.1.3 Blimps and Balloons

The first recorded air observations during a military battle were performed from a hot air balloon. More recently tethered balloons and blimps provide a means of supporting a camera and capturing images. The art of blimp aerial photography (BAP) is not as advanced as that of KAP because the balloons are reported to be more difficult to control in windy weather (e.g., winds greater than 30 mph) and more expensive to purchase, relocate, and operate. An example of a helium-filled blimp used for aerial photography is shown in Figure 3-2.

Figure 3-2. Helium-filled blimp being readied for flight.

Round balloons tend to be rather unstable and rotate in the wind more than blimps which have an attached tail structure (single ply fins held up with a fiberglass rod and monofilament line) and cylindrical shape to orient the balloon. Most of the blimps used for aerial photography are helium-filled inflatable blimps made from 3.5 to 6.0 milliliters polyurethane material formulated for its light weight, high elasticity, strength, and helium retention. The total cost of a blimp system is about $1,700 for initial blimp, rigging, remote controls, and the camera, and about $57 per job for gas maintenance and tank rental. The cost of a blimp (300 cubic feet [ft^3]) is approximately $1,000. From 220–290 ft^3 (6-8 cubic meters [m^3] of helium available from a welding gas supplier (grade 5.0) are used to fill the blimp. The average cost to fill a 242 ft^3 ranges from $70 to $100 depending on supplier. Normally, the blimp does not need to be emptied between jobs, however, additional helium must be allowed to occasionally top-up the blimp. A regulator ($40), tank ($7 per month rental), and hose ($25) are also required for filling.

A blimp with a volume of approximately 300 ft^3 (8.5 m^3) will have a net lift of approximately 10 pounds (lbs) (4.5 kilograms). Small blimps with lifting capacity up to 47 lbs are commercially available. It is recommended that the camera and rigging weight only about 1/3 of the total lift. This allows sufficient lift for the weight of the line and any wind resistance. The buoyancy of the blimp is affected by temperature, barometric pressure, purity of the gas, and altitude (elevations above sea level). The regulated flight of a tethered (moored) blimp and balloon is the same as that for kites (500 feet above the ground).

The use of blimps is restricted in windy weather (wind speeds greater than 30 miles per hour [mph]). Winds tend to push the blimp to the ground and accelerate movement from side to side making it difficult to obtain good photographs. Unloading and landing blimps is also much more difficult in windy weather. Two people are recommended for launching the blimp. A covered trailer or truck is helpful if the blimp is to be transported to many sites, thereby, increasing operational costs. Deflating the balloon at each site is expensive, time consuming, and requires more care to prevent damage to the system. Radio-controlled positioning of the camera and shutter release are also more sophisticated and may require real-time feeds of black and white video signals to ensure that the camera is properly aimed at the target.

Like KAP more advanced systems for BAP are rarely available from a single source and require the user to shop for parts from a variety of suppliers. Additionally, labor to put the system together and test and operate it should be factored in. This option is not recommended for the novice, but rather for those willing to learn a new sophisticated skill. There are a few commercial operators that are skilled and provide aerial photography.

3.1.4 Helicopters

Helicopters provide one of the most versatile means of obtaining aerial photography. The aircraft is particularly well suited for moving directly from a base of operations to a target location. Global positioning systems (GPS) can help guide the aircraft to the approximate location. Ground targets (e.g., white plastic garbage sacks stapled in the form of an "+" on the ground) help the pilot locate the actual plot corners while in the air. Often helicopters are available on the base as part of related military training. Figure 3-3 shows a Blackhawk helicopter. The cargo-hook door in the rear floor can be removed for easy nadir positioning of the camera. An alternative position is on the gun mount of the front-side window. Two people are preferred to obtain the best results. One person works with the pilot and directs the pilot, while the second person takes the pictures. Operators should be aware that taking pictures in this manner may make them vulnerable to air sickness due to the restricted field of vision through the door and the aircraft movement.

Because of vibrations caused by the rotors, camera motion may make auto-focusing features undesirable (e.g., the camera's computer seeks stationary vertical lines that may not exist). This may delay or prevent focusing or cause delays in shutter functions. Setting a camera on manual focus set at infinity works best. A fast lens (e.g., f/2.8) works best to control motion blur. A moderately fast speed film (e.g., Kodak Royal Gold film with an ASA of 200 to 400) can also increase focus and reduce motion blur. F-stop should be set to two stops below the maximum.

Figure 3-3. Blackhawk helicopter showing the location of two-camera mounting positions, side gun mount (left red arrow, lower right inset picture) and inside cargo hook door (right red arrow, upper right inset picture).

Digital cameras may also function well and may have the advantage of being able to review the image before leaving the location to verify that the picture had the proper orientation. An example of an image taken at Fort Irwin through the cargo hook door is shown in Figure 3-4.

Remote control of the camera shutter can be achieved by radio-controlled transmitters and receivers such as those like Pocket Wizard™ (Figure 3-5) and Radio Slave™. These units were designed to trigger remote flashes for professional photographers. They allow for the digital transmission of radio signals to trigger the camera shutter. These units are capable of transmitting on up to 16 radio frequencies and have a range of more than 500 yards (457 meters).

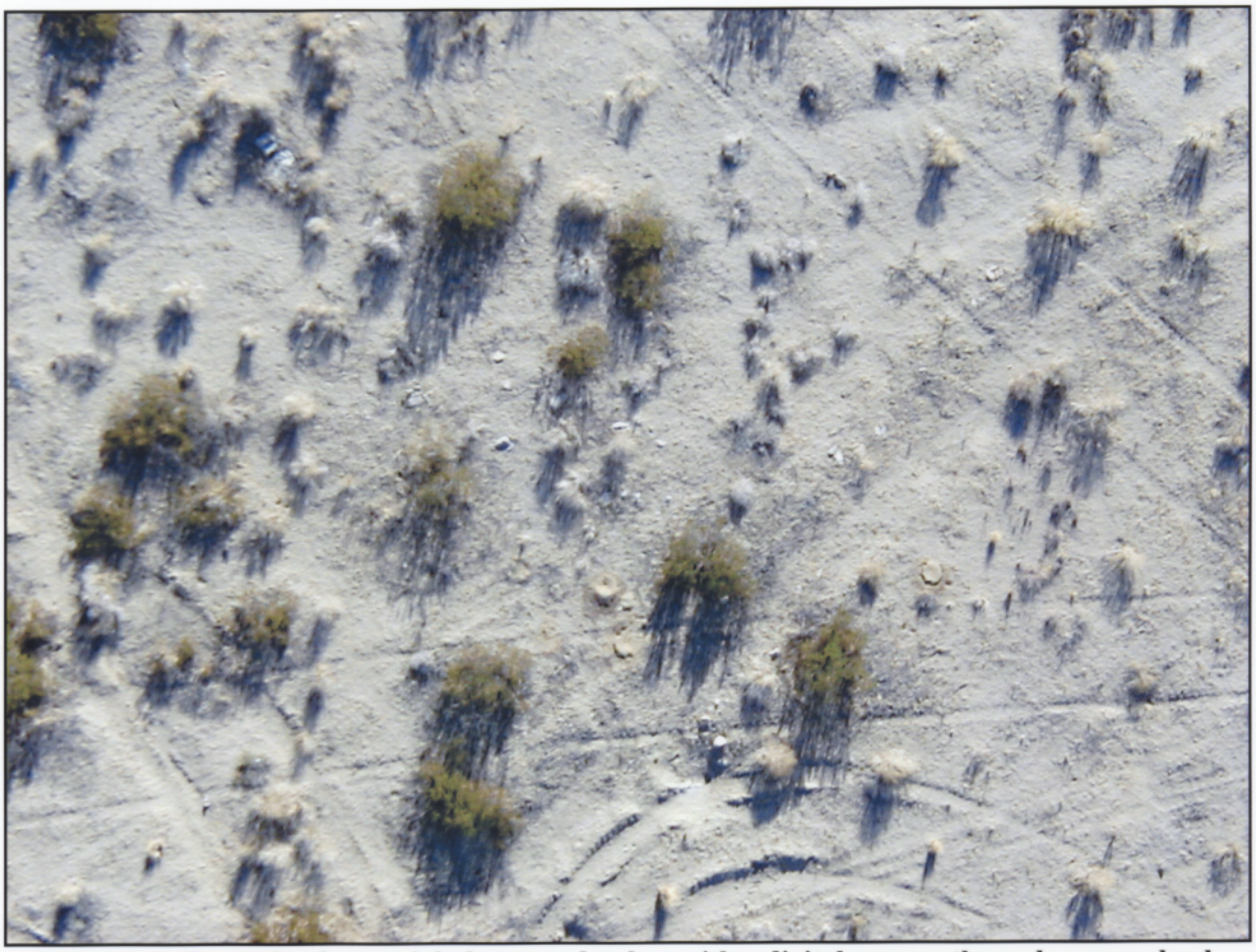

Figure 3-4. Example of an aerial photograph taken with a digital camera through a cargo hook door of a blackhawk helicopter at Fort Irwin, California.

The operator depresses a button on the transmitter which sends a radio signal to the receiver to trigger the camera shutter. The receiver is usually taped to the camera and connected by a cable. A variety of cables are available to fit most cameras, although some splicing may be required to match up all of the signals (e.g., to recognize the shutter halfway down and fully down). More information about these products can be obtained by searching for them on the Internet using standard Web search engines. They require that the camera have the features of electronic remote cable shutter-control and automatic film advance. Cost for the units range from $200 to $500 and newer models are frequently released with advanced features.

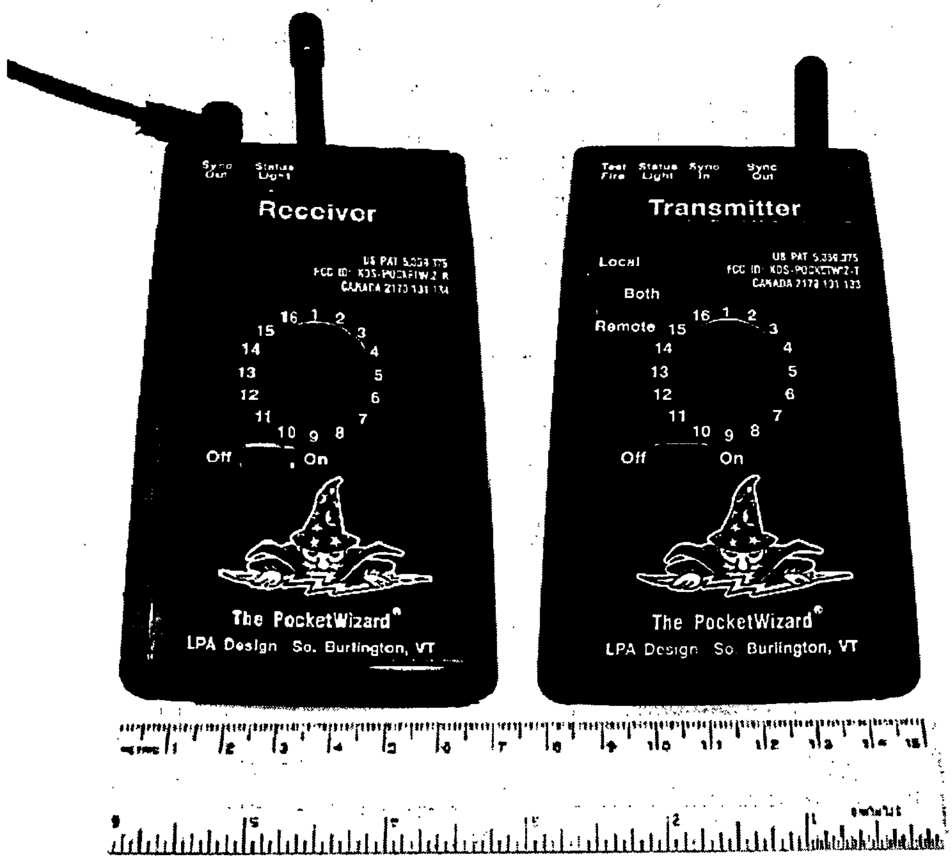

Figure 3-5. Examples of radio-controlled remote camera shutter transmitter and receiver.

Helicopters on most military bases typically fly between 61 m and 152.4 m (200 ft and 500 ft altitude) from the ground. At altitudes less than 45.7 m (150 ft) the wind created by the rotors creates too much motion in the vegetation and stirs up dust that obscures details. Altitudes of greater than 152.4 m (500 ft) need to be coordinated with the U.S. Air Force to avoid conflicts. It is a good idea to review the flight plan and photographic objectives with the pilot well in advance to ensure that objectives can be met.

3.1.5 Fixed-Wing Aircraft

Fixed-wing aircraft have been the primary means of securing aerial photography for the past several decades. A variety of aerial coverage has been collected with varying degrees of quality. It is best suited for photo coverage of large areas, although narrow flight lines are also possible. ***The Remote Sensing Tutorial***, developed by the National Aeronautics and Space Administration (NASA) also provides a history of remote sensing and other helpful information. Techniques for aerial photography are abundantly described in the literature. Excellent reference books are available elsewhere (e.g., Falkner, 1995). These books describe nearly everything that is needed by a novice to understand, use, and estimate costs with proper specifications for subcontractors. Early photographs were primarily black and white photographs enlarged from large-format (22.8 cm x 22.8 cm [9 x 9 inch]) film negatives. Much of the early work was performed as part of the

U.S. Geological Service and the Natural Resources Conservation (formerly known as U.S. Soil Conservation Service) in support of their topographic and soil-mapping efforts. More recently color and CIR photography have become available with the development of newer films. It remains the photographic method of choice for medium-resolution images and when continuous coverage of a large area is required.

There has been a steady improvement in the quality of large-format cameras, lenses, and film. Many historical photographs are often retained as "proof" books or contact prints and have inherent problems with unequal color and vignetting (a gradual darkening of the photograph at the corners of the photograph caused by the curvature of light passing through the camera lens). Enlargements overcame some of these problems by allowing the photo technician to dodge and burn the photograph during printing to produce a more uniform image. Improvements in the quality of cameras and lenses over time have also enhanced our ability to capture higher quality images. For example, improvements in lens speed (i.e., the number of elements and coatings on a lens to permit more light to be focused on the film) have reduced motion blur and built-in GPS features record flight data such as location, altitude, and other information needed for georectification directly on the film.

Because of the specialized, and often costly equipment needed to conduct aerial surveys (e.g., a good lens on a large-format camera can often cost more than $100,000), most of this work is subcontracted to commercial companies that perform such work routinely. Individuals seeking to do their own aerial surveys (e.g., using small aircraft and inexpensive cameras) will find useful information available from the publications of the American Society for Photogrammetry & Remote Sensing at http://www.asprs.org and the published proceedings of the Workshop on Videography & Color Photography in Natural Resource Assessments (asprspub@pmds.com). Another useful reference is the ***Remote Sensing Users' Guide*** (Bright et al., 1997). The manual was produced by the U.S. Army Environmental Center (USAEC), U.S. Army Topographic Engineering Center, and the USACERL. SERDP projects have also produced informative Web sites providing information about remote sensing for military applications (http://www.serdp.org).

Some of the limitations in aerial photography from a fixed-wing aircraft include restrictions in the scale of the imagery and geospatial rectification. High-resolution imagery (e.g., < 1:1000) is limited because planes can fly only so slow and at so low of an altitude. At faster speeds motion blur is a problem. At lower altitudes safety may be an issue, especially in mountainous or rough terrain. Most commercial companies are only equipped with certain lenses and telephoto or zoom lenses are very expensive or not available. Several companies have developed software to help overcome undesirable features of aerial photography. For example, software is available for mosaicing, georeferencing, color balancing, and compressing (e.g., 1/100 to 1/500 compression ratios) digital images (e.g., DIME® software at and Multiresolution Seamless Image Database (MrSID) software. When seeking to convert aerial photographs to digital images it is best to scan the film directly to obtain the best digital image. Exceptions to this are when printing can eliminate vignetting by dodging and burning or using an antivignette filter. In this case an enlargement of the film may actually result in a higher-quality digital image than scanning directly from the film.

3.1.6 Satellites

Information about satellite imagery is summarized in publications and web sites that focus on remote sensing. This information has been assembled by NASA and the USAEC in the form of *The Remote Sensing Tutorial* (NASA and the U.S. Air Force Academy) and a *Remote Sensing Users Guide* [Bright *et al.,* 1997]. The objectives of this tutorial and guide are to provide organized tools to help land managers take advantage of existing remote-sensing technology. Descriptions of satellite imagery and other associated facts are well described in these sources. Examples of imagery and additional web site links are provided in these tools.

3.2 CAMERAS AND LENSES

The selection of the proper camera equipment is essential for success in the capture of aerial photographs and images. Cameras have traditionally been developed for recording on film, but have recently witnessed the surge of digital cameras with increasing image quality. The selection of cameras and lenses are beyond the scope of this manual. However, those interested in technical reviews of camera equipment may find abundant information on the Internet using Web search engines. For a good introduction to digital photography, the reader may consult a variety of Internet Web sites (e.g., Koren, 2002).

Key desirable camera features include:

- Motor driven with electronic shutter (allows radio-transmitted remote control of shutter)
- Ability to override auto-focus features in favor of manual focus (slight motion and vibrations of camera may make it difficult to focus using auto-focus)
- Ability to accept other high-quality commercial lenses
- Fast digital processing (storage of digital images) for rapid cycling of image (reduces delays)

Key desirable lens features include:

- Fast lenses (for reducing blurring due to camera motion and increasing depth of field or focus.)
- Aperture should be set to 2 f-stops below the maximum for sharpest images (e.g., f/8 for an f/16 lens; assuming range is: f/2.8, f/5.6, f/8, f/11, and f16)
- Attachable coated lenses that accept filters (to protect the lens and reduce chromatic diffraction)
- Wide-angle (28-40 mm) lenses (yields a greater field of vision with better depth of field)

A description of light-weight instrumentation for remotely controlling the camera shutter was discussed in Section 3.1.4.

3.3 FILMS AND DIGITAL RECORDING MEDIA

In 1999, Kodak reported that "an image taken on film can hold 16 times as much information as one taken using digital camera, such as the KODAK Professional DCS 420 Digital Camera (4 megabyte [MB] image size) (Kodak, 1999). However, with the development of newer megapixel cameras, that difference is rapidly shrinking. Koren (2002) estimates that the newer megapixel cameras (e.g., 6 to 10 megapixels per image) are comparable to, or better than, a 35-mm film size. Digital cameras also reduce the problem of the film lying flat in the camera, a problem that was reported to have occurred in 60 percent of all 35 mm single-lens-reflex cameras examined, which reduces sharpness of the images up to 48 percent (Koren, 2002).

Slide films typically have smaller grains than negative films. Slide film does not scratch as quickly as negative film and when framed, is easier to handle; however, negatives have a much larger exposure latitude than slides. Slide film is easier to interpret than negative film in large-format size, but prints made from small-format films provide more detail. Proper exposure of slide film is more critical than negative film. Based on these qualities, the 35-mm negative film is preferred when enlarging to 20.3 cm x 25.4 cm (8" x 10") size and the 22.8 cm x 22.8 cm [9" x 9"]) large–format positive slide film is preferred because it can be scanned directly with little loss of detail.

3.3.1 Small-Format Films

Films are frequently rated for their fineness (e.g., the relative size of the chemical grains that react with photons). Fine-grained films are generally slow-speed films, while coarse-grained films are generally faster-speed films. A compromise between the graininess of the film and the speed must be made. Film speeds of ASA 100 are best if the camera platform is not moving or is relatively stable (e.g., tripod on the ground with large f-stop settings). For unstable platforms (e.g., vibrations and movement near the ground), faster (i.e., higher) film speeds are preferred (e.g., ASA 200 to 400). Fine-grained films that are suitable for aerial photography in a small-format size (e.g., 35 mm) are available in speeds from ASA 100 to 400 and include:

- Kodak Royal Gold (extremely fine-grained negative film)
- Fuji Superia Reala (extremely fine-grained negative film)
- Kodak Ektachrome E200 (extremely fined-grained slide film)
- Fuji Provia (extremely fine-grained slide film)

3.3.2 Large-Format Films

The selection of the numbers and types of large-format films (e.g., 22.8 cm x 22.8 cm [9" × 9"]) is more limited and some films may have to be made up custom and delivered just prior to use. An example of such custom film production is CIR films. Such film is extremely sensitive to heat and deteriorates rapidly once it is made. The purchaser often is obligated to purchase an entire roll of film (e.g., 30.5 m [100 ft]) of CIR film even it only a few frames are needed. This may increase the cost per frame. Arrangements can be made to coordinate with other photography needs at the installation to ensure that all the film is used. If necessary, experimentation can be performed (e.g., additional photos can be taken at different photo scales or additional exposure settings can be made). Because large-format films are typically used by commercial services, it is best to consult with them on recommended films that are compatible with their equipment and with which they have experience. Users may request examples of photos taken with various film types and qualities with commercial equipment to ensure that they are of acceptable quality.

Examples of unacceptable photo features for commercial services include:

- Poor image contrast (out-of-focus images that lack saturation, detail, and appear faded)
- Shadow length is too long as occurs when photos are taken too early or too late in the day
- Improper chemical processing (small discoloration blotches from water spotting or improper rinsing during processing may result in multicolored halos)
- Evidence of dust, scratches, and improper handling (accidental light leakage near edges)

3.3.3 Digital Recording Media

Removable memory chips of digital cameras come in several formats. The camera type and model will usually determine what type of memory is required. Memory cards usually range from 16 MB to 1 gigabyte. Costs range from $100 to $200 per 100 MB, although costs continue to fall as new, higher-capacity storage media become commercially available. Compact disks (CD) (e.g., 3-in CD) and Digital Video Disks are being used in some cameras and digital camcorders as a means of saving images, thereby reducing costs of image storage. The size of the storage memory chip should be consistent with the size of images being recorded. Large megapixel images may require larger storage capacity than smaller images. The storage space required for individual images, depending on how much compression can be achieved for the given format.

Hand-held digital cameras capture images in a variety of sizes. Typical sizes (number of horizontal pixels by number of vertical pixels) are: 640 × 480 (0.3 megapixels), 800 × 600 (0.5 megapixels), 1,030 × 746 (0.8 megapixels), 1,280 × 960 (1.2 megapixels), 1,600 × 1,200 (1.9 megapixels), 2,048 × 1,360 (2.8 megapixels), 2,272 × 1,704 (4 megapixels), 2,496 × 1,662 (4.5 megapixels), and 2,560 × 1,920 (5 megapixels). Image size is highly variable and is expected to change rapidly in the future, but usually maintains a ratio of about four units horizontal for each three units vertical (the same ratio as most computer monitors). [By comparison, 35-mm (actually 135 size) film has a ratio of about three units horizontal for each two units vertical (the 24 × 36 mm negative size is slightly more rectangle in shape than a digital image).] File sizes for these formats range from about 350 k for the smaller size images up to about 17.6 MB for the larger megapixel images (assuming 32-bit Tagged Image File Format [TIFF] or Joint Photographic Experts Group [JPG] file types).

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4.0 IMAGE PROCESSING

4.1 DIGITAL IMAGES AND IMAGE EDITING SOFTWARE

A variety of image formats are used to record information, store, and manipulate images. These images are produced by digital cameras and by a flat-bed or film-scanner from prints and film. These digital images can be considered raw images. Most of these images benefit from enhancements (image processing) that can be made to them using software that alters the raw image. A discussion follows about image formats and image-editing software.

4.1.1 Digital Image Formats

Digital images may be stored in various types of file formats. These file formats organize the storing of digital information of the image in various degrees of compression to conserve file storage space and adjust for the types of color information stored. The most common types of images used for image processing include the following:

- BMP - (file extension .bmp) Windows Bitmap is lossless compression originally designed by Microsoft to handle 24-bit data, but it cannot be compressed. It is seldom used except in Windows (e.g., in wallpaper and screensavers), but is accepted by most image-processing software.

- JPEG - (file extension .jpg – pronounced "Jay Peg") Joint Photographic Experts Group is a lossy compression format that can be compressed by increments to very small thumbnails. Because this format compresses the file each time it is saved, information is lost and it is not considered suitable for storage of master images. This format may be acceptable for image process if the master image file printout has a high resolution.

- TIFF - (file extension .tif) Tagged Image File Format was developed by Aldus, before Adobe bought them, and is the most widely supported format. This format is a large file and uses lossless compression.

- TIFF LZW - (file extension .lzw) Lempel-Ziv-Welch is a variation of the TIF format but is compressed (same compression as used by PKZIP). Not all image-processing software supports this format, but many do. This format is smaller (85 percent) than the TIF format.

- GEOTIF - (file extension .tif) Georectified tag Image File Format is a lossless compression format created for GIS that have a need to incorporate spatial coordinates with pixels. These files are larger than TIF files because they include geospatial coordinates.

- PNG – (file extension .png - pronounced "Ping") Portable Network Graphics is a lossless format that has many desirable features like supporting 24- and 48-bit color, compressing well, and is about 30 percent smaller than TIF LZW formats. This is a new format and has not yet been incorporated into all image-processing software.

- PCD – (file extension .pcd) Photo CD is a proprietary format of Kodak. Images are scanned on a special high-quality film scanner that provides images with excellent color registration and resolving power—its main weakness is a slight loss of shadow detail when scanning transparency film. The image file size is about 5 MB and contains options for downloading six image sizes (64 × 96; 128 × 192; 256 × 384; 512 × 768; 1024 × 1536; 2048 × 3072). When converted to a TIFF format, the largest format size results in a file size of about 37 MB. This file format is created as part of the Kodak film processing and costs about $1 per frame. It is very convenient and often cost-effective to request this file format and processing service when images are recorded on film. Other types of file formats not commonly used in image processing are:

- GIF – (file extension .gif – pronounced "Gif" like Gift) Graphic Interchange Format is a proprietary lossless compression format of CompuServe that uses only 256 color combinations (designed for the older 8-bit video boards) and is a larger file size than a 24-bit JPG file. This format is frequently used for Web site designs.

- PDF – (file extension .pdf) a format of Adobe Acrobat® used primarily for storing documents. This format is used because it maintains fidelity and integrity 100 percent when viewed across operating platforms and with different printers.

- PCX, PSD, CDR – (PaintShop® Pro, Photoshop®, and Corel Draw®). These are proprietary file formats for image-editing software. They contain many layers of additional information used by these software programs to keep track of editing history, layouts, styles, and other information. They are very large in size and not suitable for use in image processing. These types of files can be taken into the respective software programs and exported as one of the more accepted formats described above.

4.1.2 Image-Editing and -Enhancing Software

Several software packages are commercially available that permit editing and enhancing of digital images. Adobe Photoshop® is perhaps the most powerful and most expensive (e.g., about $600) software package. It contains an impressive suite of tools, including many third-party plug-ins that increase the power and standard features of the software. Advanced training is commercially available for this software in the form of workshops, third-party books, and online training. Adobe Photoshop® Elements (about $70) is a scaled-down version of Adobe Photoshop® that provides a limited suite of tools and editing features. Corel Photo-Paint® (about $250) also provides basic tools for digital image processing, but lacks many of the advanced features of Adobe Photoshop®. Picture Window Pro® is a low-priced (less than $100) alternative to Adobe Photoshop® that provides many excellent features that are useful in editing digital images. This latter software package is designed primarily for photographers.

The most commonly used features of these software packages that are important for editing digital images of aerial photographs are:

- Converting image formats
- Cropping and rotating images to match alignments in historical plots or photos

- Removing dust, artifacts, and photofeatures (e.g., optical targets and paved roads) that are undesirable in the photo
- Enhancing color balance, contrast, and brightness of the image
- Applying gradient filters to remove vignetting caused by the camera lens
- Sharpening images
- Resizing and resampling images to create smaller file sizes

Technical information about image-editing software is provided by Koren (2002) and Lyon (2002).

Sharpening is perhaps one of the most important image-enhancing processes than can be done to clarify the boundary of photo details that may have been softened by the camera lens, film, developing, flat-bed scanner glass, enlarger lens, and other image-capturing design elements. Almost all images can be improved by sharpening, except perhaps images that have already been sharpened. Such images are usually provided under a service contract from someone who processes aerial photographs. Such previously processed images, when sharpened a second time may result in over-sharpening. The signs of over-sharpening are bright halos around dark features such as shrubs (Figure 4-1) and indications of visual roughness on features that should be smooth such as soil with no rocks or vegetation (e.g., roads, playas, or sand dunes).

Figure 4-1. Example of image (1:24000) showing light halos from over-sharpening.

Digital sharpening is based on traditional film compositing techniques that were referred to as "unsharp masking." This film terminology was carried into Adobe Photoshop® and is referred to as the "Unsharp Mask." The unsharp mask locates pixels that differ from surrounding pixels by the threshold that is specified and increases the pixels' contrast by the amount specified by the user. In addition, the user specifies a radius of the region to which each pixel is compared.

Three adjustments are required in Adobe Photoshop®: the (a) amount, (b) radius, and (c) threshold (Figure 4-2).

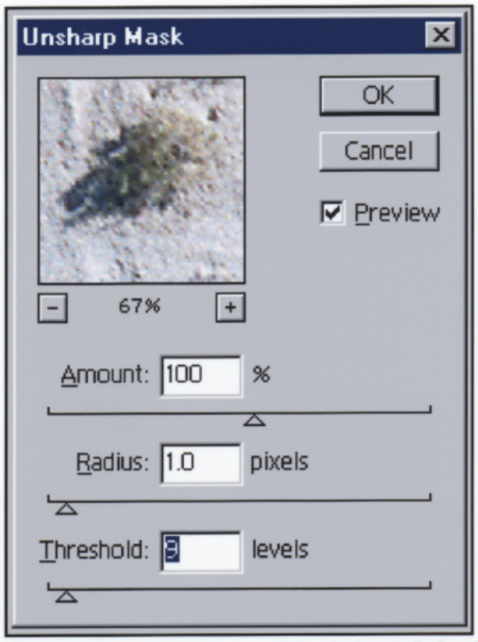

Figure 4-2. Example of Unsharp Mask in Adobe Photoshop® showing adjustment inputs.

Key features and settings include:

Amount controls how much sharpening effect (i.e., contrast) is to be applied. Values range from 1 to 500. Values for sharpening aerial photographs typically range from 50 to 100.

Radius determines the number of pixels surrounding the edge pixels that affect the sharpening (i.e., how narrow the zone of contrast will be). Values range from 0.1 to 250. However, always use a very low setting; a radius between 1 and 2 is preferred.

Threshold controls how different two touching shades have to be in order to be sharpened. Values range from 0 to 255. Settings lower than 20 are preferred with suggested values starting at 1 or 2. A value of 0 sharpens all pixels in the image. This setting should be gradually increased until areas of known smooth surface likes roads, bare areas, or sand dunes show no or little roughness (i.e., effects of sharpening or contrast).

In Adobe Photoshop®, the "Sharpen," "Sharpen More," and "Sharpen Edges" are merely preset values for the "Unsharp Mask" that do not permit adjustments or fine-tuning. Their use is mainly for quick effects and is not recommended for sharpening images that will be further processed because they lack adjustment control and may over sharpen or under sharpen the image.

4.1.3 Georeferencing Software

There is frequently a need to convert digital images into formats that include information about spatial locations. Because aircraft are constantly moving while taking pictures, the resulting pictures have distortions due to this motion. The center one-third of the image is generally the most correct if the photo was oriented in a nadir position, while the edges are the most distorted. Software packages have been developed to georeference or georectify the image as well as for mosaicing, georeferencing, color balancing, and compressing (e.g., 1/100 to 1/500 compression ratios) digital images (e.g., DIME® software and MrSID® software. Most of these software packages are considered expensive (e.g., $1,000 to $15,000). The licensing cost for the DIME® software is an annual fee of $695 and $15 for each frame for mosaicing, georeferencing, and color balancing. The cost for MrSID® Geo software ranges from a free viewer to a complete workstation priced around $4,000. Advanced training is available for these software packages.

A version of the MrSID® viewer (MrSID® GeoViewer Version 2.1) has been modified and enhanced for use by the U.S. Department of Defense. The viewer may be downloaded from: https://trms.7atc.army.mil. Please note that this site is only accessible from a military domain site and users should enter "https" not "http" when entering the Web site Uniform Resource Locator.

Some commercial aerial photography companies may provide these services as part of their contracted work, thereby eliminating the need for the software at the user end. Military installations with strong GIS support may already have this software for use in other applications. Contracting others to provide this service may also provide image correction for georeferencing and eliminate the need for purchasing the software directly.

4.2 MEASUREMENT OF PLANT COVER BY DIGITAL TECHNIQUES

The ability to measure plant cover using digital information is based on the correlation of light qualities recorded for a digital image with vegetation and other landscape features. As described, earlier color models (e.g., RGB model) record light values on an intensity scale ranging from 0 (darkest) to 255 (brightest) for each band of the model (e.g. red, green, and blue bands). Typically, information in the red band is most often correlated with vegetation and bare soil features. Information from all bands may be combined to form a single intensity value for each pixel. Histograms may summarize information from all pixels into a table of frequency values (i.e., the number of pixels at each intensity value). Figure 4-3 shows a hypothetical range of values for digital image pixels of a desert landscape.

Features with low intensity values include such things as basalt outcrops of rock, asphalt roads, and dark shadows. Vegetation consisted of a range of intensity values at the darker end of the intensity range. Some leaves are shaded and are therefore darker than leaves in the sunlight which appear lighter. Different colors of foliage may separate different species or sizes of plants. Dead plant material in the form of litter is usually lighter in color due to a loss of chlorophyll and water. Soils that contain organic matter (e.g., beneath or adjacent to shrubs) will usually be darker than soils that have little organic matter, but lighter than plant litter. Soils that are both low in organic matter and water will appear the lightest and may include features such as dirt roads, aircraft landing strips, and areas that have had their topsoil bladed off mechanically.

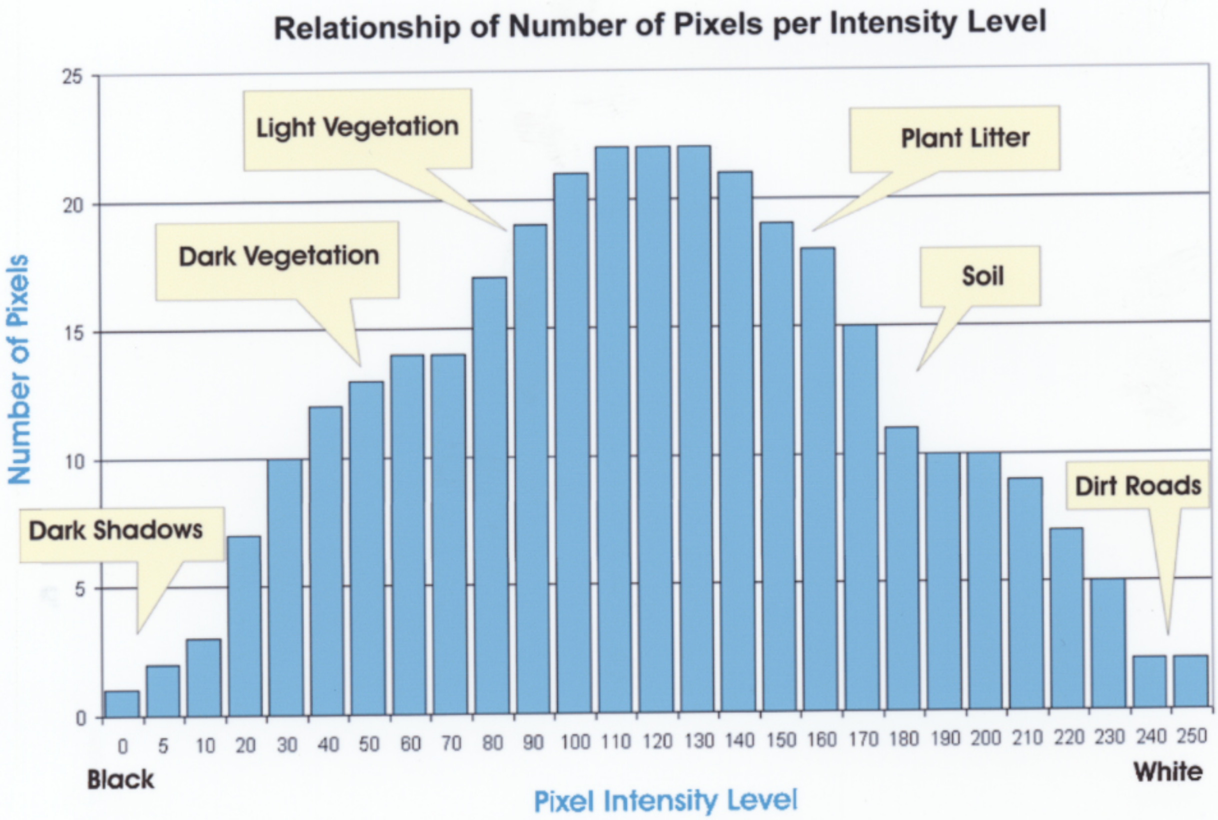

Figure 4-3. Hypothetical histogram of features in a digital image of desert vegetation.

A digital image that is prepared from a good aerial photograph will frequently contain sufficient information to allow trained technicians to separate pixel information using image-processing software into meaningful landscape features that can be represented by classes of features based on their intensity level. The process of selecting a range of intensity levels which best captures a particular feature is referred to thresholding or density slicing.

Image-processing software packages vary in their ability to find and evaluate these intensity threshold levels. The simpler packages operate strictly using gray-scale images and a simple means of setting the threshold level. They often lack import and export functions and may have rather rudimentary abilities to measure digital objects. Intermediate packages use more color information from several bands as well as a wider range of color bands. They may also incorporate filters to eliminate undesirable pixels such as small pixels or clusters of pixels (e.g., pixel clusters less than six pixels in size) that may result from light reflections, color aberrations created by the camera lens, and image-sharpening processing. They also offer greater capabilities in visualizing results and in measuring or exporting analytical results. Advanced packages may provide the ability to evaluate groups of pixels with a range of color values in the context of pixels surrounding these groups. Generally speaking, the greater the number of features and capabilities incorporated into the software the more complicated and expensive the software. However, such higher-end software, frequently automates extraction of features and permits greater accuracy at a cost savings to the user. This software may contain learning sets and programmable scripts to automate processing.

In addition to image-processing software, other image display software packages have been developed to expedite the extraction of data from data sets and the ability to display that information in screen-displayed images and high-quality printed maps. Two-dimensional graphing software permits statistical analyses of complex patterns to be displayed. Of rather recent development has been the use of GIS software that permits the display and higher analyses of data sets that are dissimilar (vegetation, soils, slope), except for their geographic position or location. This GIS software has become the standard tool for analyzing large data sets such as occur at military and government installations.

The measurement of plant cover by digital techniques incorporates a combination of software techniques to achieve optimal results. The continual development of new software and upgrade in software power and capabilities will result in a constant change in the tools available to help managers over time. The description of techniques and software described here should be thought of as a snapshot in time of a process that is ever-improving and increasing in power and applicability. When we first started this project there were only a couple of image-processing software packages with rather rudimentary features. Now there are dozens of packages with sophisticated features. While the techniques will at first appear rather challenging and complicated, they nevertheless, provide the only working and practical solution to solving the measurement of desert vegetation over large areas. It should also be kept in mind that the cost and availability of detailed large-scale imagery is becoming increasingly more available at lower cost. It is assumed that future imagery will be of even higher quality.

A description of selected software packages follow. It is likely that in the process of evaluating software other equally powerful, or more powerful, software packages exist. As software is updated, it is also probable that newer versions will contain enhancements that were not available at the time of the preparation of this manual. The mention of specific software packages does not imply any government endorsement for the product. Such products are named and described as an example of software that has come to the attention of the authors. It is also probable that not all of the software's capabilities or limitations have been comprehended by the authors, thereby, making it desirable to seek assistance directly from the software company's technical support and training services to better understand the complete power and limitations of the software.

4.3 TYPES OF IMAGE-PROCESSING SOFTWARE

4.3.1 ImageTool

ImageTool (IT) is one of the best-known freeware software packages available. It has a surprising number of basic features, but is limited in sophisticated enhancement and measurement features, image size, and customer support. It is limited to images that are less than 33,371,877 pixels (5,775 × 5,775 or about 95.5 MB of file space). Larger images have to be cropped or resized to be analyzed. While color images (e.g., 25-bit RGB TIFF images) can be opened, they must be converted to gray-scale images to be analyzed. It has a limited number of tools for enhancing contrast, stretching histograms, and color correction. Because it is freeware, users should not expect customer support nor training as offered by other commercial software packages.

The software was written using Borland's C++ version 5.0.2 and the source code for the executable is available free of charge. IT was developed in the Department of Dental Diagnostic Science at the University of Texas Health Science Center, San Antonio, Texas (UTHSCSA). The program was developed by C. Donald Wilcox, S. Brent Dove, W. Doss McDavid, and David B. Greer. It incorporates many of the features of the original image-processing software of the National Institutes of Health (NIH), but has added features and many refinements. Version 3.0 of the UTHSCSA IT is available free of charge at the Internet Web site: http://ddsdx.uthscsa.edu/dig/itdesc.html (Web status as of May 1, 2002).

The first step in using IT is to download and unzip the software (software comes zipped and must be unzipped with software such as WinZip®. WinZip® is available with a 21-day evaluation period from Nico Mak Computing, Inc. at http://www.winzip.com (Web status as of May 1, 2002) ($29.00 single license user cost after the evaluation period). The unzipped files provide the software, user's documentation, images, and other plug-ins. The software can be installed using install-shield software supplied with the software, or by using the "Install" option within WinZip®. The installed software will guide the installation to match the desired path and computer workstation. Next load an image (e.g., a color 24-bit RGB TIFF image) of appropriate size (e.g., less than 33 million pixels) by selecting the **File** command option on the toolbar at the top of the monitor display, and select **Open Image F2**. Enter the file and path for the image being opened.

To convert the color image to a gray-scale image, locate the command **Processing** in the toolbar at the top of the screen and select it by positioning the cursor over it and clicking the left button of the mouse. A pull-down submenu will appear. Next select the **Color-to-Grayscale** command option (Figure 4-4). After a few seconds a gray-scale image will appear positioned over the original color image. Enlarge this image (use the magnifying glass icon with the + sign on the toolbar) so that the details of vegetation and the soil surrounding the shrubs are clear.

The second step is to manually select the threshold of luminosity that best corresponds to the shrub canopy cover. This is done by using the gray-scale image. Select the **Processing** command from the toolbar. A pull-down submenu will appear. Next select the **Threshold** command option (Figure 4-4). This will display a side-bar menu. Then select the **Manual…Ctrl + F7** command option. This will bring up manual-threshold display panel showing a histogram representing the number of pixels within the image at different intensity values. Below the histogram is a scale bar with values ranging from 0 to 255. The image that appears beneath the display panel will be totally red (a default threshold value of 255).

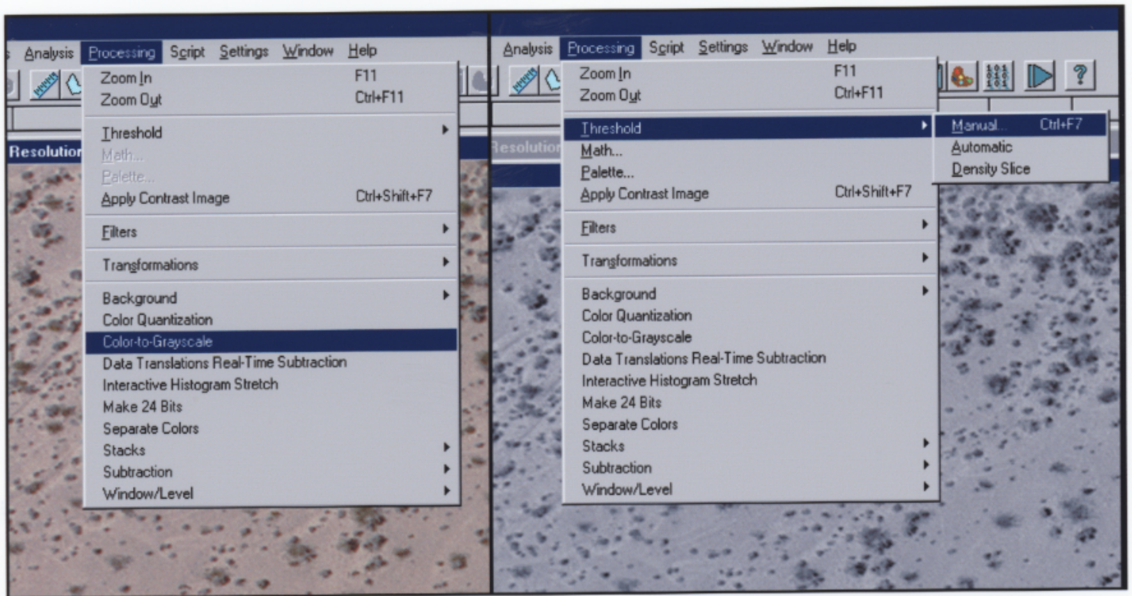

Figure 4-4. Examples of pull-down menus for creating gray-scale images and setting thresholds with ImageTool software.

To select the threshold that best matches the shrub canopy cover, position the cursor over the right end of the scale bar. Press down on the left mouse button with the cursor on the right end of the 0-255 scale bar and hold the button down while sliding the (mouse) end bar to the left. As the end cap of the scale bar moves to the left, the red in the image beneath the display panel will be reduced or cleared to show the lighter areas of the image such as roads and soil. Continue moving the cursor to the left until all the red is cleared from the image except directly over the shrub canopy. To ensure that the proper threshold is achieved, it is helpful to move the cursor below the apparent target threshold and observe the overlay pattern. Note what image features are overlaid with red (e.g., shadows, vegetation, soil, rocks, etc.). Then move the cursor to values greater than the apparent target value and observe the resulting overlay pattern. This can be done several times until the user is sure that the selected threshold best represents the shrub canopy cover and is not underrepresented (not all of the shrub vegetation is covered) or over represented (soil and other objects are also covered). The user may choose to record the numerical threshold value shown in the panel to the right of the histogram and scale bar (e.g., 0-126).

When thresholding is complete, select **OK** to create the shrub silhouette image. Save the black and white image by selecting **Save Image** from the **File** pull-down menu on the toolbar. Enter a file name and select TIFF as the type of image and press the **Save** button (Figure 4-5).

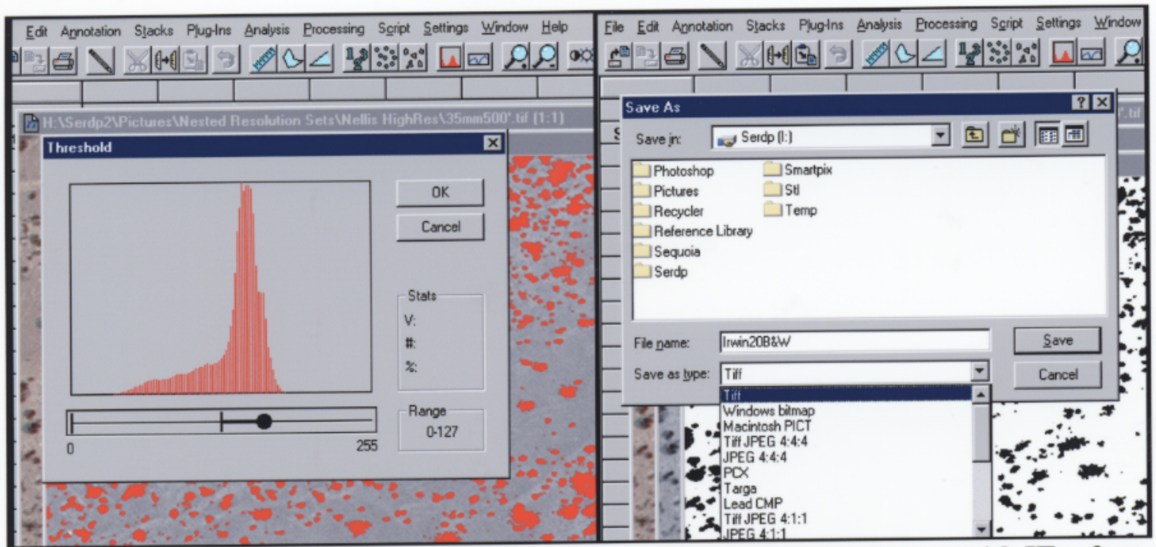

Figure 4-5. Examples of pull-down menus for thresholding and saving images with IT software.

To determine percent cover, select the **Analysis** pull-down menu from the toolbar, then select **Count Black/White Pixels**. The count values will be displayed in the **Results** spreadsheet. It may be necessary to minimize images or move them lower on the screen to reveal the underlying spreadsheet. The percent cover of black pixels will be expressed as a percentage under the column heading **Black%**.

To remove undesirable smaller pixels (often considered noise), choose **Processing** from the toolbar. Then select **Filters**, then **Erosion**. Alternately, this feature can be selected by pressing F9. Dilation can be similarly selected by pressing F10.

4.3.2 Sigma Scan Pro®

Sigma Scan Pro® was among the first software packages released for image processing in the medical research community. It contains many feature options for manipulating and processing digital images. Its strengths lie in its ability to process very large files (the largest of all packages reviewed), zoom in and out while in most menus, and the ability to export colored masks overlaid on the original image. This latter feature is useful for printing validation sheets that show the extent of canopy covered by the threshold values. However, the software does not have many of the more sophisticated features for measuring objects (e.g., percent cover must be calculated by using multiple steps) (i.e., mathematical expressions into spreadsheet cells), rather than having the parameter automatically calculated like some other software, creating easy linkage to other software (e.g., Microsoft Excel® spreadsheets), or thresholding for selected color patterns (e.g., an eyedropper selection tool that can be adjusted in size and placed over the desired object).

4.3.2.1 Procedures for Setting Intensity Thresholds

To select and open a TIFF-formatted digital image use the following commands (see Figure 4-6): first select the **File** command from the toolbar at the top of the software screen. This brings up a pull-down menu. From this menu select the **Open** option which activates a side-bar menu. From this menu select the **Image** option. This provides the users with an opportunity to specify the file path and name. Look in: ***(subdirectory name)***, Files of type: ***All***, File name: ***(image name.tif)***, then left-mouse click on the **Open** button. (**NOTE:** The file loads faster when the **Enable Preview** option is unchecked.) Next select and set the histogram intensity threshold values that best distinguishes vegetation canopy cover. Boundaries use the following commands (see Figure 4-7):

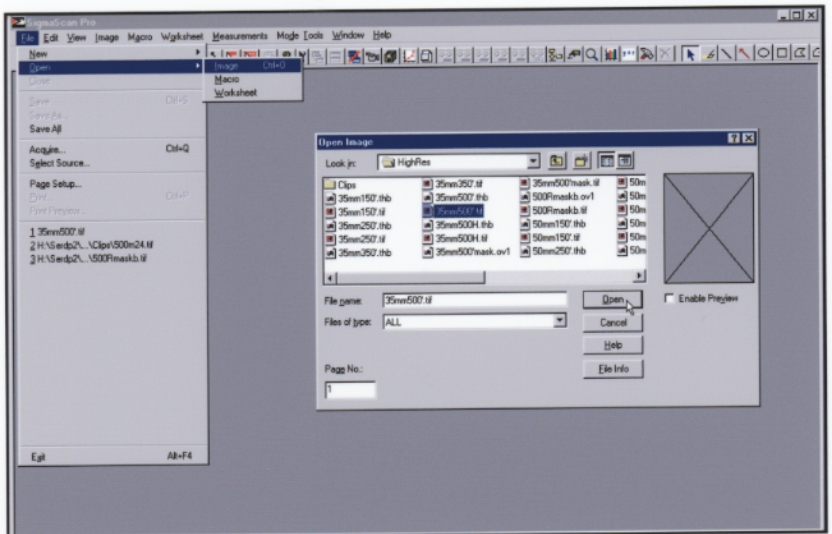

Figure 4-6. Selecting and opening a file in SigmaScan Pro®.

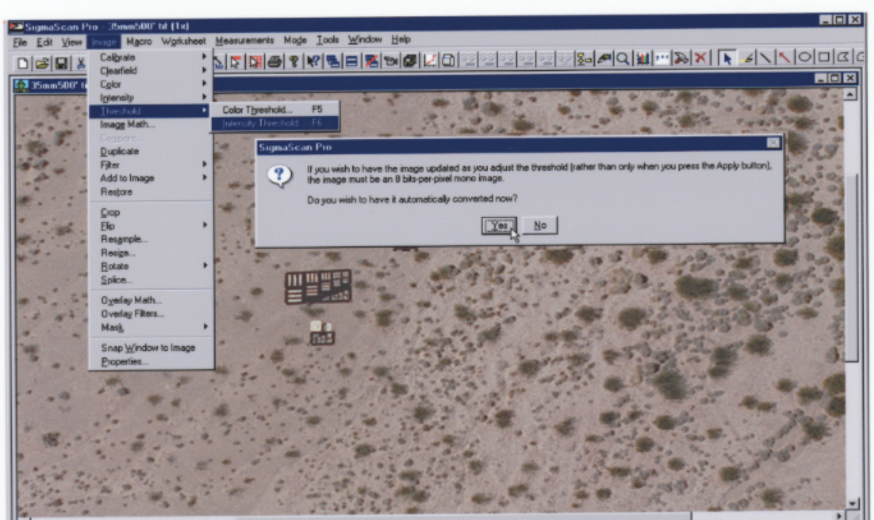

Figure 4-7. Selecting an intensity threshold for mono or color digital images.

To set the intensity threshold while retaining a colored image on the screen (important if you wish to print a colored image later) select the **Image** command from the toolbar at the top of the software screen. This brings up a pull-down menu. From this menu select the **Threshold** command. This activates a side-bar menu. From this menu select the **Intensity Threshold** option. The user is then prompted to convert the colored image into an 8-bits-per pixel mono image (i.e., a graytone image). Reply to the question ...convert now? by selecting **Yes** if you desire to work in a mono-image or **No** if you want to retain the color image.

A histogram pop-up menu is displayed allowing the user to set the lower and upper bounds of the threshold values for pixels to be included in the threshold mask. Usually the user would accept the lower or darkest intensity value of **0** (lightest). The intensity level can be entered in the **Intensity** window [***n***] or by clicking and dragging the slide-bar beneath the histogram. This is done by clicking the left-mouse-button on the right-hand square of the colored bar, holding it down, and dragging it to the right slightly, release mouse button, then click left-mouse button on the **Apply** button to view results of applying the intensity value. When using mono-image the change in color (e.g., red overlay) will be immediate, but when if the user desires to retain the colored image, the **Apply** button must be pressed to see the results. Alternatively, threshold values can be entered directly into the **Intensity** box window (Figure 4-8).

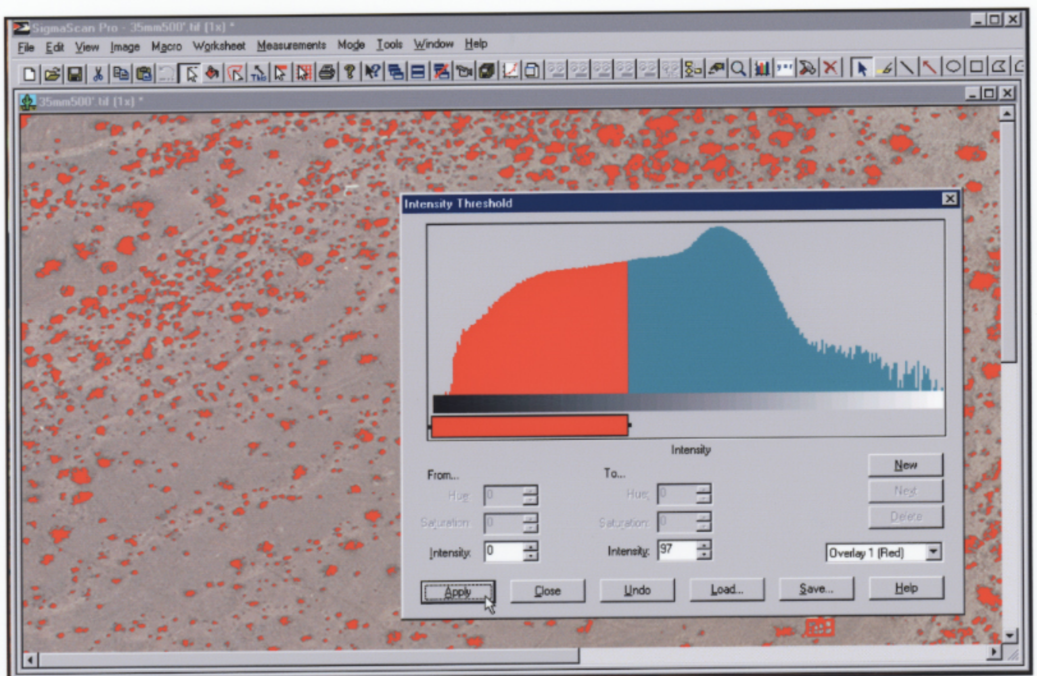

Figure 4-8. Setting intensity thresholds while retaining the colored image.

By using this technique the underlying colored image is retained and permits the user to print the threshold color (e.g., red) on top of the underlying color image. Having a colored image is often easier for the eye to interpret if the proper threshold value has been applied, but makes the file size larger and the threshold view is not dynamic (i.e., the apply button must be selected to see the results).

The proper threshold value extends the threshold color to cover as much of the vegetation canopy as possible without including adjacent darker soils or plant litter. Several threshold levels should be tested to determine the best setting. Examples of proper and improper threshold levels are shown in Figure 4-9.

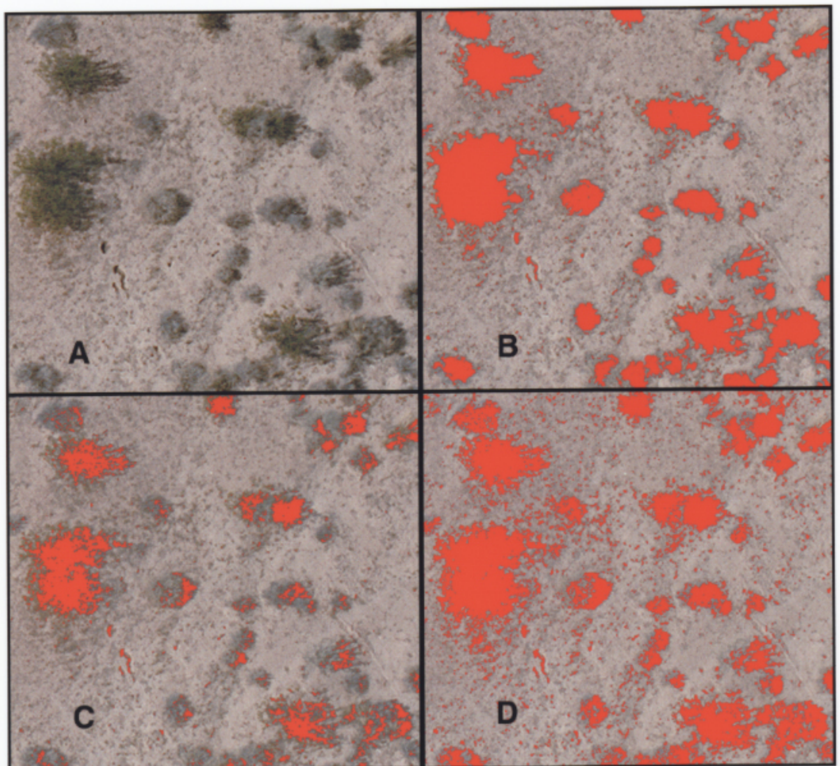

Figure 4-9. (A) Color image to be thresholded. (B) Proper threshold level includes most vegetation, but minimizes inclusion of soil and litter. (C) Image with threshold set too low, not all plant canopies are covered within the area threshold. (D) Image threshold set too high, background soil and litter are included within the area threshold.

To set the threshold values using an 8 bits-per-pixel mono-image, the user proceeds as explained previously. A user would use this choice to speed up the thresholding process once the approximate values are known and the user feels comfortable with the ability to properly set the threshold values. When the user is prompted to **...convert now?,** the user responds **Yes**. The command sequence for setting threshold values on an 8 bits-per-pixel mono-image is shown in Figure 4-10. Note that using an 8 bits-per-pixel mono-image (black and white image) makes the view of the image thresholding dynamic and you can immediately see the mask color over the shrubs change as you move the right-hand square of the colored bar to the left or right. The masked image will be saved as gray-tones and the file size will be slightly smaller than the file size of a colored image.

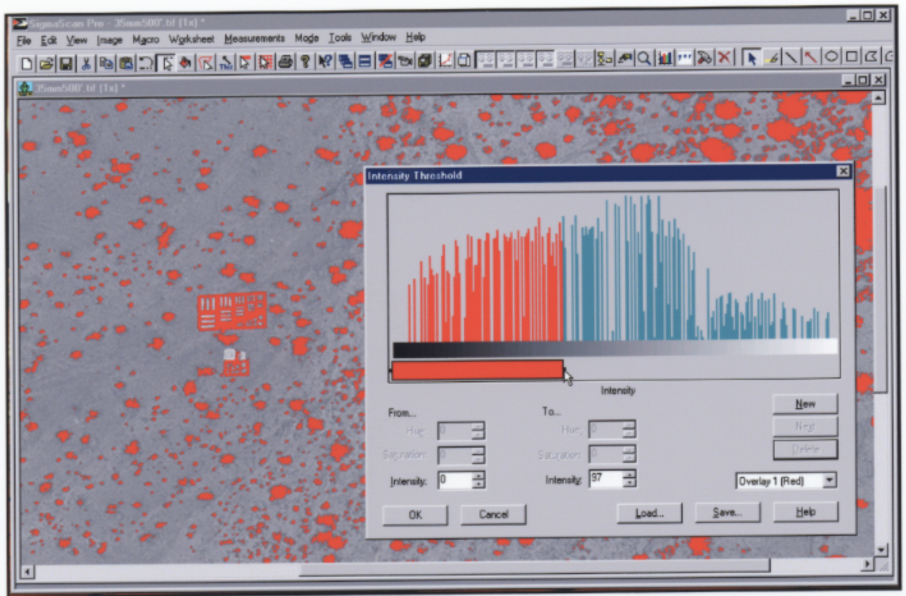

Figure 4-10. Converting image to gray scale and adjusting threshold values with slider bar.

If you do not click exactly on the square you will create a second bar (in the event you want to break up the threshold scale into smaller segments and display them with different colors). The user can delete this bar with the delete button at the lower right of the histogram. After selecting the proper intensity threshold, release the mouse button, move to the **OK** button, and click the left-mouse button.

4.3.2.2 Applying Filters to Remove Object Noise

Within most images there are small pixels of low intensity that are considered object noise. These pixels may result from such things as small rocks, annual plants, or from camera artifacts created by the distortion from the lens, light scattering, dust on the film when scanned, or other causes. These pixels can be removed by using the Overlay Filters (Figure 4-11). This is done by selecting the **Image** command from the toolbar at the top of the software screen. This brings up a pull-down menu. From this menu the user selects **Overlay Filters** option. This activates a pop-up menu that prompts the user for information. Within this menu enter the following values: **Source Overlay**: Overlay 1 (Red); **Destination Overlay**: Overlay 1 (Red); **Iteration:** 1; **Edge Speed (1-5):** 1; **Erosion Filters**: (check) Normal. To fill in holes in the canopy, the **Special Filters** can be set to: (check) Fill Holes. Apply the overlay filter commands by clicking the left mouse button on the **Apply** button of the **Overlay Filters** pop-up menu.

Figure 4-11. Sigma Scan Pro® menus for using overlay filters to remove small pixels.

4.3.2.3 Creating an Intensity Threshold Mask of Shrub Canopy Cover

Once a threshold value(s) has been set that includes the silhouettes of most shrubs, it is desirable to create a threshold mask that can be used to create shrub canopy contour maps with other software. In order to prepare a mask, the user selects the **Image** command from the toolbar at the top of the software screen. This brings up a pull-down menu. From this menu the user selects the **Mask** option which brings up a pop-up menu that prompts the user as to the type of mask that is desired. The user selects the **With Overlay 1 (Red)** option (Figure 4-12). This creates an image of vegetation canopy cover as dark silhouettes on a white background.

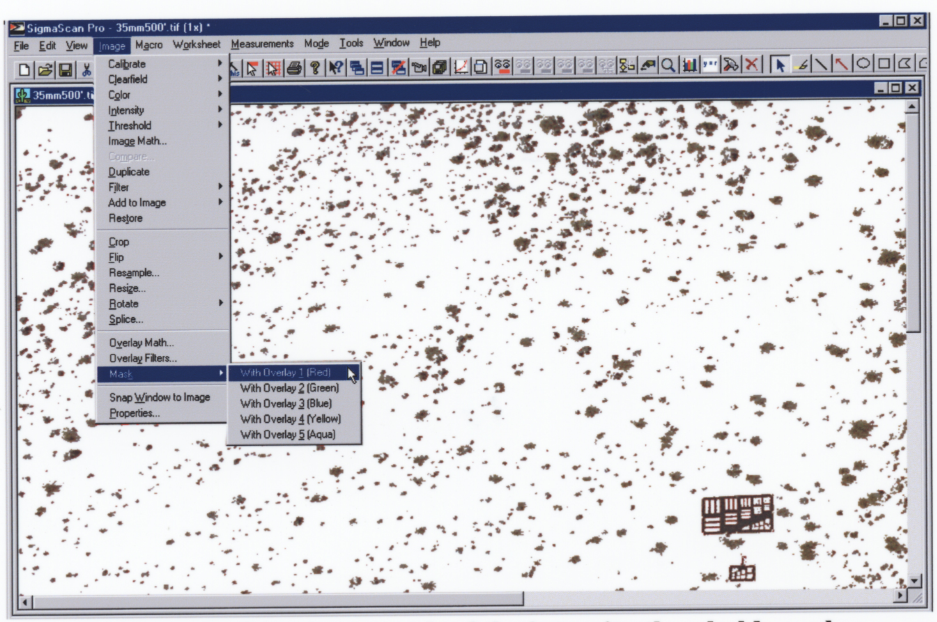

Figure 4-12. Creating a mask of the intensity threshold overlay.

4.3.2.4 *Saving Threshold Masks for Canopy Cover as a TIFF Image*

The user selects the File command from the toolbar at the top of the software screen. This brings up a pull-down men. From the menu, the user selects the **Save As...** option. A pop-up menu is activated prompting the user for a file path and name. Upon entering the File name: ***(maskfilename.tif)***, the user selects from the **Save as Type** option: *TIF 24-bit*; and from the **Subfile Type**: *Uncompressed RGB*, and clicks on the left mouse button on the **Save** button of the **Save As ...**pop-up menu (Figure 4-13). These commands save the mask file for further analyses.

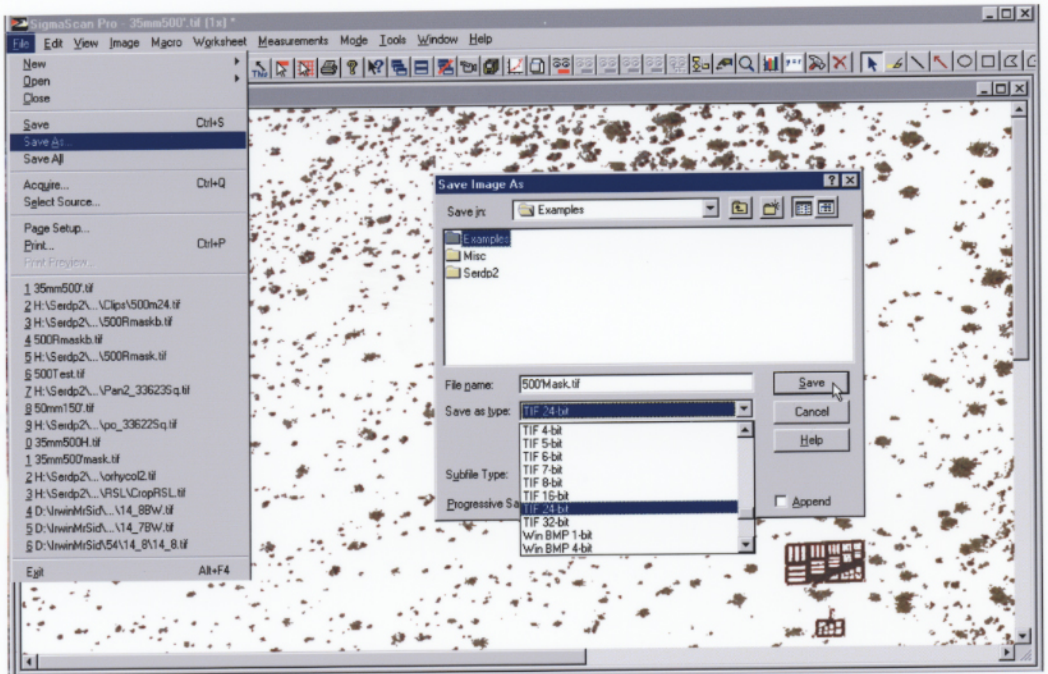

Figure 4-13. Saving the mask file as a 24-bit TIFF image.

It is a good idea to print a copy of the mask overlay and underlying color image on high-quality glossy film or paper as well as to record the threshold values and other settings for future reference. These can be stored in a three-ring binder in clear plastic-protector sheets. It is helpful to periodically refer back to these images to ensure that the technician is consistent in setting thresholds and other parameters.

4.3.3 Image Pro® Plus

Image-Pro® Plus incorporates most of the advanced features of medical-imaging software, with sophisticated measuring and viewing features. This software is one of the most powerful packages on the market today for performing analyses of vegetation images. However, the software does not have the ability to handle geospatial information (e.g., geotiff files) with embedded GIS-spatial projections (e.g., world projection and state plane). In order to use geotiff files like IKONOS they must be first opened in Adobe Photoshop®, cropped, contrast enhanced (use the "Image/Adjust/Auto Contrast" command), and saved as a TIFF image. Image files created by Image-Pro® Plus must then be imported into GIS software such as ArcView/Image Analyst®, or ERDAS Imagine®, and georeferenced when the geospatial coordinates of the image corners are known. Additionally, the size of the image that will load and process properly in Version 4.1 is restricted to about 150 MB. Large IKONOS images or scanned aerial photographs (e.g., 500 MB) will not load properly; however, smaller file sizes (e.g., 145 MG of 9 inches [in] × 9 in aerial photographs scanned at 800 disintegrations per inch [dpi]) will load and process properly. Future software versions may be enhanced to handle larger file sizes. The software also provides a simple means (i.e., flattening image) of correcting unequal color-balance in an image due to vignetting (e.g., dark corners and a bright photo center caused by camera-lens distortion).

ImagePro® Plus,Version 4.1 has the ability to export image masks (e.g., 1,200 dpi black shrub silhouettes on a white background) at the same scale as the image from which they are processed, rather than having to rely on the screen-capture feature (e.g., pressing Shift-Print Screen then pasting the captured image into image-editing software such as Adobe Photoshop® and saving it as a named TIFF-image file). Such screen-captured images typically have much lower resolutions (e.g., 72 dpi) than image files that can be saved without resizing the image. Hand-drawn notations added to the image or colored masks overlaid on the original photographic image must still be saved as screen-captured images.

The user's group that supports this software is relatively large and provides excellent opportunities to communicate with other users on a daily basis. Users seeking answers to questions can post questions on a user's group Internet site (register at http://www.solutions-zone.com/ipednld/subscriber.asp or user groups at: http://www.mediacy.com). Users may also search the archive files available at: http://www.mediacy.com/tech/ipts_ugml.html where such questions and comments are bundled and e-mailed to registered users daily. This can be a helpful source of solutions that is not contained in the user's guides.

4.3.3.1 Loading Image Files

Instructions provided here are based on ImagePro® Plus, Version 4.1 and may not necessarily reflect features or procedures available with newer versions. To open or load an image, select and press with the mouse cursor the **File** command from the toolbar at the top of the window (Figure 4-14). This activates a drop-down menu. Next select **Open** from the command list. This activates a pop-up menu **Open File** which displays the path and file name information. With the cursor on the **Look in** box, browse through the drive and file path on the hard drive and select the file name you wish to load. Double-click on the desired file name or press the **Open** button when the proper file name appears in the **File name** window to load the image. If the file is too large, an error message will pop up explaining that the image is too large. The image may have to be resized or cropped into smaller files sizes should this occur.

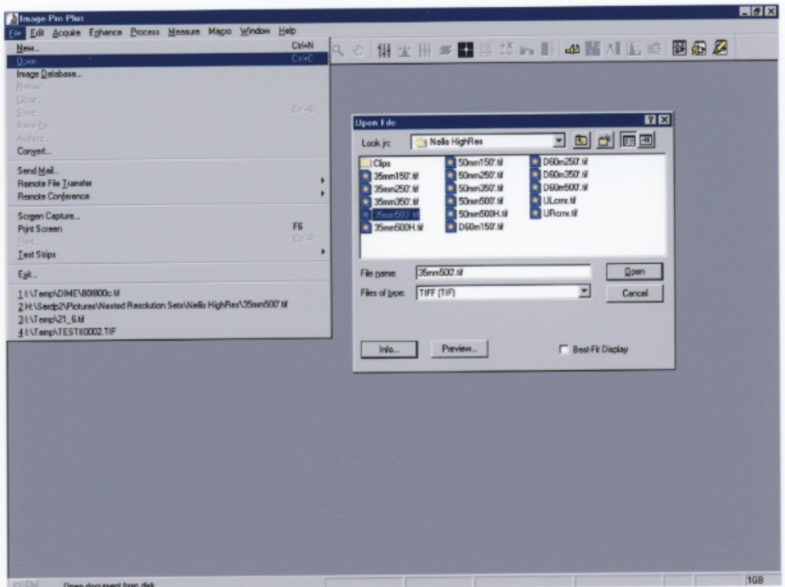

Figure 4-14. Opening file images in Image Pro® Plus, Version 4.1.

4.3.3.2 Selecting Proper Threshold Values

Once the image has been loaded, move the cursor to the **Measure** command from the toolbar at the top of the window (Figure 4-15). This activates a drop-down menu. Next select **Count/Size** (indicated by the red number 1 in Figure 4-15). This activates a pop-up menu which displays information needed to set histogram threshold values and count objectives. Ensure that the options **Measure Objects** and **Apply Filter Ranges** are checked and that the option **Manual** is selected (black dot). Next select the **Select Colors…**option (indicated by the red number 2 in Figure 2). This will bring up a **Segmentation** pop-up menu.

Position the cursor along the sliding bar under the histogram peaks and slide the bar (indicated by the red number 3 in Figure 4-15) from left to right until the full extent of the shrubs are covered by the red selection color (color can be changed to other colors if it interferes with the color of vegetation such as the red color of oak trees in the fall where a blue selection color may be more appropriate).

The red band (R button) will be the usual default band when opening this pop-up menu using the RGB model and it is the band most often correlated with vegetation. After a value has been selected for this red band, values can be set for the green and blue bands which are similarly adjusted.

It is sometimes helpful to move the sliding bar beneath the histogram curves to the right and left (smaller and larger numbers) to notice what affect these bands have on selecting the optimal values referred to as a histogram threshold value. Sometimes the blue band will contain information about shadows cast by the vegetation and adjusting it can result in including or excluding areas associated with the shrubs. Once a proper combination of values has been selected that best approximates the area occupied by the vegetation, then **Close** the **Segmentation** pop-up menu (indicated by the red number 4 in Figure 4-15) which returns you to the **Count/Size** pop-up menu.

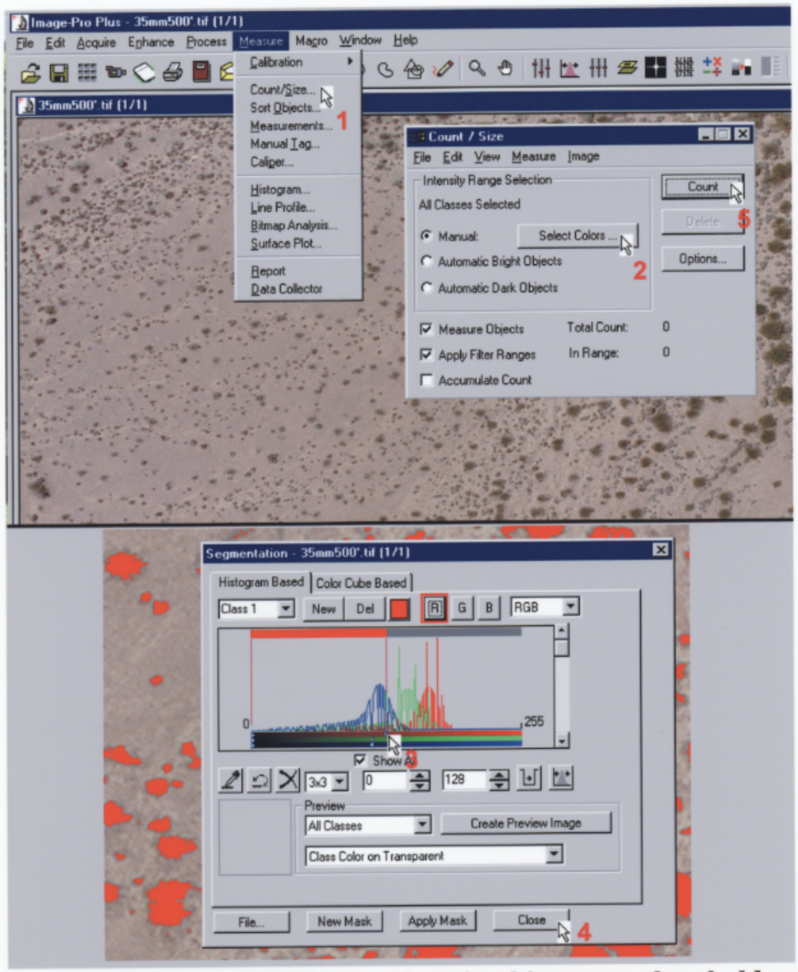

Figure 4-15. Selecting count/size and setting histogram threshold values.

To perform a count of the area defined by the histogram band values (thresholds), select the **Count** command (indicated by the red number 5 in Figure 4-15). This begins the calculations and may require several minutes to complete if using large files. When it is complete, the vegetation in the image will be overlaid in red (or user-specified color). In order to verify that the thresholding appears to be properly selected, the image can be enlarged and panned to different areas of the image and the count performed. The red selection can be deleted using the **Delete** command (located just below the red number 5 in Figure 4-15) in the **Count/Size** pop-up menu. Pressing the count command will reactivate the counting process and display the red selections. Repeating this cycle helps the user confirm proper threshold values and check for subtle differences in the image color nonuniformities often associated with vignetting or exceptionally light or dark soil types. The iterative process of counting and deleting the count and adjusting the values will ensure that the best fit for the vegetation is achieved. If aerial photographs are all exposed equally, then the threshold values will probably be consistent from image to image. However, occasionally, flight lines running in opposite directions can create different light and color values that may require different threshold values for each flight line or each image, if soil color differences are pronounced. A good technique is to frequently confirm threshold values. Color-balancing software can be used to adjust color balancing.

4.3.3.3 Vignette Correction

A method of correcting vignetting (unequal color) due to darkening of the image corners and lighter photo centers is to use the **Flatten Background** command. This is done by selecting the **Measure** menu from the toolbar at the top of the screen (indicated by the red number 1 in Figure 4-16). The **Image** command from the **Count/Size** pop-up menu is then selected (indicated by the red number 2 in Figure 4-16). Select the **Flatten Background** option (indicated by the red number 3 in Figure 4-16). This will bring up a Flatten Background pop-up menu. Next, select the **Bright** option and enter a low value (e.g., 7 Pix) for the number of pixels. Press **OK** (indicated by the red number 4 in Figure 4-16) to complete the vignette color-balancing correction. Should the correction using the value of 7 (pixels) be undesirable (e.g., less than adequate judged by the evenness of color from corner to corner of the image) then the user can press **Undo** from the pull-down menu from the **Edit** command in the toolbar at the top of the screen. The process can be repeated with new values until an acceptable product results. The corrected image can then be saved under a *new* name as a *new* file. It is best not to save it back to the same file name (overwrite the file) to ensure that the integrity of the original image remains of archival quality in the event that later corrections are needed. It is recommended that images be corrected for color balance and then saved and cropped into smaller pieces for processing. If necessary, DIME® software should be used to color-balance and georeference images into a single color-corrected image than can be cut into pieces for subsequent processing. This will result in better color balancing between flight line images.

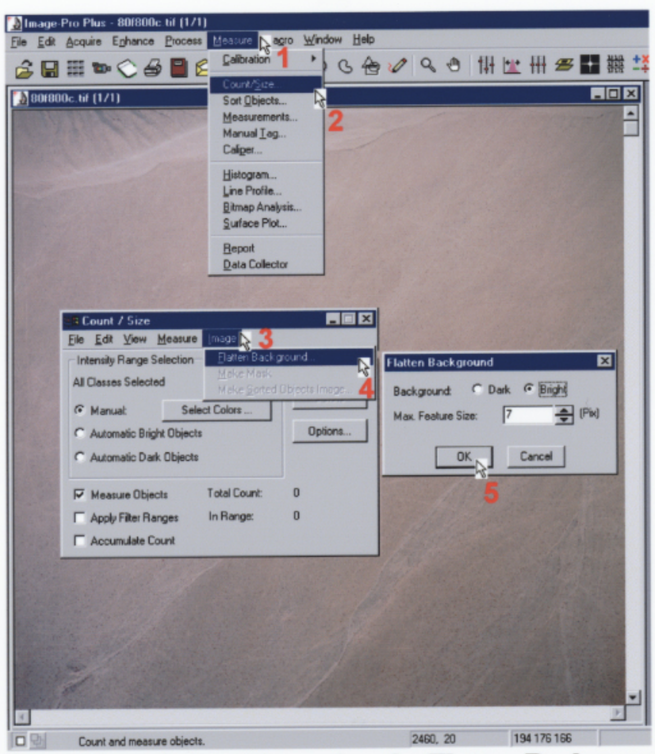

Figure 4-16. Correction of vignetting using the Flatten Background Command.

4.3.3.4 Selecting Which Measurements are to be Counted

Many options are available when selecting parameters to be measured during the count procedure. To select the appropriate parameters, select the **Measure** option from the **Count/Size** pop-up menu (Figure 4-17). This brings up the **Select Measurements** pop-up menu. The parameter **Per-Area** (percent of the total area) should be selected to measure percent canopy cover in addition to other parameters that are desired such as **Area** or **Diameter (mean)**. Pressing the **Measure** button in the lower right-hand corner of the pop-up menu will enter the parameters to be measured when the **Count** function is selected from the **Count/Size** pop-up menu.

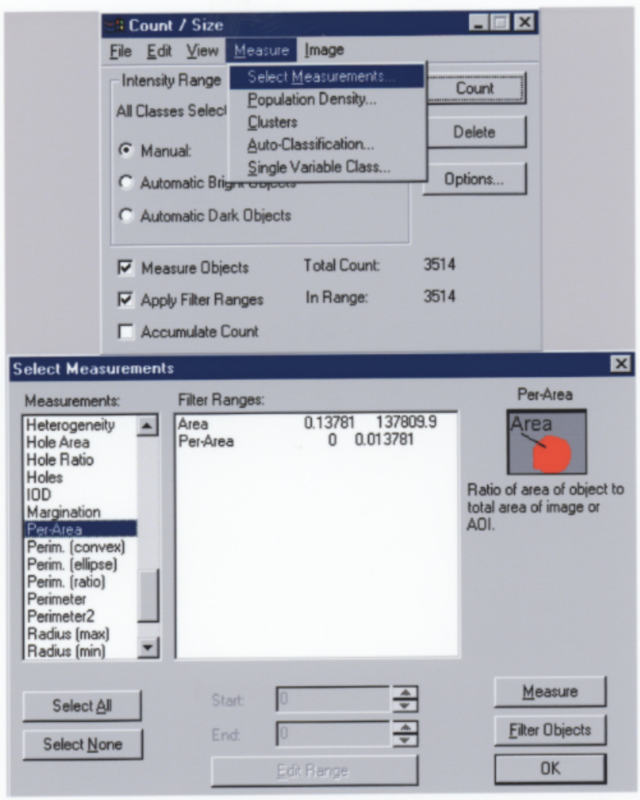

Figure 4-17. Selecting the measurement parameters.

4.3.3.5 Selecting an Area of Interest to be Counted

Before the counting process is finalized, it is usually desirable to select an area of interest (AOI) if an area smaller than the entire image is desired. It is also desirable to prefilter the data to ensure that holes within the canopy are filled and that the proper mask (fill and color) has been selected. This is done by selecting the **NEW AOI** from the tool bar icons just beneath the pull-down menu bar at the top of the screen (indicated by a red number 1 in Figure 4-18). The □ icon is used to select areas square in shape. The mouse cursor is placed in the upper left-hand corner of the area to be selected and while pressing the left mouse button the cursor is moved down and to the right to create a square area of appropriate size. When the proper area is selected, the mouse button is released (indicated by a red number 2 in Figure 4-18). This **AOI** can then be repositioned to new areas by left clicking on the mouse cursor while in the middle of the square and dragging it to a new location. The cursor will change from a single diagonal arrow to a four-headed arrow aligned in the cardinal directions of the compass when it is properly positioned to relocate the square to a new location within the image.

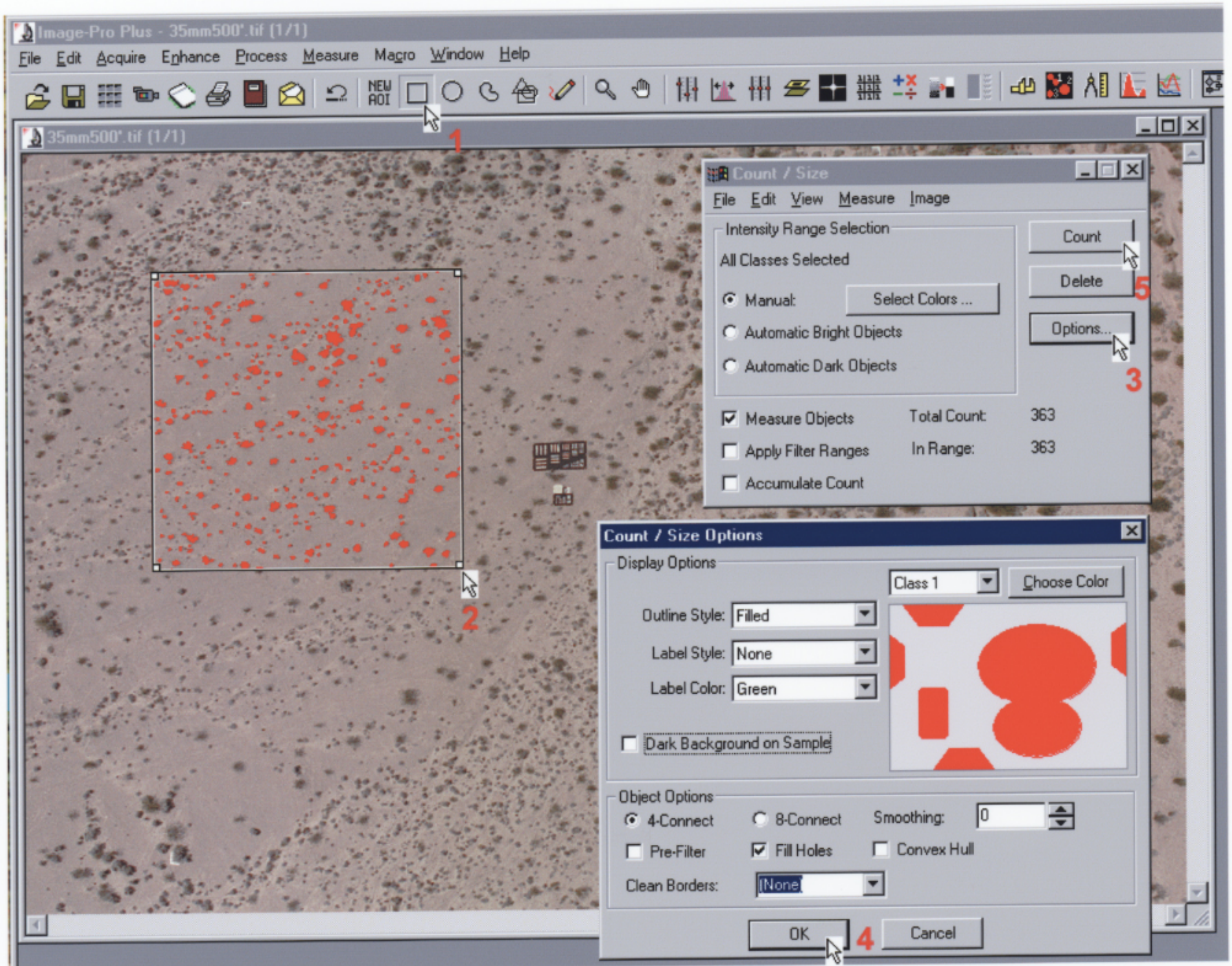

Figure 4-18. Selecting the area of interest and count options to be used.

4.3.3.6 Changing the Count Options

To change the count options available to the user, the **Options** button (indicated by a red number 3 in Figure 4-18) is selected from the **Count/Size** pop-up menu. This brings up a **Count /Size Options** pop-up menu. This menu is used to select features such as **Display Options** (e.g., outline colors, style, and labels) and **Object Options** (e.g., fill holes and size of objects not to be included in the count). When these have been properly set (see examples in Figure 4-18), then the **OK** button is pressed (indicated by the red number 4 in Figure 4-18). To activate the selection options, the **Count** button is pressed (indicated by the red number 5 in Figure 4-18). Only the objects within the **AOI** will be counted.

4.3.3.7 *Viewing Statistics of Measured Parameters*

Once objects have been measured, it is desirable to view the statistics. This is done by selecting the **View** from the **Count/Size** pop-up menu (Figure 4-19). The **Statistics** option is then selected from the pull-down menu that is activated. This brings up a pop-up display box with the statistics. The box can be resized by selecting and dragging the corner of the box.

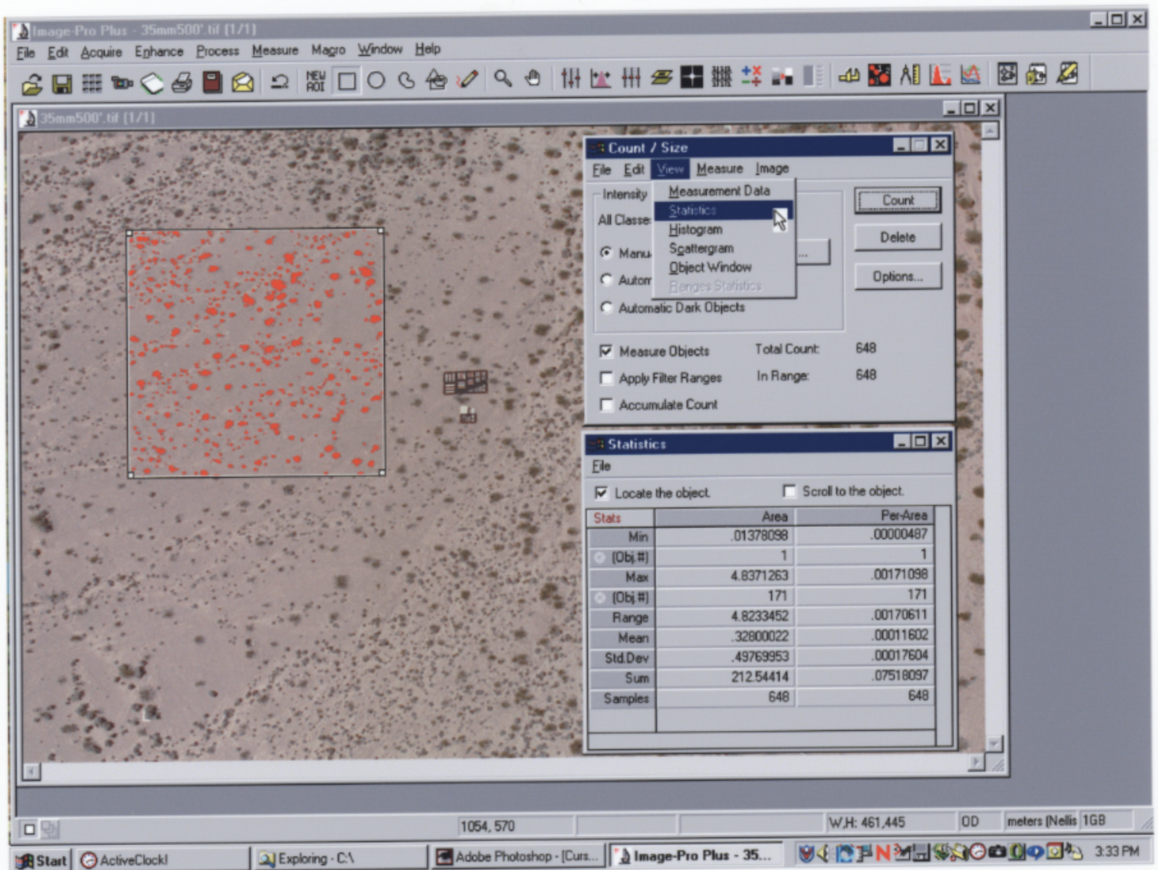

Figure 4-19. Viewing statistics of measured parameters.

The statistics can be exported to a Microsoft Excel® table if desired (select **File** from the Statistics box, then select **DDE to Excel**). The percent cover is shown as a fraction in the **Sum** row of the **Per-Area** statistics column.

4.3.3.8 *Unselecting Objects that Should Not be Counted*

It is possible to unselect objects that have been counted that are not to be included in the measurements (e.g., roads, buildings, optical targets). This is done by entering the Count/Size pop-up menu and from the **Edit** pull-down menu selecting the **Toggle Objects On/Off** (Figure 4-20). This will bring up a pop-up menu instructing the user to left click on the mouse to unselect the objects. Objects that are unselected will not be taken into account during the measurement calculations.

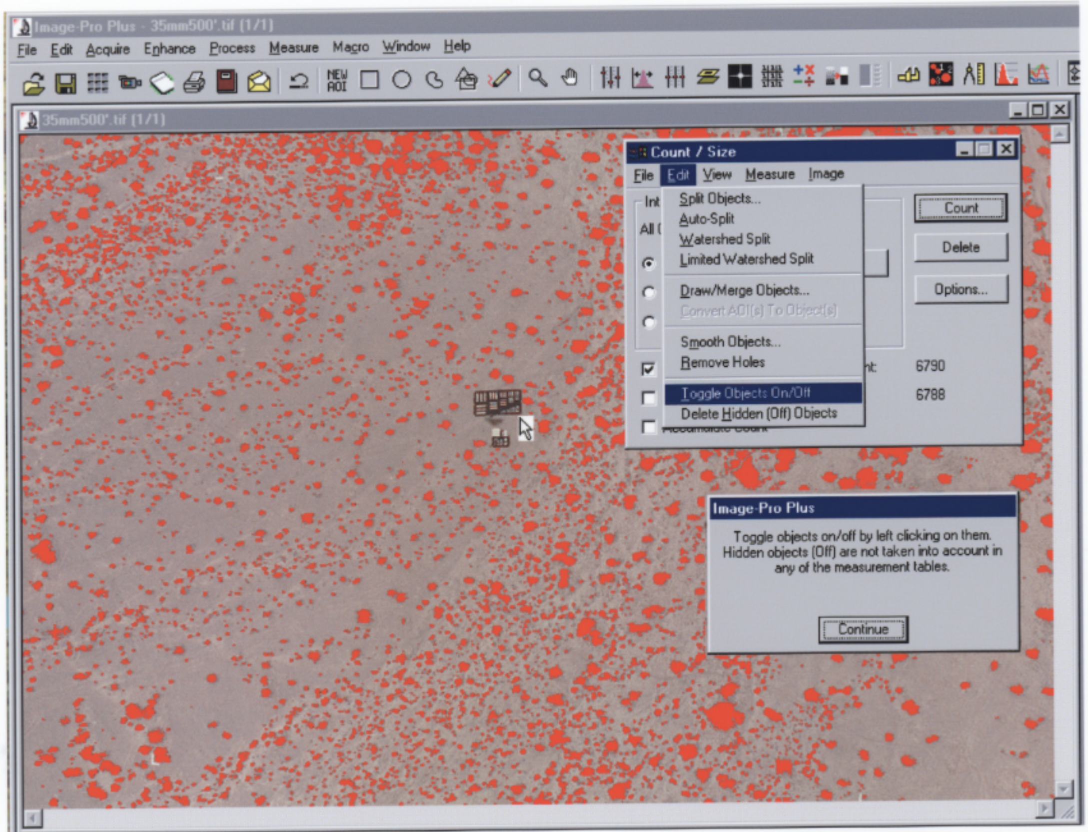

Figure 4-20. Unselecting objects that should not be measured.

4.3.3.9 Creating a Mask of Shrub Silhouettes

To create a mask showing white silhouettes of shrubs on a black background, select the **Image** pull-down option from the **Count/Size** pop-up menu (Figure 4-21). Then select the **Make Mask** option from the pull-down list of options. The mask will then need to be inverted to create a black silhouette of shrubs on a white background. This is done by selecting the **Enhance** option from the command menu at the top of the screen. Then select the **Invert Image** option (Figure 4-22). This procedure will create a mask containing black shrubs on a white background. The image can then be saved as a separate TIFF image file with its own unique new name.

4.3.3.10 Saving Images

New images created with Image Pro® Plus can be saved by selecting the image (click on the image; the darker [e.g., blue as opposed to gray] title bar will indicate that the image is selected). Choose from the **File** option of the command menu at the top of the screen (Figure 4-23). Next, select the **Save As** option from the pull-down menu. Verify that the path and file name are properly named and the path is located. It is sometimes desirable to write down the threshold values, file names, path, and other important information in a notebook or data log to ensure that files can be found in the future and that settings were appropriate. This permits data validation by others.

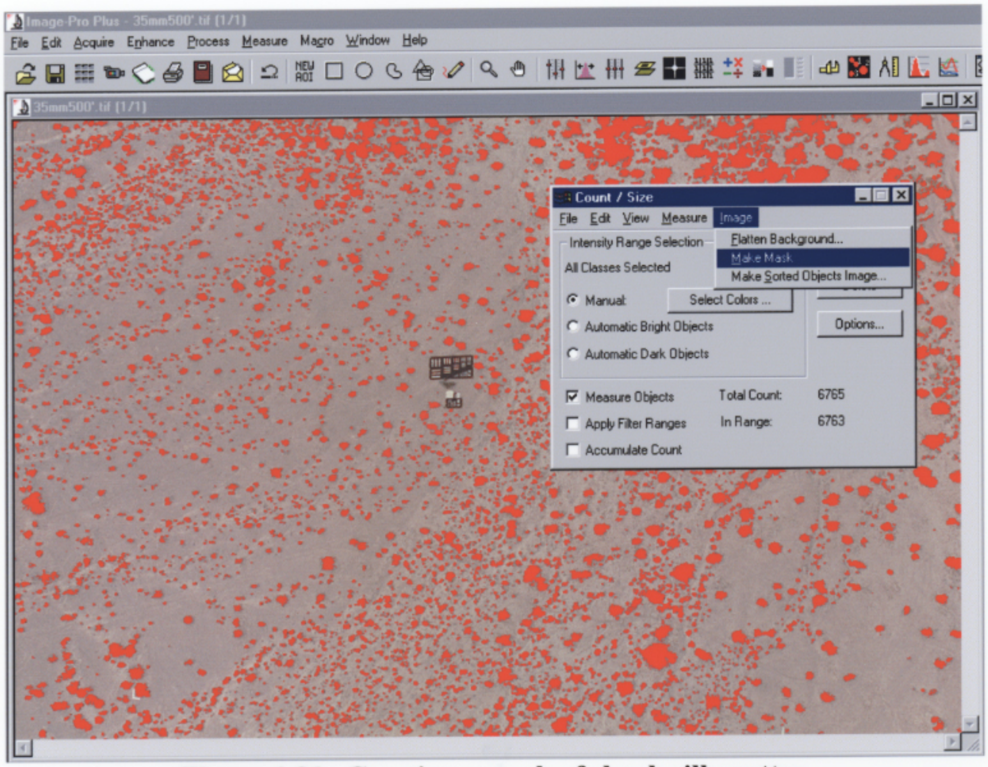

Figure 4-21. Creating a mask of shrub silhouettes.

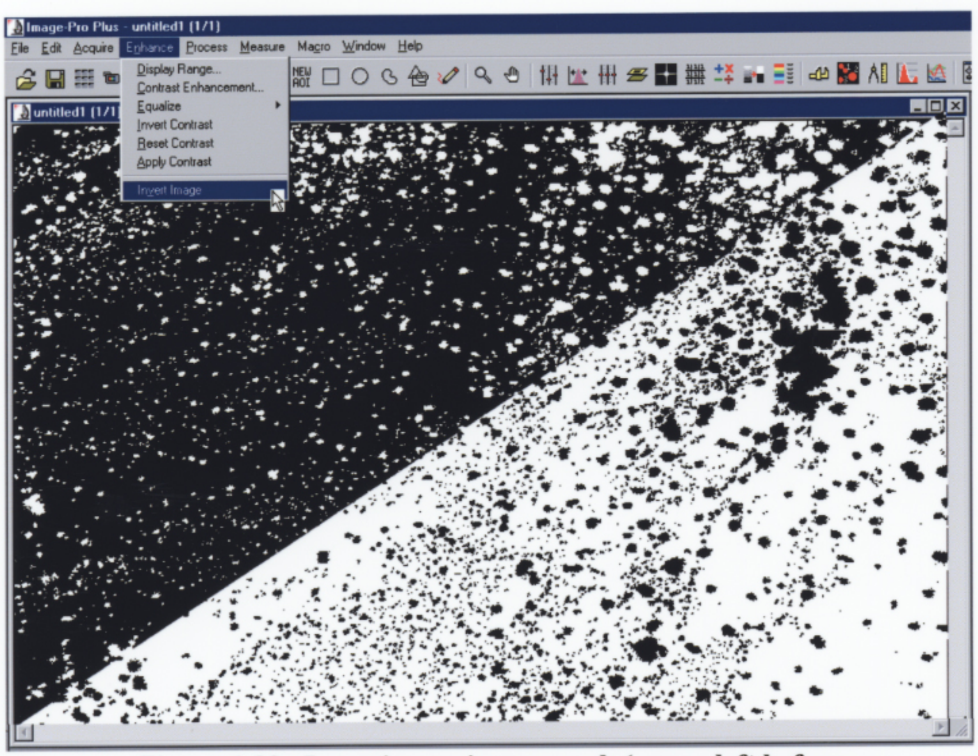

Figure 4-22. Inverting an image mask (upper left before conversion/lower right after conversion).

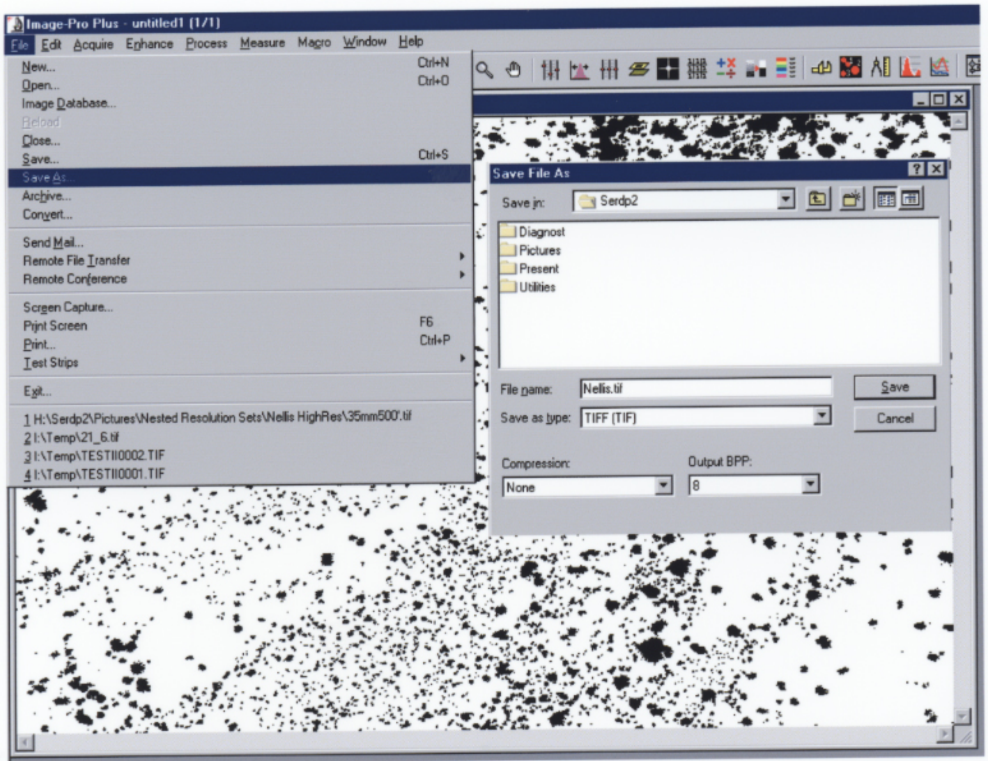

Figure 4-23. Saving a new image file.

4.3.3.11 Printing Images

Printing high-quality images produced during the measurement can also be used to verify that settings appear to be appropriate (e.g., threshold values are set properly and vignetting is not a problem). If screen-captured images are to be printed, they should be made only of enlarged areas because of the lower quality of image (compare printout from saved image and screen-captured image in Figure 4-24).

4.4 IMAGE MAPPING SOFTWARE

Because it is often easier to grasp information that is in a graphical format than in a tabular format, it is desirable to present data in the form of maps. Such maps are used to present information in multicolored two- or three-dimensional screen displays or printed maps. Information in such maps can be tied to attribute (source) tables and queried in a variety of ways. Of recent development has been software that adds power and flexibility to the creation of maps. Most of these software products are associated with what we refer to as GIS that tie map features to spatial coordinates as well as attribute tables. This geospatial connectivity permits the linking of various types of data into more useful forms to facilitate the communication of the status and changes in the system. This section describes several leading software packages that provide mapping and GIS capabilities as well as software to convert images to tabular formats that can be used by these packages.

To load an image, start the software by double-clicking on the file **tif_convert.exe** or clicking on a shortcut icon if one has been previously prepared by left-clicking on the file and dragging it from the Microsoft Windows Explorer file list to the desktop. Next, select **File** from the tool bar at the top of the software screen. A pull-down menu will appear. From this menu select **Open**. An **Open** pop-up screen will appear showing the pathway and file name for the image to load. Navigate to the image and press the **Open** button in the **Open** pop-up screen to load the image.

Once the image has loaded, the file data can be exported by selecting **Export** from the top of the screen. A pull-down menu will appear. From this menu select **Grid**. A **Grid Export** pop-up menu will appear (Figure 4-25). Enter the numerical value for the grid size (e.g., 10 for a 10 pixel x 10 pixel grid size). The pathway will default to the pathway of the image file. The export file name will default to the image name appended with a **dat** extension to the file name. If another file name or pathway is desired, this should be properly entered and **Export** button in the **Grid Export** pop-up menu clicked. In the event that the same image name is opened a second time the software will warn the user that the file name currently exists and prompts the users for another name or to overwrite the file. This may occur if the user wishes to create export files using more than one grid size. A list of recently processed images is displayed in the **File** pull-down menu. Once the file is created, an **Export Complete** pop-up menu will appear asking the user if the file is to be viewed (Figure 4-26). Respond **Yes** or **No**. By responding affirmatively, the user has the opportunity to ensure that the data file appears in the proper format. The file will be opened with Microsoft's WordPad®. The Z values should vary between values of 0 and 1.0 if the export has been successful. After the file is viewed, WordPad® is closed and the **Grid Export** pop-up menu is closed by clicking on the **Close** button.

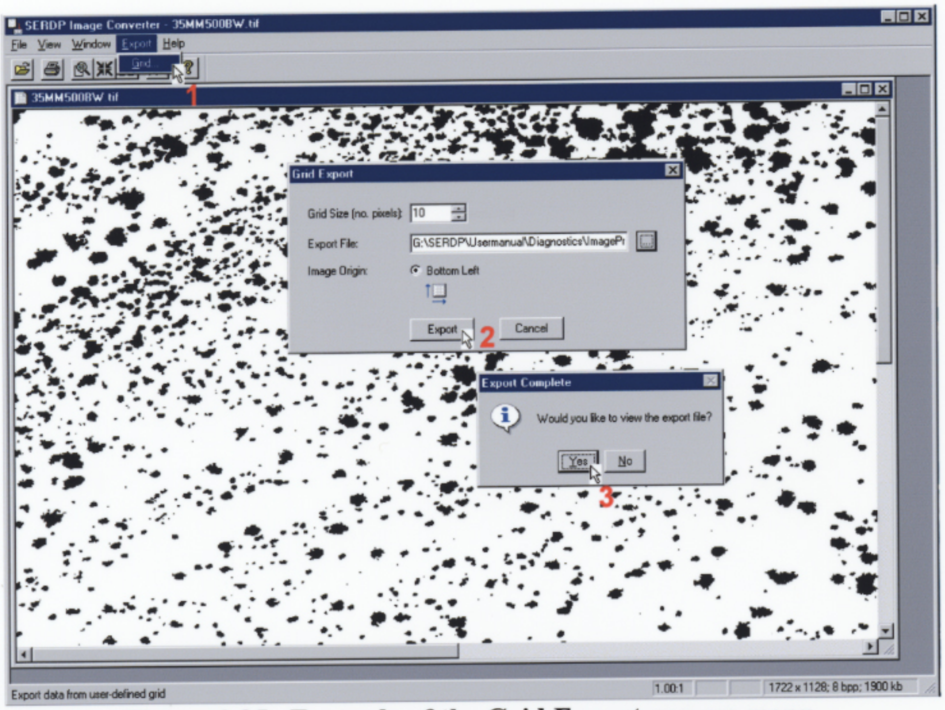

Figure 4-25. Example of the Grid Export pop-up menu.

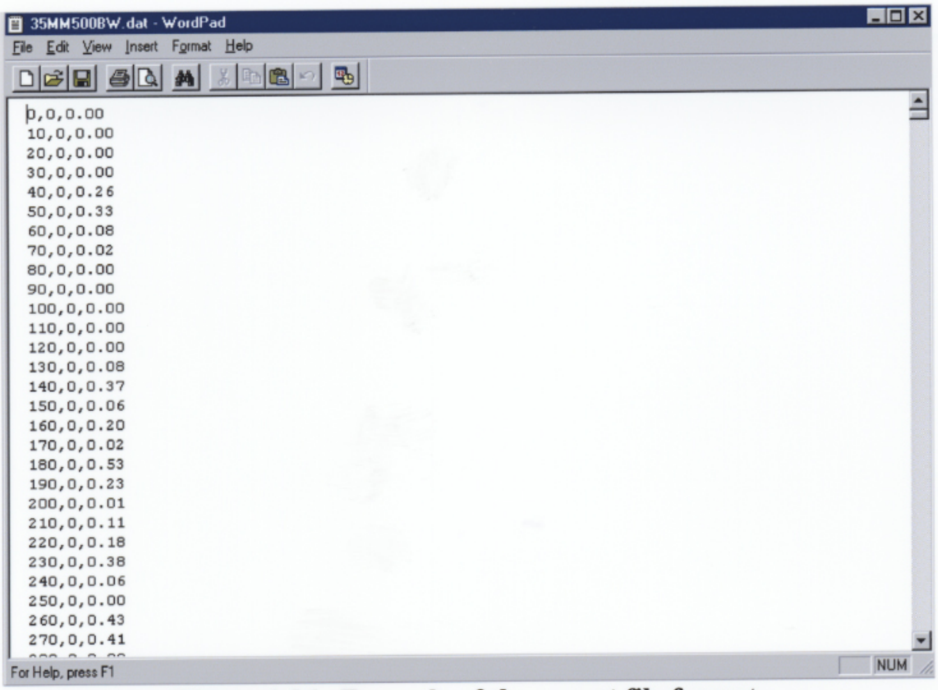

Figure 4-26. Example of the export file format.

Other tools available in the toolbar include the ability to enlarge or reduce the image, and to print the image to a Microsoft Windows® printer (use the **Print** option from the **File** menu at the top of the screen) with the normal printer setup options.

4.4.2 Surfer®

Surfer® for Windows is a contouring and three-dimensional surface mapping and plotting program that runs under Microsoft Windows®. The software (available for approximately $600) converts data into contour maps and surface plots that can be readily imported into GIS software. For a detailed description of the current software version and pricing refer to the Web site: http://www.goldensoftware.com/. Procedures associated with Version 7.0 are described herein. The software was originally developed to support topographical, landscape, and geological mapping and includes more than a dozen gridding method options such as statistical kriging, minimum curvature, moving average, and nearest neighbor. The software is developed to interpolate up to 1 billion XYZ data points (limited by available memory). It also permits smoothing and grid filtering. It permits object management to facilitate editing objects such as toggling on and off axis labels, legends, and titles. Maps can be exported in DXF, SHP, BNA, BLN, MIF, GSI, GSB, EMF, WMF, CLP, CGM, TIF, BMP, JPG, TGA, PNG, PCX, DCX, WPG, and PCT formats.

4.4.2.1 Loading a Data File

The first step in using the software is to load a data file. Data file formats accepted include: DAT, TXT, SLK, XLS, WKx, WRx, CSV, BNA, or BLN formats. Normally, a DAT file format is used (produced by SERDP Image Converter software). The DAT file format consists of ASCII text in the form: X, Y, Z (carriage return), where X is the horizontal coordinate (e.g., longitude or easting in meters) or raw pixel column number, Y is the vertical coordinate (e.g., latitude or northing in meters) or raw pixel row, and Z is the percent cover value (e.g., 0.24) saved in a file name with a dat extension (e.g., *filename*.dat). Select the **File** option from the toolbar at the top of the software screen. This activates a pull-down menu. From this menu select the **New** option. Then select **plot document** from the options and press **OK**. Next, load the data file by selecting the **Grid** option from the toolbar at the top of the software screen (indicated by the red number 1 in Figure 4-27). This activates a pull-down menu, then select the **Data** option. This brings up an **Open** pop-up menu and permits the user to identify the path and file name to be used. Once this information is entered, press the **Open** button in the **Open** pop-up menu (indicated by the red number 2 in Figure 4-27). This brings up a **Scattered Data Interpolation** pop-up menu that allows the user to select the gridding method (Figure 4-28). Normally, the **Minimum Curvature** gridding method is selected, especially when large data sets are used. The user then clicks on the **OK** button to proceed. This procedure creates a grid file from the original data file (*filename*.dat). The grid file contains the information needed to create a map. The user is referred to the software documentation manual provided with Surfer® for other options such as statistical kriging that may be available when creating a grid file. The grid file is normally stored at the same location as the data file, using the same name but a different extension (e.g., *filename*.grd).

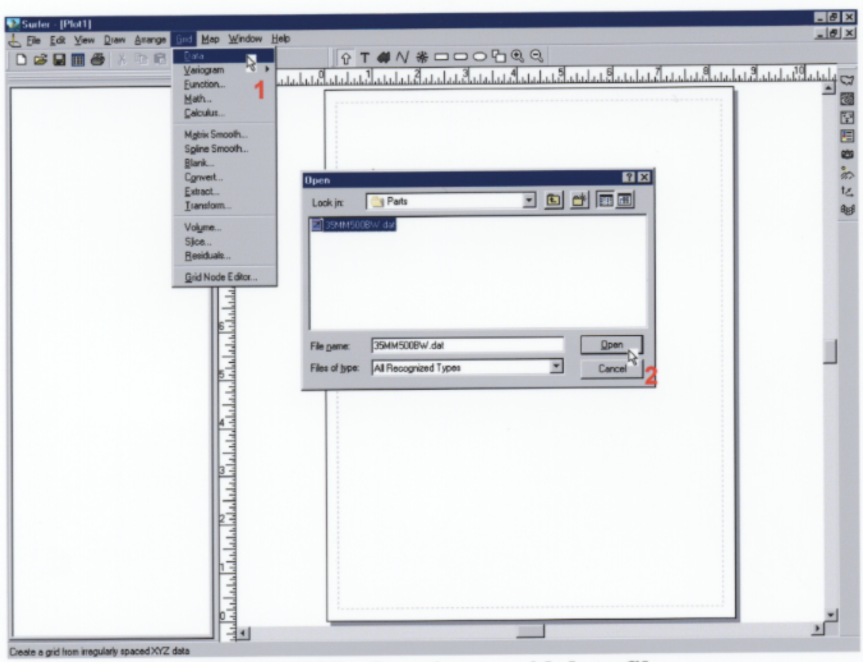

Figure 4-27. Opening a grid data file.

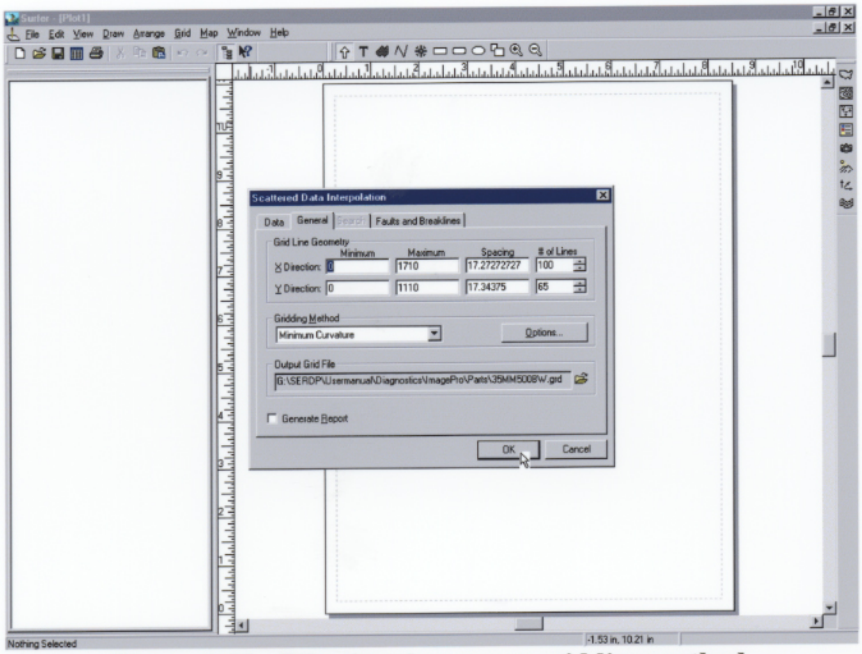

Figure 4-28. Selecting the proper gridding method.

4.4.2.2 Loading a Data File to Create a Contour Map

The next step in the process is to create a map using the grid file. This is done by selecting the **Map** option from the toolbar at the top of the software screen (indicated by the red number 1 in Figure 4-29). This activates a pull-down menu. From this menu select the **Contour Map** option. Then select the **New Contour Map...** option from the slide-out menu.

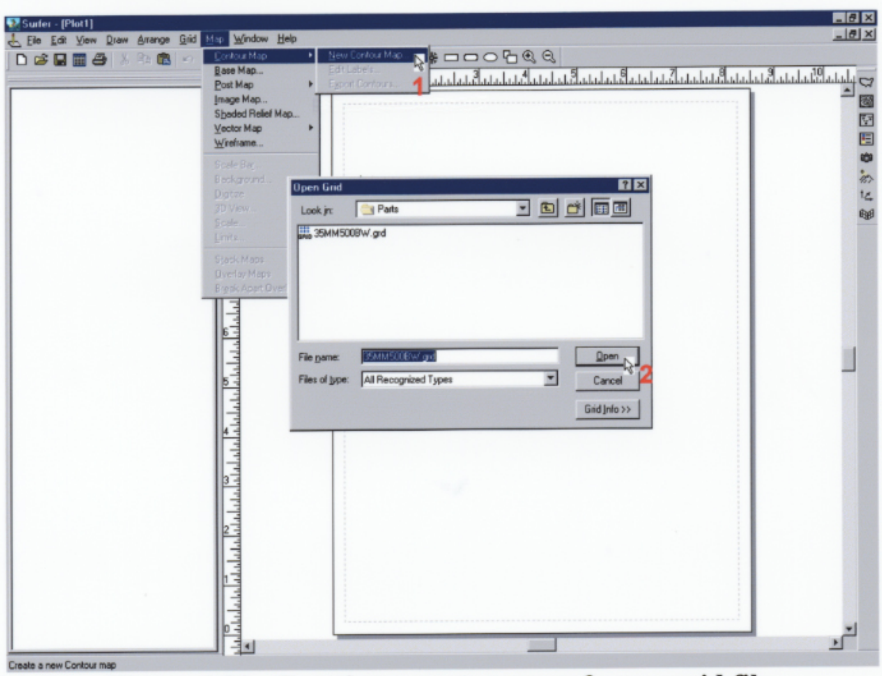

Figure 4-29. Creating a contour map from a grid file.

This brings up the **Open Grid** pop-up menu. The user is then prompted to enter the grid file pathway and name and click the **Open** button at the bottom of the menu to proceed. A **Contour Map Properties** pop-up menu is opened providing opportunity to alter the **Options** and **Levels** (selected by tabs as shown in Figure 4-30). Clicking the **Levels** tab allows the user to edit the numerical values for the levels, the line presence and thickness, the fill color, the label features, and any hach attributes of the map (Figure 4-31). In order to create a map that is relatively free of unnecessary map features, it is necessary to select the proper settings. The property **Label** under the levels tab of the **Contour Map Properties** (Figure 4-31) assigns a label (a number for the interval such as 0.2 or 20 percent) to contour intervals. Since labels are not wanted in the final map click on each **Label** that is set to **Yes** to change it to a **No** value. Next, delete any numerical **Level** that is not needed by clicking on any undesirable number in the row and then clicking on the **Delete** button (Figure 4-32). When it is necessary to change the numerical value of a **Level**, double click on the number under the **Level** column and a **Z Level** pop-up menu will appear, prompting the user to enter a new value. A good distribution of cover values to be used in creating cover maps in Surfer® are those that fit the quadratic equation $y = 0.5x^2 + 0.5x$, thus yielding percent cover value intervals of 0, 1, 3, 6, 10, 15, 21, 28, 36, and 45. The use of these levels spreads the range of cover values found in arid lands with greater emphasis being placed on low cover values.

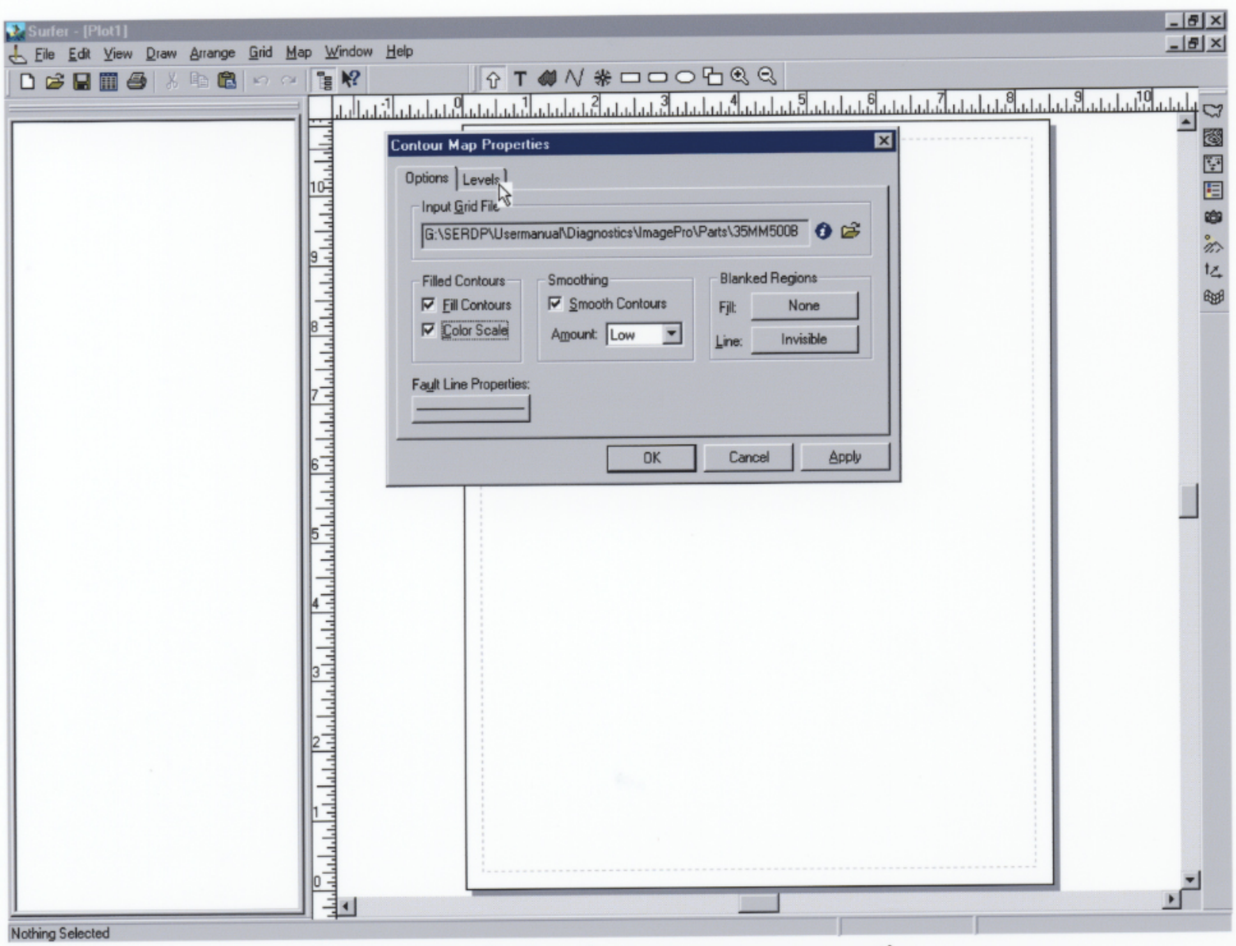

Figure 4-30. Setting the contour map properties.

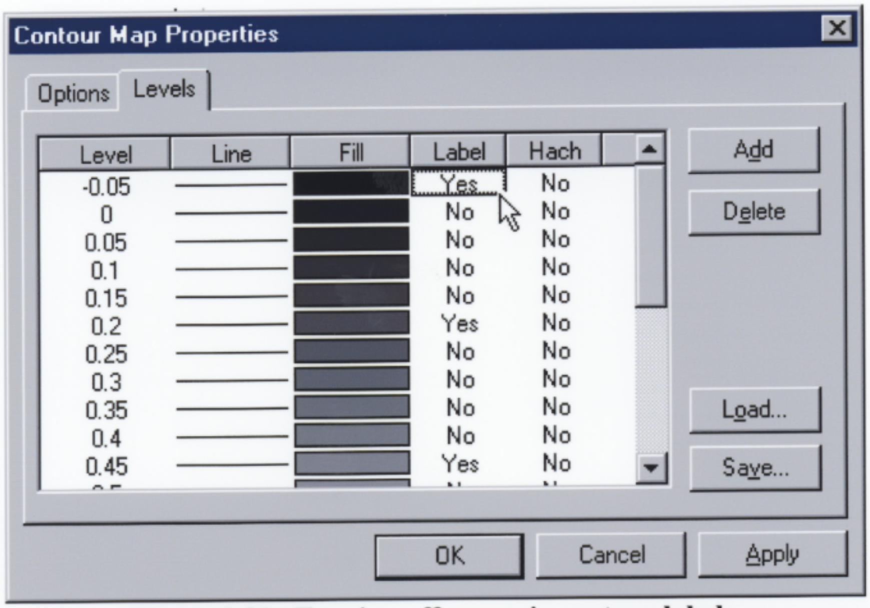

Figure 4-31. Turning off numeric contour labels.

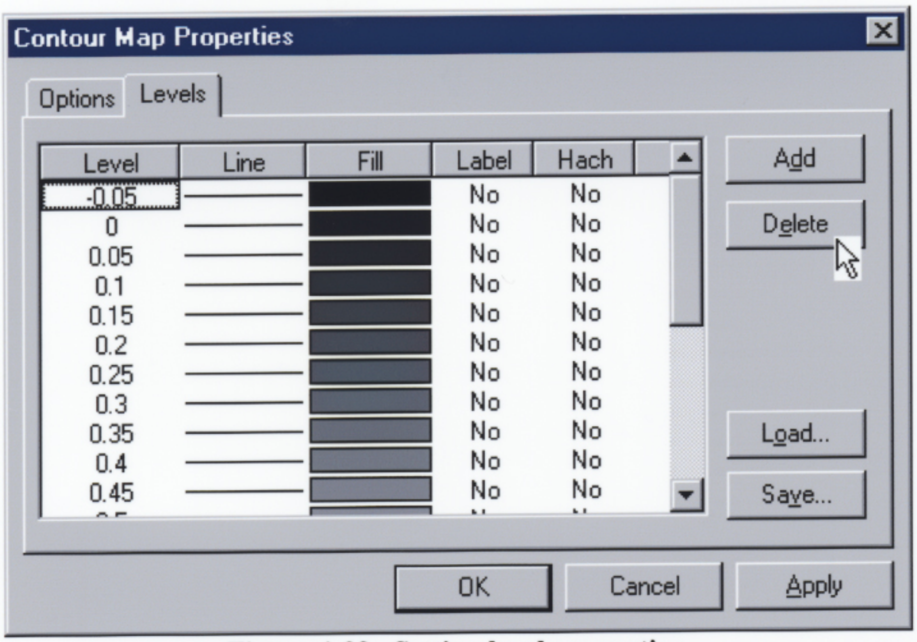

Figure 4-32. Setting level properties.

The value of the largest percent cover should be given the value that best approximates the maximum plant cover value found from ground samplings. Values above that can be incorporated into a mountain mask that typically captures all values associated with dark volcanic rock formations and rocky mountains. For example, if the maximum plant cover were measured at 27 percent then a value of 28 would be selected for the largest value. All values calculated from the grid cells that are greater than this value would be included in the largest map units (e.g., calculated values of 36, 50, or 75 percent would be included in the 28 percent or greater value if it were the largest value used for the Z level).

The decimal equivalent of the number is entered (e.g., .05 for 5 percent cover) and the **OK** button is clicked (Figure 4-33). This procedure can be repeated for each number until all of the values have been entered correctly. New levels can be added by clicking on the **Add** button.

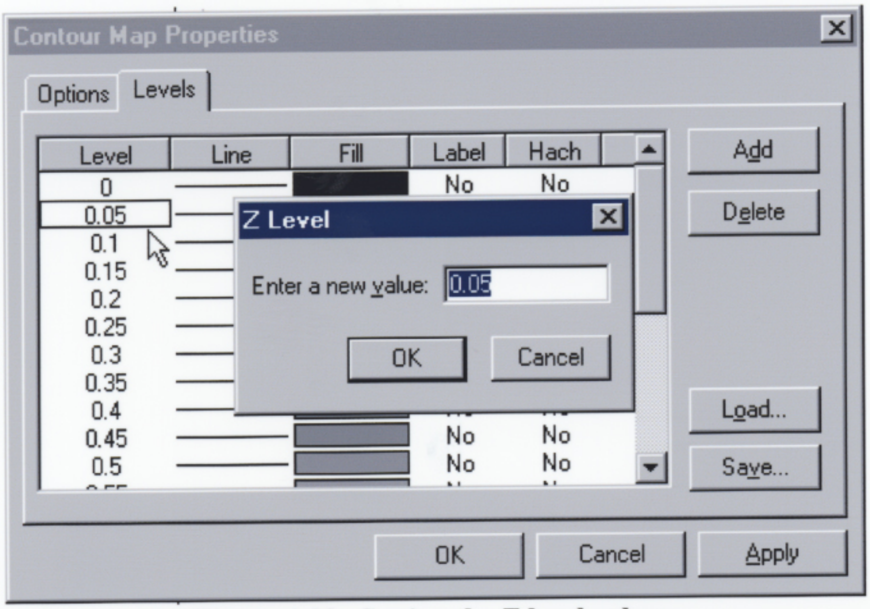

Figure 4-33. Setting the Z level values.

The line thickness of the contour intervals is then set by clicking on the line and selecting a style, color, and weight that best shows the polygons (Figure 4-34). Commonly used values include a solid line style, of black color, and weight of 0.000 in. Before a map is exported as a TIFF image, it is usually desirable to convert all line styles to a blank or invisible.

The reason for doing this is to ensure that the black color of the line is not interpreted as a mountain mask which is often shown as black areas on the map. However, if the map is exported as an Environmental Systems Research Institute (ESRI) shapefile then the lines are saved separately as a different shapefile from the polygon area, thereby eliminating the need to convert line styles to invisible.

The fill pattern and color are set by clicking on the fill color to be changed (the red number 1 in Figure 4-35). The **Fill Pattern** should be clicked and set to the solid black color as opposed to any of the patterned designs. The **Foreground** box should then be clicked (the red number 2 in Figure 4-35) and the color selected that best represents the color gradient of choice (e.g., the color ramp for plant cover can consist of white for no plant cover and increasing shades of green, with a black mountain mask selected as the largest cover value). The available colors are displayed by clicking on the slide bar arrow (the red number 3 in Figure 4-35). When an acceptable color is found, the user clicks on the color (the red number 4 in Figure 4-35) and then clicks on the **OK** in the **Fill Property** box menu. When all of the colors have been selected, the user clicks on the **Apply** button (the red number 5 in Figure 4-35) of the **Contour Map Properties** box to return to the displayed map.

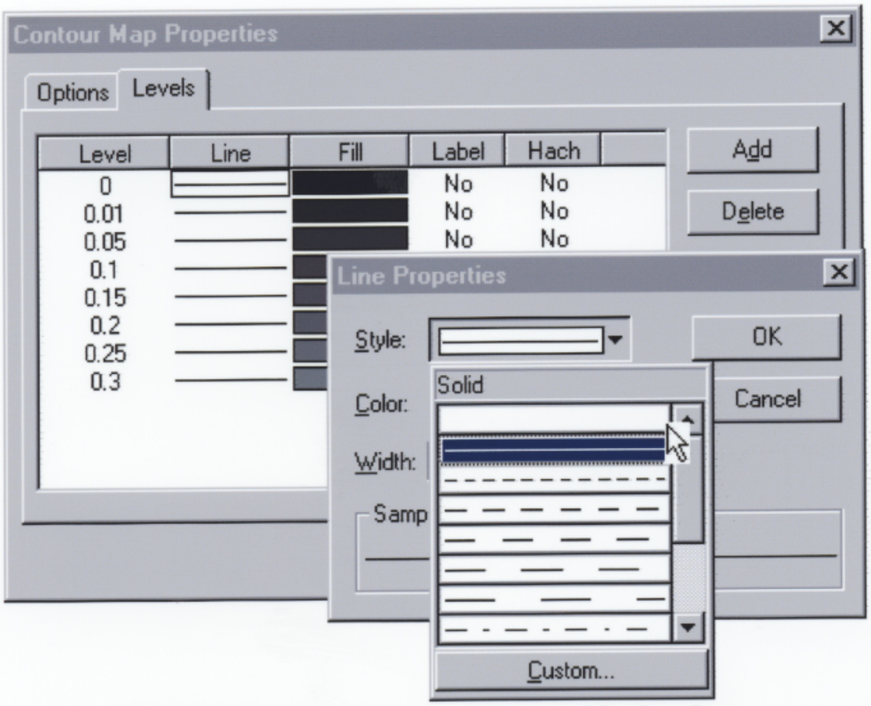

Figure 4-34. Setting contour lines to blank values.

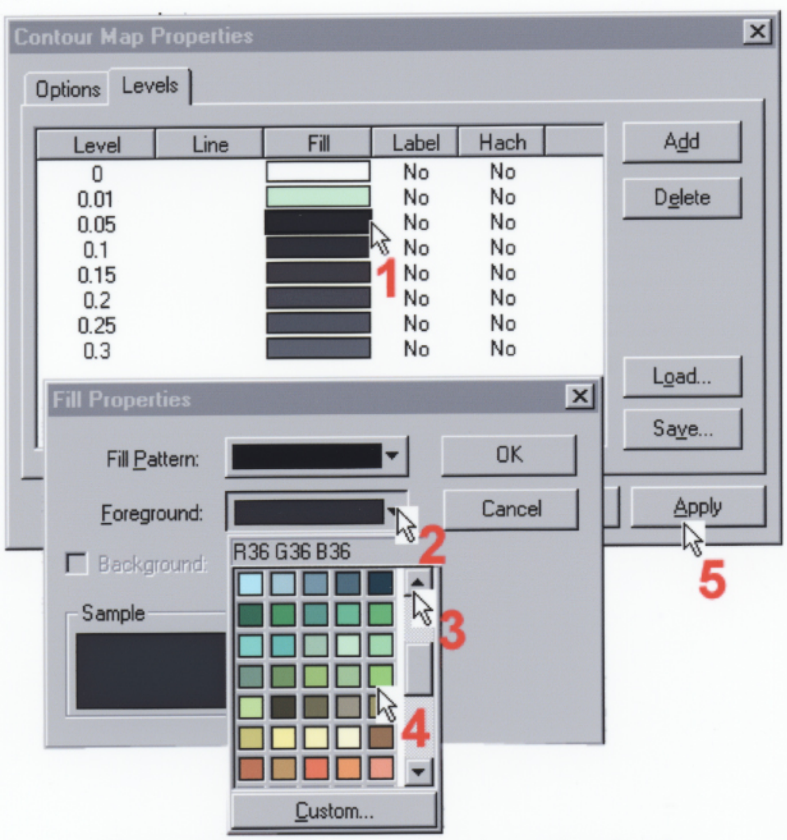

Figure 4-35. Assigning colors to contour levels.

4.4.2.3 *Exporting a Surfer® Map as a TIFF File*

To export a map as a TIFF file, the user converts all contour lines to blank or invisible as previously described. From the software tool bar at the top of the screen the **File** command is selected. This activates a pull-down menu. From this menu the user selects the **Export** command (the red number 1 from Figure 4-36) which activates the **Export** pop-up menu that permits the user to enter the pathway, file time, and file name. The user then selects the **Tagged Image (TIFF) (*.tif)** file format option (the red number 2 from Figure 4-36) and clicks the **Save** button (the red number 3 from Figure 4-36) on the **Export** pop-up menu. This activates a **Tagged Image (TIFF) Export** pop-up menu. And permits the user to set the width and height of the image in pixels (the red number 4 from Figure 4-36). These values can be approximated from the pixel sizes of the original image. Because the image to be exported will include page margins to the sides and top and bottom of the image, the image should be exported slightly larger (e.g., 20 percent larger than the original image) to account for these margins. For example, if the original image was 1,000 pixels wide by 1,000 pixels high, the export image would be approximately 1,200 pixels wide by 1,200 pixels high. The **Color Depth** option should be set to **True Color** and the **Maintain Aspect Ratio** should be checked. When these values have been entered, the **OK** button is clicked, saving the file (the red number 5 from Figure 4-36).

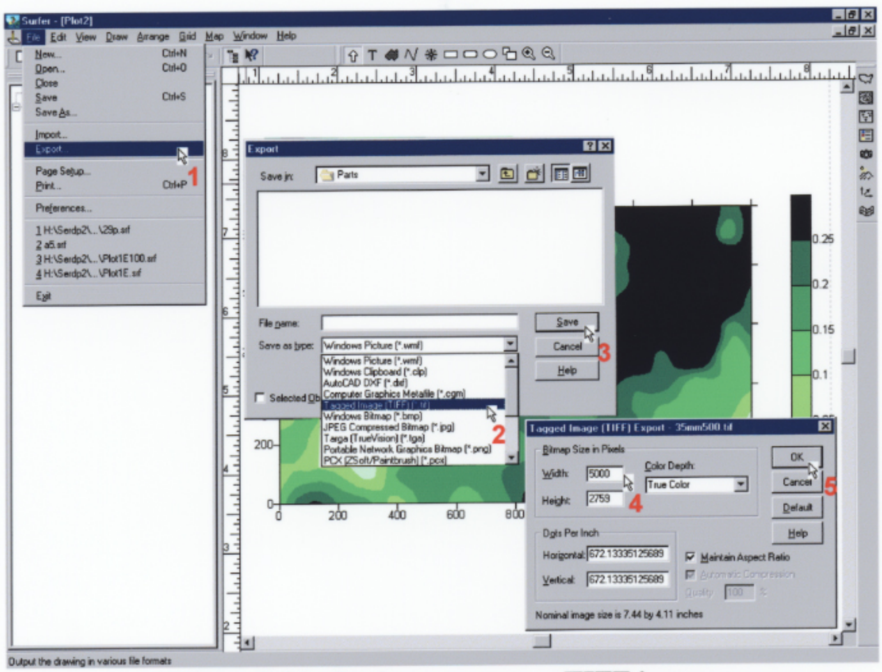

Figure 4-36. Saving a map as a TIFF image.

4.4.2.4 *Cropping and Mosaicing Surfer® TIFF Images in Adobe Photoshop®*

The file can then be opened in Adobe Photoshop® and the image carefully cropped to the margins of the map (i.e., the white margins and black border of the map are marked with the rectangular marquee tool). It is recommended that the image be enlarged so that individual pixels can be seen (otherwise the exact edge of the image may not be selected). Starting at the upper-left-hand corner of the image click and pull the marquee tool to the lower left-hand corner. Note that starting in other corners like the lower right-hand corner will not permit scrolling of the window to the other corners. The image is cropped by clicking on the **Image** pull-down menu and selecting the **Crop** command. This reduces the image to only the map area defined by the marquee line (called by users the "marching ant") line.

The image should then be resized to exactly the same number of pixels (width and height) as the original image used to calculate plant cover. This is done by selecting the **Image** command from the software tool bar at the top of the screen which activates a pull-down menu. Next, select **Image Size...** which brings up an **Image Size** pop-up menu. The number of pixels for the image should be entered for width and height.

The **Constrain Proportions** and the **Resample Image** options should be checked. In the **Resample Image** option, space should be set to the "Nearest Neighbor" option. This ensures that any new pixels that are created in stretching or shrinking the image to the proper size will be only of the colors assigned to the polygon contour areas (e.g., all areas will be black or white). Other options such as "Bicubic" create new intermediate colors halfway between the two adjacent colors (e.g., gray pixels between white and black polygons), thereby creating extra categories of pixels unrelated to the two original types (i.e., black and white) previously created by the graphing software. The area represented by these new intermediate colors is not accurately placed within the proper class (color) and thereby contributes inaccuracies to the new GIS theme. The document size and properties can remain as the default values. When all of the values have been entered the **OK** button is clicked in the **Image Size** pop-up menu. The image is then saved as a cropped and resized image.

When several adjacent images have been created, it is desirable to mosaic four to nine images together into one large file. The ability to mosaic images in Adobe Photoshop® is limited by printer type and computer memory to about two to three images wide by two to three images high. It is done by selecting a starting image (usually at one of the corners). From the **Image** command of the tool bar at the top of the software screen, the **Canvas Size** option is selected. This brings up a **Canvas Size** pop-up menu box. Next, enter the new size of the canvas in pixels. For example, if the image size were 100 pixels wide by 50 pixels high and if the user wanted to add nine images (three images wide by three images tall), the user would enter a canvas size of 300 pixels wide by 150 pixels high. The user would indicate which corner the image would be placed into by checking on the corner of the grid box shown in the **Anchor** option. An alternative method of sizing the canvas is to select percent as the unit of value. In this example the user would enter 300 percent wide by 300 percent high if nine images were to be mosaiced together. The **OK** button would then be clicked showing a new image in the corner of a blank canvas.

The images to be added to the expanded canvas are then opened, copied, and pasted. Each image is copied by selecting it with the rectangular marquee tool, and then selecting **Copy** from the pull-down menu (the **Edit** command from the toolbar at the top of the software screen). The original image with the expanded canvas is then reselected and the **Paste** command (the **Edit** command from the toolbar at the top of the software screen). The new image will be pasted into the center of the image with the expanded canvas. The move icon (located to the right of the rectangular marquee icon and indicated by a cursor and a plus sign) is selected (it is the default tool after a paste) which allows the image to be positioned next to the starting map image. The user may want to enlarge the view to ensure that the newly placed image is not overlapping the adjacent image (an overlap of a few pixels can create slight distortions in the resulting mosaic). Each new map image to be added is opened, selected, copied, pasted, and positioned into place. If prior images need to be repositioned, the user selects the **Show Layers** (from the **Windows** toolbar at the top of the software screen). The user then selects the image icon corresponding to the image that is to be repositioned, clicks it, and selects the move icon from the icon tool bar. The user can then position that layer within the canvas. When all of the images have been correctly added, the mosaiced images are merged into one image using the **Flatten Image** from the **Layer** command from the toolbar at the top of the software screen). The merged image is then saved as a new image (with a new name). Opening the **Image Size** pop-up menu (from the **Image** command) will permit the user to verify that the mosaic contains the correct dimensions in terms of the number of pixels (width and height). Slight corrections, if needed, can be made by resizing the image using the procedures described above.

4.4.2.5 Exporting Surfer® Images as an ESRI Shapefile

To export an image as an ESRI shapefile using Surfer®, the user first prepares the map by turning off all nonessential map features such as map legend, axis, title, etc. This is done by unchecking these features from the object manager visible in the upper left-hand corner of the software screen. Only the contour objects should be checked. Next, the area around the map should be eliminated. This is done by double clicking on the **Right Axis** object which brings up the **Right Axis Properties** pop-up menu (Figure 4-37). Select the **General** tab and uncheck the **Show** box of the **Labels** option. Next, select the **Ticks** tab and set the **Minor Ticks** and **Major Ticks** to **None.** Repeat this procedure for each axis. If the procedure has been done properly the black and white squares at the sides of the map will appear at the edge of the map (Figure 4-38) as opposed to being separated from the map with space in between as in Figure 4-37. If the squares are not immediately adjacent to the map, select the axis where the space appears and recheck/reset the properties of the axis. This will ensure that only the map area is exported and not additional white space that may have been reserved for the placement of label tick marks associated with the axes.

Next, click on the **File** command from the software tool bar at the top of the screen. This activates a pull-down menu. From this menu the user selects the **Export** command (the red number 1 from Figure 4-38) which activates the **Export** pop-up menu. This menu permits the user to enter the pathway, file type, and file name. The user then selects the **ESRI Shapefile (*shp)** file format option (the red number 2 from Figure 4-38) and clicks the **Save** button (the red number 3 from Figure 4-38) on the **Export** pop-up menu. This activates an **ESRI Shapefile Export** pop-up menu, and permits the user to set the georeference grid coordinates for the lower left-hand corner and the upper right-hand corners of the shapefile (Figure 4-39). These values can be entered in any planar coordinate system, such as latitude and longitude, or state plane, or Universal Transverse Mercators (UTMs) (e.g., decimal degrees, meters, or feet) that is consistent with the units to be used later with ESRI's software. Note that longitude values are entered as negative values in the Western Hemisphere (North and South America). Values exported as shapefiles may need to be corrected to ensure that they fit the new projection system. This can be done using ESRI's ArcView® Image Analysis (use the **Align Tool**) or ERDAS Imagine® software.

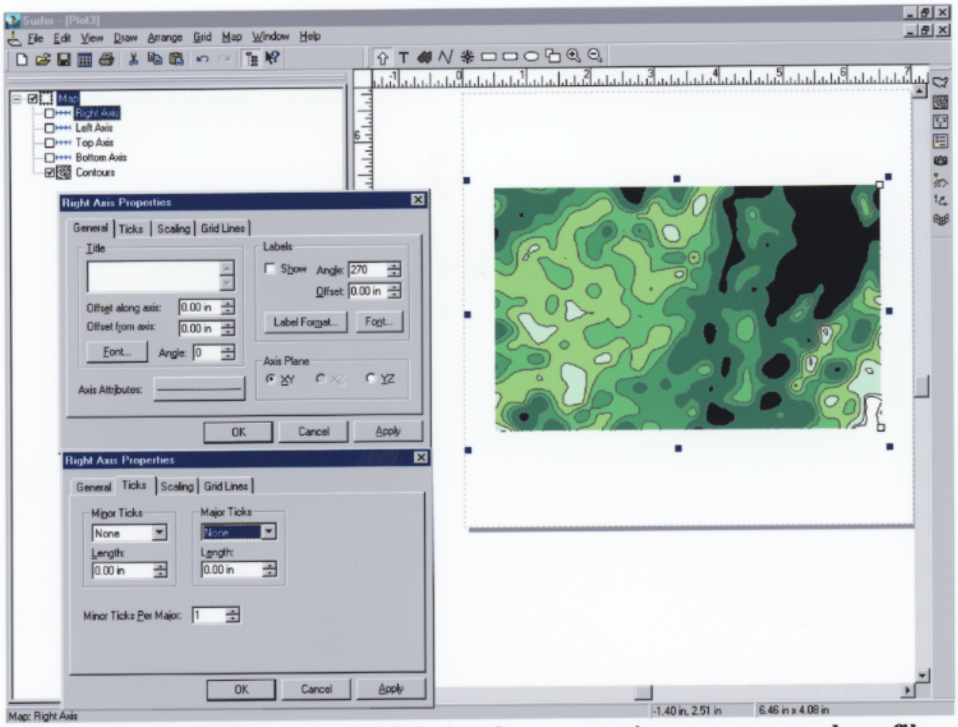

Figure 4-37. Hiding axis and labels when preparing a map as a shapefile.

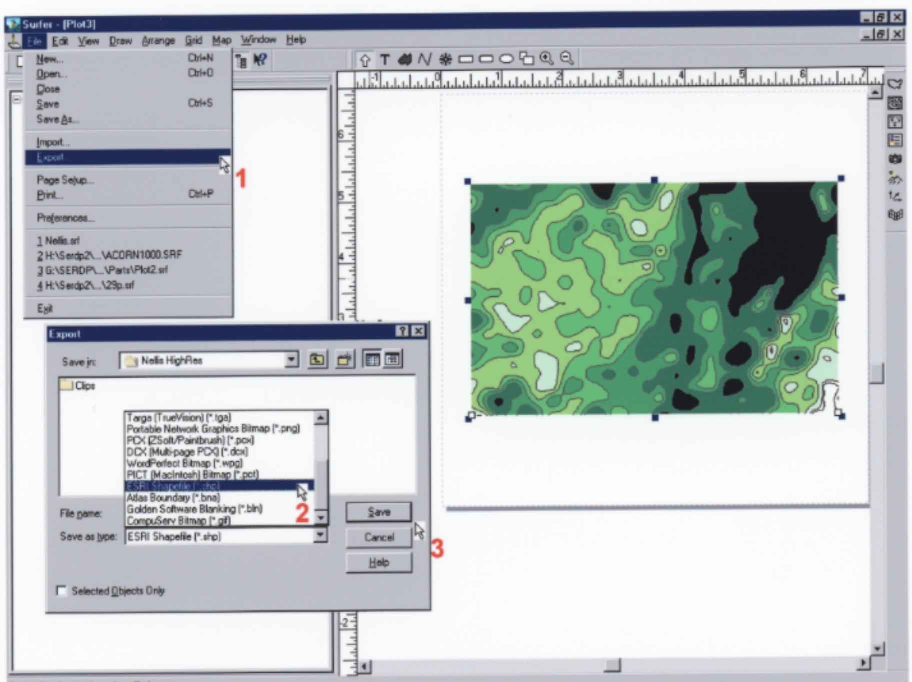

Figure 4-38. Exporting a Surfer® map as a shapefile.

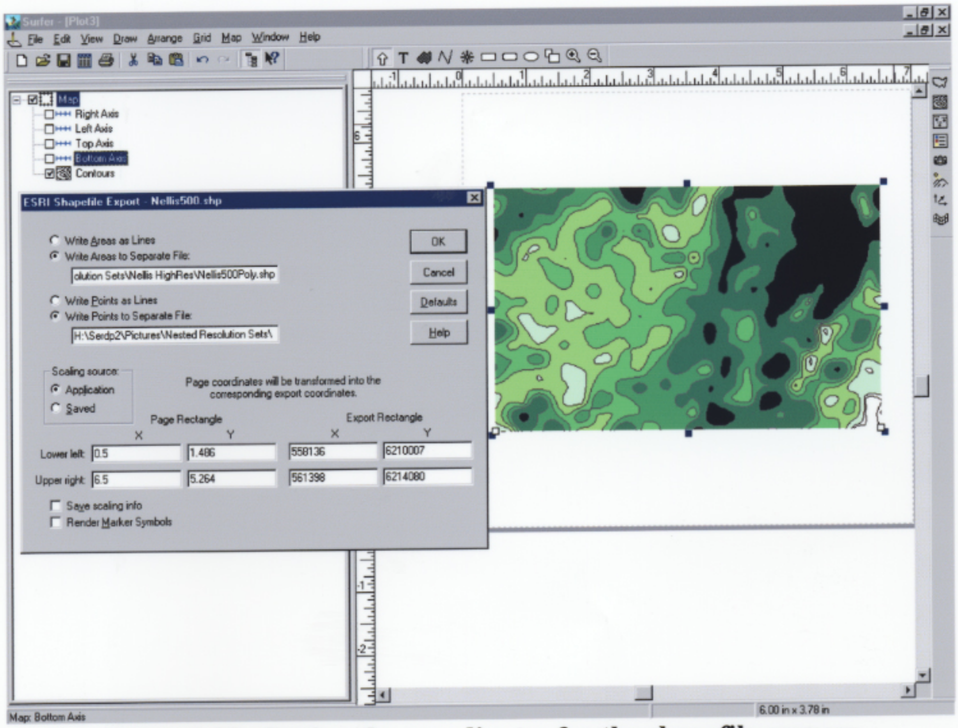

Figure 4-39. Setting the coordinates for the shapefile corners.

4.4.3 ArcView® Image Analysis

ESRI ArcView® Versions 2.x and 3.x provide the ability to extend the usefulness of that software by allowing users to develop scripted modules that provide additional analytical capabilities to their basic ESRI GIS software. These scripts are written in the programming language called Avenue®. However, newer versions of ArcView® include ArcMap® that uses a different programming language called Visual Basic®. One useful extension that was written for the earlier versions (e.g., Version 3.2) of ArcView® is an extension prepared by ERDAS® called the ArcView® Image Analysis extension. It provides many of the features of the more powerful ERDAS® Imagine, but at a significantly lower price than Imagine. This software can be purchased for less than $3,000. This software has not yet been released for ArcMap® at the time that this user's manual was prepared. The software enhances image integration, display, and analysis. It provides a tool to rectify TIFF images to images that have coordinate systems such as Imagine images and Geotiff images.

Image rectification is the process of transforming an image from a file coordinate system into a map coordinate system. This is done using the **Align tool** to perform the rectification process, also referred to as georectification. The following discussion provides a simplified procedure for georectifying TIFF images from Surfer® maps so they can be converted into on shapefiles. The user is referred to the software users manuals for more detailed descriptions on how to use these software tools. The following procedure was written using software features available in ArcView® Image Analysis Version 1.0 for Windows® and ArcView® Version 3.2. Once created the shapefile can be used in either the older ArcView® or the newer ArcMap® GIS software.

4.4.3.1 The Image Rectification Procedure

The first step is to install ArcView® and ArcView® Image Analysis software and ensure that they are working properly by using the quick start tutorials. Also, make sure that the Image Analysis extension is selected and active. This is done by selecting **File** from the toolbar at the top of the ArcView® screen. Then select **Extensions...** from the drop-down menu. Use the scroll bar to reveal the **Image Analysis** option. Check (left mouse click or equivalent) the box to the left of the **Image Analysis** option and click **OK** to activate the Image Analysis extension. When properly installed, the pull-down option: **Image Analysis** will appear on the toolbar at the top of the software.

The next step is to load a base image that is georectified and the new TIFF image that is to be aligned and georectified with this base image. This is done by selecting (click on) the **Add Theme** icon (a plus sign on top of a white diamond). Alternatively, the user can select **View** from the toolbar at the top of the software screen. Then select **Add Theme...** to add the georectified base image or feature (e.g., a topographic map). An **Add Theme** pop-up menu will appear and prompt the user to enter the drive, directory path, and file name. Click OK when the information is correct. The data Source Type should read: Feature Data Source (e.g., for a topographic map) or Image Data Source (e.g., for a geotiff or an Imagine image). It should not read: Image Analysis Data Source (this will be used to load in the unrectified TIFF image in the next step). Next, use the **Zoom In** button on the tool bar to zoom in on the area of the base image where the new non-georectified image will be placed. Create a rectangle slightly smaller than the boundaries using the Zoom In tool. The new image will be placed within this area. If the base image is too small, the added image may obscure the underlying image and make the alignment process more difficult. The approximate boundaries of the alignment corners should be visible when the new image is placed on top of the base image.

Next, add the TIFF image you want to be rectified and aligned. This is done by selecting the **Add Theme** icon from the toolbar to add the nongeorectified image. An **Add Theme** pop-up menu will appear and prompt the user to enter the drive, directory path, and file name of the image to be aligned. The data source type should read: **Image Analysis Data Source** (not Image Data Source nor Feature Data Source). Click **OK** when all information is correct. A pop-up menu will appear called: "Calculate Pyramid layers for (image name)?" The menu displays the following message: "This image does not have pyramid layers. They allow for rapid display at varying scales. Do you wish to create them Now?" The user can respond Yes, No, or seek additional information by selecting the help option. The pyramid layers are similar to thumbnail size images that can be displayed at various scales, they permit the user to zoom in and out of the image and facilitate the rapid display of the image. Normally the user would respond Yes to this question.

The preceding steps will load the TIFF image into memory, but will not display the image yet. Next, click on the name of the newly loaded TIFF image which should appear in the View panel of the screen. The theme name will have a box around it and a check mark to the left of the image. Select the **Align Tool** icon (a black square with a diagonal arrow emerging to the upper right-hand of the square). If this icon does not appear, the extension is not properly installed or selected (i.e., the extension checked as first described in this procedure). Once the Align Tool and the theme are selected, the image will be positioned within the center of the area defined by the Zoom In tool as described previously. Size (i.e., zoom in) the view of the two new images to ensure that the corners of the "From" image (nongeorectified image) and the corners of the "To" image (georectified image or feature) are clearly visible.

The next step is to choose alignment points from the two images to be matched up. This is done by positioning the cursor over the corner of the nongeorectified image. Select this corner by clicking on the left mouse button (or equivalent). This will position a moving line anchored at the "From" corner point. Next, position the cursor by moving the mouse to the "To" corner and left mouse clicking (single click not a double click) to select the new coordinate. An alternative to this manual method of locating the "To" corner is to right-click on the mouse once the left mouse button has been clicked on the "From" corner. Next, hold down on the right mouse button (this brings up an option box) and move down the options until the **Enter "To" Coordinate** is highlighted. Release the right mouse button. The **To Point** pop-up menu will be activated and prompt the user to enter the X and Y coordinates of the "To" corner. When the values (e.g., UTMs value) have been entered, click **OK**. This will align the new image to the one that has the proper spatial coordinates. If a mistake is made, right-click on the mouse and select the **Delete Selected Link** from the options box. This will undo the last linkage. Repeat the "From" and "To" coordinates until at least four pairs of control points (the corners) are selected (a pair is a "From" and a "To" coordinates). This will align the new image to the one that has the proper spatial coordinates. Control points may be edited using the Pointer tool as described in the user's manual for ArcView® Image Analysis.

4.4.3.2 Saving the Georectified Image

The last step in the procedure is to save the new image as a shapefile that has been rectified. This is done by selecting the **Theme** menu from the toolbar at the top of the software screen. Next, choose **Save Image As**. A **Save Control Points** dialog box appears asking the user if they want to save the control points as a separate shapefile. These may be useful to verify proper positioning of the corners and alignment of several such georectified images. Click **Yes** to save these control points as a shapefile. Next, a **Save Name of Image As** menu appears. Give the new image a name and select the appropriate drive and directory path. Click **OK** to save the new georectified image. The new image will be saved as a georectified image of either an Imagine Image or Tiff Image (select type by using the **List Files of Type:** option window). The new image can now be used in standard GIS queries to estimate area of different training areas with different shrub cover percentages.

4.4.4 New GIS Software Tools

The development of new GIS software has had a significant impact on the way land managers at military and government facilities view data and approach problem solving over large areas. It has facilitated the ability to summary data and effectively communicate it to others. This software is growing in sophistication and complexity, however, there is a rather steep learning curve before users master it. The fact that the software provides its own programming language adds to its power, allowing the user to develop new applications. This has resulted in the development of many applications that can be used by managers at military and government facilities. It is anticipated that new software extensions will be available in the future with even greater enhanced capabilities. Many of these software packages will make earlier software obsolete and simplify the image analyses process.

The user is encouraged to contact Internet Web sites (for examples see Appendix 7-3) to stay current with the latest releases. A variety of workshops and conferences are also held to inform users of new developments and applications. The integration of remote-sensing techniques and GIS is relatively well developed and forms the basis for standard geographic analyses using small-scale imagery (e.g., satellite imagery) and image-processing. It is beyond the scope of this user's manual to describe these techniques. This manual has focused more on large-scale imagery and new image-processing techniques that bridge the gap between conventional GIS and more labor-intensive field techniques. A brief description of selected software follows.

4.4.4.1 ArcView®/ArcGis®

ArcView® and ArcGIS® provide the foundation for most GIS applications. It provides the ability to query spatially-related data and create maps for displaying resulting information. Because of the level of sophistication required to use this software, the user is referred to ESRI at http://www.esri.com for more information about their products and training. Instruction on how to use the software is beyond the scope of this user's manual. Specific applications are available on their Web site. Training is available at most colleges and universities in addition to training provided by ESRI.

4.4.4.2 Feature Analyst™ Extension for ArcView® 8.2

This extension to ArcView® is available for Versions 3.X and 8.2. The software permits the identification of image features based not only on image intensity values selected at specific thresholds, but offers additional power by evaluating pixels surrounding the feature. Once the features are identified, they can be saved as points, lines, and polygons in ESRI shapefiles. One of the strengths of the software is its ability to learn based on inputs from the user (e.g., selecting areas that are properly and improperly classified once the initial classification has been made). It also works directly with rectified images (e.g., geoTIFF and Imagine® images) so georectification is not required; however, it will also permit the user to use nonrectified images as well.

This Feature Analyst™ software is a rather new addition (introduced in the fall of 2001 and made available for ArcView® 8.2 in the spring of 2002) to the image-processing software currently on the market and promises to meet many of the needs. Because Feature Analyst™ is relatively new, we have not had the opportunity to evaluate it in detail in time to be included in this user's manual. This software (demonstration and authorization key once purchased) is available from Visual Learning Systems in Missoula, Montana (http://www.vls-inc.com/). The cost of Feature Analyst™ is approximately $6,800 for a lifetime subscription. Yearly maintenance includes upgrades and support and is available for approximately $750.

4.4.4.3 ENVI®, Geomatica®, and Imagine®

Several software packages have been developed to process satellite images and aerial photographs. Most of these have been applied to satellite imagery for the purpose of remotely sensing changes to land cover. These software are very specialized and have relatively steep learning curves. They are frequently used to prepare imagery for use with other GIS software. They tend to be rather expensive (e.g., more than $5,000) for professional versions and typically require a larger investment of hardware to support and run them effectively. They are usually very powerful and may require more extensive training. No attempt is made here to describe them in detail. The user is referred to the Internet Web sites that support these products:

Environment for Visualizing Images (ENVI®) can be reached at: http://www.rsinc.com/envi/

Geomatica® can be reached at: http://www.pcigeomatics.com/

ERDAS Imagine® can be reached at: http://www.erdas.com/

These software packages all incorporate higher-order classification algorithms, image enhancement, and contrast stretching capabilities as well as registration and mosaicing functions. Another added feature of each of these suites is that they all include scripting capabilities that allow the user to create custom routines.

Some of the more familiar higher-order algorithms used for image classification are the maximum likelihood, minimum distance, and parallelpiped decision rules. The overall objective of image classification procedures is to automatically categorize all pixels in an image into classes or themes based upon empirical relationships. In the case of each of the classifiers mentioned here, the user provides training areas prior to execution. That is, the user chooses pixels that fall into a predefined category such as 'Forest,' 'Grassland,' 'Soil,' "Water,' etc. The spectral patterns in these training areas are evaluated in the computer using a user defined decision rule to determine the category of each pixel in the image. The output of image classification can be in the form of graphic products, tabular data, or digital information files that can be input into a GIS.

Image enhancement techniques improve the ability to visually interpret an image by increasing the inherent distinction between features in a scene. This process attempts to optimize the complementary abilities of the human eye and the computer monitor.

Contrast stretching is a term commonly used in computer enhancement, where the density values in a scene are expanded over a great range. Consider an image whose digital number range between 30 and 100. Only a narrow portion of the full 256-bit range of possible display levels is shown. A more expressive display would result if the entire dynamic range of values, from 0 to 255, was utilized. Enhancement techniques common to the aforementioned suites include linear, square root, and equalization stretches. Figure 4-40 shows an example of an applied linear stretch. It is apparent from looking at the images that enhancement techniques generally make the task of identifying image features easier for the user.

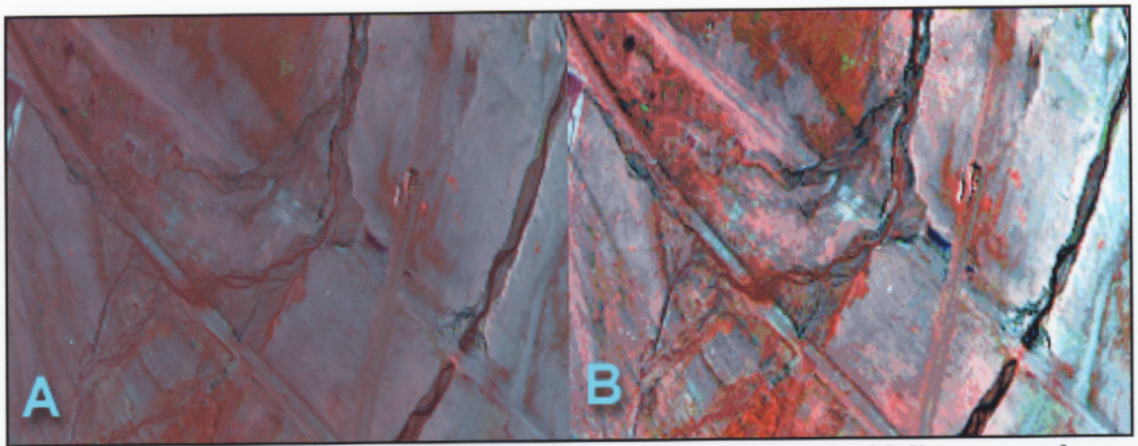

Figure 4-40. Applied linear stretch. (A) raw image , (B) image with linear stretch.

Image rectification and registration operations aim to correct distorted or degraded image data to create a more accurate representation of the original scene. Distortions range from variations in the altitude, attitude, and velocity of the sensor platform to factors such as panoramic distortion, earth curvature, or relief displacement. To correct for these variables involves the processing of raw image data to compensate for geometric distortions, to calibrate the data radiometrically, or to eliminate noise present in the data. The intent of geometric correction is to correct the inherent distortions so that the corrected image will have the geometric integrity of a map.

Figures 4-41 shows an image acquired using the Daedalus 1268 scanner. On Figure 4-41 one striking feature allowing the user to know that this is a raw, unrectified image (A) is the geometric shape of the panels along the road. They appear to be parallelograms rather than square. After the image went through a rectification procedure (B of Figure 4-41), the geometric integrity of the panels is normalized.

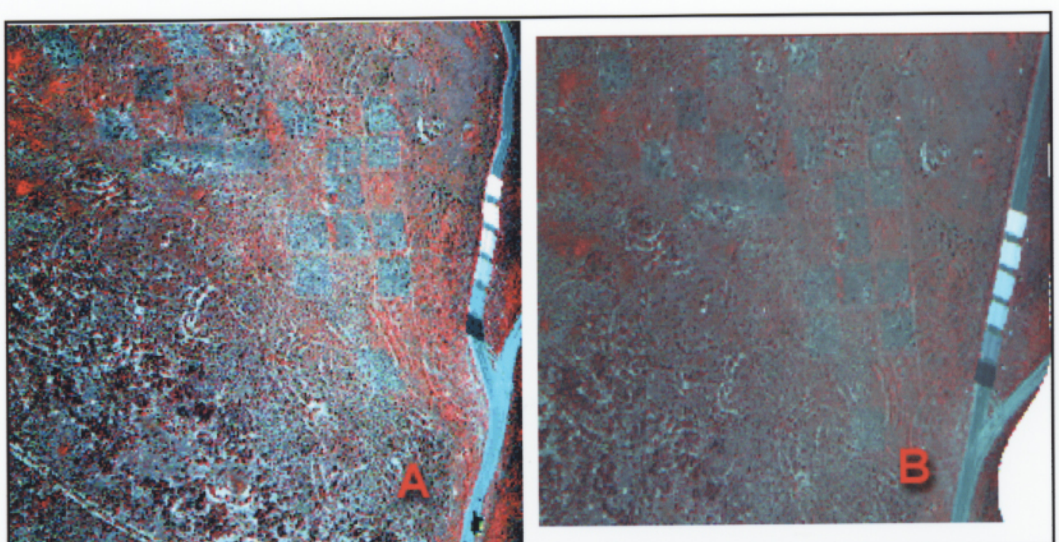

Figure 4-41. Rectified image effect: (A) raw image-note misshaped panels on right; (B) rectified image.

Choosing an image-processing package depends upon the user's needs and capabilities. RSI's ENVI focuses on extensive radiometric calibration techniques and holds the market on hyperspectral image analysis. ERDAS Imagine is not only an image-processing tool but it also has extensive GIS capabilities and interfaces directly with ESRI products. PCI Geomatics is an overall image-processing tool that contains many modules to adapt its capabilities to include photogrammetric processing that allow the user to create ortho-rectified images and digital elevation models.

Prices for the various software packages vary. ENVI ranges from $4,900 to $6,600 for Windows and up to $9,800 for UNIX licenses. Geomatica licenses start at $5,000 for Windows and $7,500 for UNIX. Additional Geomatica modules cost up to $3,000.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon findings from many small experiments during this project and from practical experience gained in actually using techniques, several conclusions can be drawn and recommendations made:

- The use of small-scale satellite imagery (e.g., 10 to 30 meters per pixel resolution) is of limited value in detecting cover changes in shrubs at canopy cover percentages below 10 percent. Satellite imagery should be used to obtain the "big" picture and aerial photography used to obtain the "details."

- The use of large-scale satellite imagery (< 1 meter per pixel resolution) shows promise for future use, but does not capture all of the shrub details. It should only be used as an index of changing shrub cover.

- The use of helicopters is faster and more efficient than using blimps or kites for small areas on most military installations of a small size. However, large areas are best photographed using fixed-wing aircraft specifically designed for such photo acquisition.

- Film scales of 1:1000 to 1:4000 yield the best estimates of plant cover. Scales smaller than this (e.g., 1:15000 to 1:24000) should only be used as an index of shrub cover.

- Scanning rates of about 300 dpi for photos of optimal scale (e.g., 1:1000 to 1:4000) are sufficient to capture canopy cover details and scanning rates of higher values do not increase cover accuracy, only file size.

- Camera lenses should be as fast as possible to avoid motion blurring when shooting aerial photographs by hand from an aircraft. Purchase only fast lenses even though they are usually more expensive than slower lenses, but worth the extra quality.

- Cameras that focus automatically often create unpredictable timing of the exposure due to ground motion created by the aircraft and the lack of vertical structure needed to focus on an image area. The camera's focus should be set manually to infinity when possible to avoid this problem.

- Photographs should be clear (sharp) enough to identify plant canopy edges if they are to be used for rapid assessment of vegetative structure image processing. Commercial imagery should be tested and evaluated to ensure that aircraft, camera, and film types provide the quality that is needed before large-scale projects are funded. Digital images should be georectified and color-corrected as part of commercial services to be provided.

- Statistical differences are measurable between technicians using image-processing software (e.g., setting threshold values); however, the differences are not greater than errors measured for mean canopy cover using ground methods to sample vegetation, where line-intercept techniques are frequently misused and the vegetation undersampled in the interest of time.

- Shadows, dark-colored rocks, or straw-colored litter may yield false signals, especially when smaller scale imagery is used. Higher resolution imagery may help compensate for these false signals by enabling the software to better identify the canopy cover of vegetation. Test runs of small areas may help avoid expensive photo projects that provide less-then-optimal results on larger areas.

- Vignetting and unequal lighting (e.g., north- and south-facing slopes, or different colored soils) in the same photograph should be corrected with color-balancing software before further processing to eliminate false signals due to color intensity differences.

- Measurements of object size classes are readily obtained, but differentiation of individual species is limited and users should use other ground-based methods every five years to collect trends in plant community composition.

- Ideally, site-wide imagery should be taken every year, however, budgets usually restrict the imagery to about once every two to five years. Areas receiving more frequent and heavy use for training should be photographed annually.

- Measurements of vegetation and other digital objects with commercially available image processing software are encouraging and can be used with other computer software to produce GIS themes.

- Three to six software packages may be needed to edit images, process images, and create acceptable GIS themes. A high-ended computer should be selected to reduce processing time (faster processing and greater memory is essential).

- Quality image processing assumes a high level of technician skill. When turnover in personnel is high (< 1 year average time period at the installation), a program of adequate training and additional incentives to retain employees should be considered to ensure that learning skills are transferred to new personnel.

- There are many excellent Web sites that should be utilized for acquiring skills and information about digital photography and image processing. Web sites referenced in this user's guide and links found at those Web sites should be periodically revisited for new information.

- A forum for information exchange in the form of a remote-sensing workshop should be provided biennially to all military branches (not just the Army's ITAM Workshop) to encourage the sharing of techniques and new ideas. The U.S. Department of Agriculture's Forest Service's Remote Sensing Program (http://www.fs.fed.us/eng/rsac/) provides an excellent program model or example of how to promote this exchange of information.

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APPENDICES

APPENDIX A

COVER MAPPING AT FORT IRWIN, CALIFORNIA, USING AERIAL PHOTOGRAPHY AND IMAGE ANALYSIS SOFTWARE

(see attached report)

COVER MAPPING AT FORT IRWIN, CALIFORNIA USING AERIAL PHOTOGRAPHY AND IMAGE ANALYSIS SOFTWARE

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Introduction

The amount and type of military training that goes on at Fort Irwin, California can have adverse effects on vegetation and other types of ground cover that hold soil particles in place. This can leave areas of the installation open to increased levels of wind and water erosion. One of the keys to combating this problem lies in the rehabilitation efforts of the LRAM (Land Rehabilitation and Maintenance) office. The job of this office is to determine areas of the installation that have undergone increased levels of degradation due to military training and then to employ various techniques to rehabilitate them. The use of LCTA (Land Condition Trend Analysis) spatial data can be extremely useful in the selection of areas of the base that need to be targeted for LRAM efforts. In the past the Fort Irwin LCTA program has used field-collected data and GIS tools, such as spatial analyst, to interpolate grids of percent cover. This method statistically analyzes the field collected data and then creates contour lines of similar percent cover values. The use of this technique has been utilized to determine general areas of similar percent cover values. Because of the statistically small sample size (295 vegetation plots) it is difficult to obtain the level of detail that would be required by the LRAM office to effectively target rehabilitation efforts. The LCTA office is now conducting new remote sensing technologies developed by Dennis Hansen and Kent Ostler of Bechtel Nevada to solve this lack of specificity in vegetative cover analysis. The new methods uses current aerial photographs of Fort Irwin (1:24000) and image analysis software to develop a more specific index of percent cover.

Using Sigma Scan Pro®

Sigma Scan Pro® is a program that has the ability to analyze the pixels of a digital photograph and select pixels that are darker than the ones that surround them. With desert plants that are usually somewhat darker than the soil background it can be very useful in picking out vegetative cover from a photograph. This software also allows the user to "threshold" the image analysis. This means that you can vary the intensity at which an image is analyzed. Sigma Scan Pro® employs a tool called an Color Histogram that can show what percentage of each color of the visual spectrum a given pixel is comprised of. A technique known as a "Histogram Stretch" can be used to make certain intensity values of the spectrum show up better (i.e., contrast is improved). This can be extremely valuable when trying to differentiate shrubs from their background (soil) by making them darker and easier to detect. An Intensity Histogram may be more useful for this process because it is better at differentiating between shrubs and other non-vegetative "noise", such as shadows or dark colored soils. Using a combination of the two histograms may be the most beneficial in differentiating shrubs (for photography of 1:16000 or greater, the use of a color histogram is not valuable). Overlay filters can also be used to erode out features that are smaller than a certain pixel size. This can be helpful in getting rid of non-vegetative "noise" such as animal burrows or other landscape features that may appear dark on an aerial photograph. The "measurements menu" can be used to determine how many pixels within the photography are comprised of the selected shrub features. These features can then be masked on to a white background for easier analysis.

Steps:
1) Open the digital image that you wish to analyze in Sigma Scan Pro®.
2) Zoom the image into a point just before you begin to see the pixels show up.
3) Select Intensity Threshold from the Image menu. This will overlay a red mask on certain pixels in the image with a default intensity value. Before it does this it will ask you to convert the image to gray scale.
4) Convert the image to gray-scale unless you wish to use the color histogram to threshold the image (color thresholding is not necessary on images at 1:24000 scale). If you already have a threshold value selected for the analysis of all your images, then do not convert to gray scale to save processing time.

5) Once the thresholding window comes up use the "histogram slider" to determine the correct value based on how much of the overlay red covers the shrubs being analyzed. (Once a threshold intensity has been done for one picture, the same threshold value can be used for all pictures being analyzed in a given area.
6) Select Overlay Filters from the Image menu and use them to drop out all features that are smaller than a certain pixel size. (You will have to play around with this feature to determine what pixel size is right to use for that image). Overlay filters should not be used for 1:24000 photography.
7) Use the Masking feature under the Image menu. Select "With overlay 1 (Red)". This will remove all of the threshold selected features and mask them on a white background.
8) Save this masked image as a 24-bit TIFF file.

Using the SERDP Tiff Converter

Once you have the image of the shrubs on a white background it is then time to do the statistical analysis for vegetative cover. The TIFF converter overlays a grids onto the TIFF image, and then analyzes each individual grid square and determines which portion of that square is dark in color and which portion is white. In this way it can compile a list of percent cover statistics for the image.

Steps:
1) Open the 24-bit TIFF in the Converter program (disable the preview window).
2) Export the file at grid size 10 pixels x 10 pixels.
3) The program will create a table of statistics in a ".dat" file.
4) The tiff converter will ask you if you want to view the output file. Click no to decrease processing time.

Using Surfer® 7.0

The Surfer® 7.0 software takes the statistics created in the Tiff converter and uses them to create contour lines of similar percent cover values for that image.

Steps:
1) Select "Data" from the "Grid" menu. Open the ".dat" file created by the tiff converter.
2) Adjust the Wire Frame settings to make the analysis more exact (100x100 is a good place to start). 100X100 is a good wireframe to use for 1:24000 photography. Also make sure that the gridding method is Minimum Curvature. This will create a Surfer Grid (.grd) file.
3) Choose New Contour Map from the Map Menu. Open the grid that was created from the ".dat" file in Surfer.
4) From the Contour Map Properties menu choose Fill Colors, Color Scale, and Smooth Contours.
5) Under levels on the same menu you can choose what % cover classes to use.
6) Fill Properties on the same window allows you to select what colors to use to represent each cover class from the Foreground Color Window. (The line on the 0% level can be made invisible.
7) Make all of the boundary lines between classes invisible.
8) Once a legend is created for the contours, save it so that you can use it on all subsequent photos in a given analysis.
9) Export the completed map as a tiff file. Saving it over the original masked image created in Sigma Scan will save hard drive space.

Using Adobe Photoshop®

Steps:
1) Bring the exported file up in Adobe Photoshop®.
2) Use the Crop Tool to cut out the map image, not including the black border of the map. Zoom all the way in to decide where to place the cursor.
3) Save the cropped image over the exported Surfer Tiff file.

4) The images from several photographs can then be pieced together on a canvas within Adobe Photoshop®. (Make sure to make the canvas only large enough to accept all the pixels for the images being mosaiced). To know how large to make the canvas, open a cropped image and choose image size from the image menu. This will tell you how many pixels high and wide you cropped, exported Surfer Tiff is. Then multiply these dimensions based on how many photos make up the length and width of your desired mosaic. When performing the mosaic, make sure to zoom all the way in so that you can line up the images properly with each other and the edge of the canvas.
5) Once all images have been mosaiced, save the image as a copy of a tiff. (mosaiced images must be either square or rectangular for georefrencing purposes).

Writing the TIFF World File

Each section of the cover map must be georefrenced so that it can be opened within ArcView®. This is done by writing a TIFF World File (.tfw) for the "copy of a tiff" that was saved within Adobe Photoshop®.

Steps:
1) Open the notepad accessory on you computer.
2) Open ArcView® and add the orthocurrent.shp file. Label the tiles within this file.
3) Determine the UTM coordinate of the upper left and the lower right hand corners of your mosaiced cover map.
4) If you know the label numbers for the photos used in the mosaiced cover map, they will correspond to the labeled orthocurrent tiles. (Orthocurrent.shp is the coverage for the 1997 labels. 2001 photography will be labeled differently).
5) You can create a new theme within ArcView® that adds points to the corners mentioned for he mosaiced image, and then use the "addxycoor" script to determine their UTM coordinates. (You may want to zoom all the way in so that you can place the points accurately on the corners).
6) Open the notepad and follow the following instructions for writing the lines of the TIFF world file:

   a. Line 1:
      ([x-value of lower right corner] – [x-value of upper left corner]) / [image width]
      Ex: = (559500.0000 – 549000.3595) / 2157 pixels
      = 4.868
   b. Line 2:
      Assume to be 0 (zero)
   c. Line 3:
      Assume to be 0 (zero)
   d. Line 4:
      ([y-value of lower right corner] – [y-value of upper left corner]) / [image height]
      Ex: = (3894750.00001 – 3936750.0000) / 8616 pixels
      = -4.875
   e. Line 5:
      [x-value of upper left-hand corner]
      Ex: = 549000.3595
   f. Line 6:
      [y-value of upper left-hand corner]
      Ex: = 3936750.0000

The Written Text file should look like this:

```
4.868
0
0
-4.875
549000.3595
3936750.0000
```

7) Once the file is written save it as a ".txt" file using the exact same name used to save the mosaiced cover map within photoshop.
8) Open "Explore" under the start button on the desktop and navigate to the folder where both the mosaiced map and world file are saved. They must be saved in the same spot.
9) Change the file type from ".txt" to ".tfw" by renaming the file, but do not change the actual name, only the ending.
10) Once a world file is written for one section of the base it can be used for all other sections of the base by simply changing lines 5 and 6 to correspond to the UTMs of the upper left corner of the new mosaiced image. The new world file will have to be saved to correspond to the correct name of the new mosaiced image. (This is important because you may have to piece several mosaiced images together to cover the whole base, each of which will need its own world file).

ArcView® Image Analysis Extension (ArcView 3.2a)

After your mosaiced sections have been georefrenced they need to be converted to shapefiles within ArcView. This is done using the ArcView® Image Analyst extension.

Steps: 1) Open ArcView® and enable the Geoprocessing Wizard and Image Analysis extensions.
2) Add your mosaiced image as an Image Analysis Data Source, not an Image Data Source.
3) Pick a feature in the cover map from your lowest cover class and zoom in on it. (It is best to Pick a small oval or regularly shaped feature).
4) Under "Seed Tool Properties" on the Image Analysis Menu make sure that the "Include Island Polygons" box is checked and the "Seed Radius" is set to 5 pixels.
5) Use the Seed Tool from the Image Analysis Toolbar to drag a small rectangle within the cover class feature.
6) The analysis will place a green line around what it considers to be the boundary of the image. (Since resolution is low on these image files, the feature may have fuzzy edges where it is hard to tell where the boundary between features of two cover classes exists).
7) Click on the ArcView® Vertex Tool. This will make drag boxes appear on the green boundary line. Drag the boundary line in so it is completely contained within the correct color of the cover class for the feature being looked at.
8) Select the pointer tool from the ArcView® Toolbar. This will remove the drag boxes from the new boundary line. With the boundary line still selected (black boxes around the line); choose Find Like Areas" from the Image Analysis Menu.
9) In the "Find Like Areas" window click the "New" button and name the "Output Image Theme" Make sure the "Selected Graphics" box is checked.
10) Label the "Class Name" to correspond to the cover class you are trying to convert. Hit enter and then press OK. This will select all of the areas within the image whose pixels have the same color as the cover class being converted.
11) Repeat steps 3 through 10 for all cover classes within the image. In the "Find Like Areas" window (step 9) keep the "Output Image Theme" name the same, but change the "Class Name" to correspond to the cover class being analyzed.
12) Once all of the cover classes have been analyzed, and the output image theme is complete, you must then convert this theme to a shapefile by selecting the theme and choosing "Convert to Shapefile" from the Theme Menu. A separate shapefile theme must be generated for each mosaiced section of the base.

13) Once all of the mosaiced sections of the installation have been converted to shapefiles, you can merge the individual themes using ArcView® Geoprocessing Wizard, which will appear under the View Menu. Choose the merge option, select all of the themes to be merged, and press enter.

Removing Mountain Noise in the Analysis

The image analysis in Sigma Scan Pro® can tend to confuse shadows in the mountainous areas for extremely high cover, so it may be necessary to clip the shapefiles to remove areas in the mountains. This is beneficial to the ITAM office at Fort Irwin because we are only concerned with training lands (>20% slope).

Steps:
1) Create a slope coverage from a Digital Elevation Model (DEM) using ArcView® Spatial Analyst. Select the DEM theme and then choose "Derive Slope" from the Surface Menu.
2) Select the new slope theme.
3) Choose "Map Query" under the Analysis Menu. In the "Map Query" window select the slope theme from the layers box by double clicking. Make sure that it shows up in the equation box, then click the ">" button and type 20 into the equation box. Click "evaluate". This will create a "Map Query" theme.
4) Select the "Map Query" theme and convert it to a shapefile.
5) Open the new shapefile theme's attribute table. Use the "Query Builder" to select all records with a Gridcode = 1.
6) Select "start editing" from the Table Menu. Then select "delete records" from the Edit Menu, then click "stop editing" and save the edits. This removes from the new theme any area >20% slope.
7) Open the Geoprocessing Wizard and select "clip themes". Clip the cover map based on the new slope theme. This removes any cover polygons in the areas of the base greater than 20% slope.

It may not be possible to clip the entire installation cover map based on the slope theme. You may have to clip it one section at a time, in which case it would be helpful to clip the slope theme to a size that approximates the sections size. Then you would have to merge all of the clipped sections.

Selecting the Correct Thresholding Value for Comparability

In order to look at changes in cover from one set of photography to the next you need to make sure that the Sigma Scan Pro® software is looking at the two sets of images in the same way. Sometimes photography from one year can have different brightness and contrast factors that can affect the analysis of the photography. In order to make the photograph sets comparable it is necessary to choose a threshold value for the second set, which looks at the shrubs in the same way that it did for the previous set of photography.

Steps:
1) Open a tiff image from the first set of photographs to be analyzed within Sigma Scan Pro®. It is best to choose a photograph from an area where changes in the shrubs has not occurred.
2) Shrink down the image so that you can bring up the corresponding photograph from the new set of photography.
3) Select a shrub in each image that does not appear to have changed much. Sigma Scan Pro® has a feature in the lower left hand corner of the screen that identifies the coordinates of the cursor on the photograph. You can select a shrub in one image and copy down the coordinates, and then go to the next photograph and move the cursor around until you find the shrub with the same coordinates. If the shrub does not appear to have changed, then this will be a good shrub to use for the analysis.
4) Follow the instructions listed in "Using Sigma Scan Pro®" to apply the threshold that was used to analyze the first set of photographs. Make sure to zoom way in on the photograph to a point just before you begin to see pixels in the image. The threshold you choose will overlay a red mask on top of all of the shrubs to the extent that your thresholding value determines.
5) Follow the procedures used to apply a thresholding value to the image from the second set of photos. This time you will want to convert the image to a gray-scale.
6) Once the new image is converted to a gray scale you can use the "Histogram Slider" to apply different threshold values as you move it along the histogram, and see how much of the shrubs get covered by the mask with different values. With both images opened on the screen, and the

correct threshold value applied to the first photograph, simply slide the histogram slider back and forth until the mask over the shrub being looked at in the new image matches the mask over the same shrub in the old image.

7) When the mask for the second image matches the mask for the first image simply read the thresholding value off of the thresholding window and apply the same value to the rest of the photographs in the analysis.

Making a Map of Shrub Cover Change

Once cover maps are made for both sets of photography it is then possible to make a map that shows areas of shrub cover increase and decrease. The maps must be made as instructed above so that they can be compared accurately. It is very unlikely that you will be able to use the same thresholding value to analyze photographs from two different years, so make sure to follow the instructions listed in the last section. It is also a good idea to use the same slope mask to clip both years maps.

Steps: 1) Add the Spatial Analyst Extension to ArcView® and open both cover maps.

2) Select one of the cover map themes and choose "convert to grid" from the Theme Menu. Do the same for the other year's cover map so that both themes are converted to raster coverages.

3) Select "Map Calculator" from the Analysis Menu. Use the calculator to subtract the older cover map from the more recent one, and press evaluate. This will subtract all of the individual cell values within the raster coverages so that the output will contain cell values for a given area that are either a positive number, negative number, or a 0 (zero). Positive numbers represent varying levels of increase in cover, negative numbers represent decrease in vegetative cover and 0 shows areas of no change.

4) Use a dichromatic scale from the new themes legend to more easily differentiate increase, decrease, and no change areas.

The Importance of Ground Truthing

Remote sensing data is almost useless without ground-truthing that will apply real world numbers to the classes that you come up with in an analysis. The cover classes that are arrived at in this analysis are arbitrary and do not mean much to the user without ground-truthed cover values. They can provide information about levels of change from year to year however. Because of the variability in photographic contrast and brightness levels from year to year and other variables in this type of analysis it is a good idea to do some ground-truthing. This way the cover classes will provide more information to the end users. Here at Fort Irwin LCTA permanent plot data will be used to ground-truth the photography.

Steps: 1) Simply overlay the LCTA % cover data that corresponds to the year you are trying to ground-truth. Make a text table (.txt) within Excel® that contains the % cover values and UTM coordinates for the LCTA plots and add it to the ArcView® project. Then use the "Add Event Theme" option under the View Menu to create a point theme from it.

2) Use the "Assign Spatial Data" feature of the Geoprocessing Wizard look at which cover class each LCTA plot falls into. This will add new fields to the LCTA plots theme attribute table. One of these fields will be the cover class associated with each LCTA plot.

3) Use the "Query Builder" to select all records from a given cover class and export the records as a text file.

4) Open this text table within Excel®. Look at the range of % cover values and determine the range of percent cover values for this cover class. Make sure to throw out any outliers that may be the result of analysis noise. Repeat the same steps for all cover classes to get the range of percent cover values that are represented by each cover class.

APPENDIX B

PLANT DAMAGE ASSESSMENT TECHNIQUE FOR EVALUATING MILITARY VEHICULAR IMPACTS TO VEGETATION IN THE MOJAVE DESERT

(see attached report)

Bechtel Nevada

DOE/NV/11718–613

Plant-Damage Assessment Technique for Evaluating Military Vehicular Impacts to Vegetation in the Mojave Desert

September 1, 2001

SERDP Project CS-1131

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ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A new plant-damage assessment technique was developed by plant ecologists from Bechtel Nevada at the U.S. Department of Energy's National Nuclear Security Administration Nevada Operations Office and funded by the Strategic Environmental Research and Development Program Project CS-1131 in cooperation with the U.S. Army's National Training Center (NTC) at Fort Irwin, California. The technique establishes linear transects the width of vehicle tracks from evidence of vehicle tracks in the soil (usually during a prior training rotation period of 30 days or since the last rain or wind storm), and measures vegetation within the tracks to determine the area of plant parts being run over, the percent of the impacted parts damaged, and the percent of impacted parts expected to recover. It documents prior-damage classes based on estimates of damage that plants have apparently experienced previously (as assessed from field indicators of damage such as plant shape and height). The technique was used to evaluate different vehicle types (rubber-tire wheels vs. tracks) in six areas at the NTC with different soils and training intensity levels. The technique provides tabular data that can be sorted and queried to show a variety of trends related to military vehicular impacts. The technique also appears suitable for assessing other non-military off-road traffic impacts. Findings report: (1) differences in plant sensitivity to different vehicular impacts, (2) plant cover and density by species and training area, (3) the degree to which wheels have less impact than tracks, and (4) the mean percent survival is inversely proportional to the degree of prior damage received by the vegetation (i.e., plants previously impacted have lower survival than plants not previously impacted).

INTRODUCTION

This study was conducted by plant ecologists from Bechtel Nevada and was funded by the Strategic Environmental Research and Development Program Project CS-1131 in cooperation with the U.S. Department of Energy's National Nuclear Security Administration Nevada Operations Office and the U.S. Army's National Training Center at Fort Irwin, California. Plant damage caused by vehicular traffic passing over the vegetation can be estimated by a simple plant damage assessment technique that incorporates the collection of field data and its analyses. The technique is relatively rapid and efficient. It yields considerable information about plant community structure, vehicular impacts, and plant recovery, and it provides a means of comparing sites to evaluate their relative degree of past plant disturbance. It not only permits the evaluation of plant community data, but also provides details about individual species response and their relative sensitivity to military or recreational vehicular impacts.

The technique is designed to assess recent impacts (e.g., one to four weeks) rather than cumulative impacts (e.g., one to four years). Cumulative impacts are better assessed by other techniques, such as the Land Condition Trend Analysis (U.S. Army Environmental Center, 1999) or comparable techniques that provide quantitative values of reductions in canopy cover and shifts in plant community composition (Bonham, 1989; Kent and Coker, 1992). The plant damage assessment technique requires recent vehicular activity in an area where the density of vehicle tracks are sufficiently spaced so as to be able to clearly identify individual tracks and the impacted vegetation. It is limited when tracks are too numerous (e.g. multiple passes), too old, or not clearly discernible as might result from a recent rain, or when crushed vegetation blows away during a wind storm. Ideally, it is performed in the spring of the year when vegetation is green and a week or more after the vehicular impact to permit time to determine surviving plant parts, such as leaves, branches, or new sprouts.

METHODS

Field equipment required for measurements includes a simple centimeter tape measure (a spring-loaded metal tape works best) or ruler, pencil and data form, or palmtop computer with spread-sheet capabilities. Data analyses are best performed on a desktop personal computer with spreadsheet, statistical, and database software capabilities, although they can also be calculated by hand. A simplified diagram of typical field conditions is shown in Figure 1. The assessment technique consists of identifying a vehicle track of interested in a selected area. This can be done by driving along a road and observing intersecting tracks of interest such as the type of track (e.g., wheeled versus tracked types and their widths). A starting point is determined for the survey. This may be done by using a random number of paces in from the road in areas where vegetation is present and representative of the area to be evaluated. Global positioning satellite coordinates are recorded or the position marked on aerial photographs or topographic maps. The width of the vehicle track is then measured using a tape measure (in centimeters). This should include the outermost measurement where evidence suggests the widest width of the track. For example, some tank tracks may have a narrow rubber skid and a wider metal support for the track.

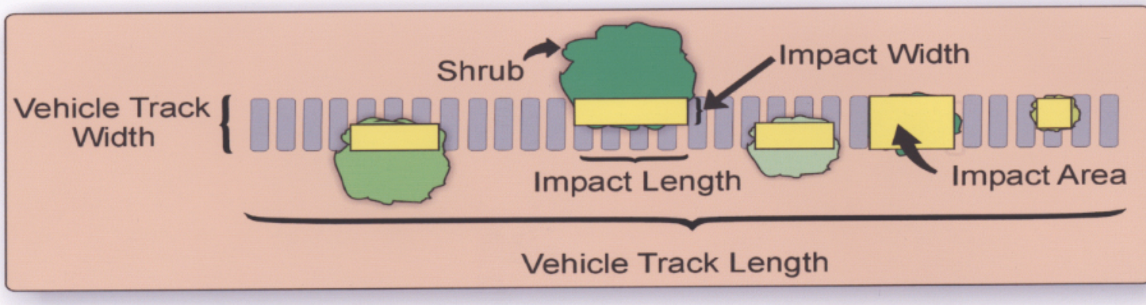


Figure 1. Diagram of typical field conditions for assessing plant damage from vehicular traffic.

The proper width would be the widest part of the track; in this case, the metal support that can potentially crush or damage vegetation. For rubber-tired wheels, the width would be from side to side, or from outside of the first dual tire to the inside of the second dual tire. This will be the width of the belt transect. Only one side of the vehicle (e.g., the right set of wheels or tracks) is measured at a time. A return trip can measure impacts on the other side of the vehicle (e.g., the left set of wheels or tracks). The distance in paces is then recorded to the nearest plant. This value is recorded as a pace length on the data form or spreadsheet. Paces can later be converted to centimeters. The measured length of 50 to 100 consecutive paces will give the mean distance in centimeters of a pace's length.

When the first plant that is within the track belt transect is encountered, several measurements for that plant are taken. First, the species alphacode is recorded. The alphacode consists of its standardized abbreviated scientific name, usually comprised of the first two letters of the genus and the first two letters of the species (U.S. Department of Agriculture, 1996). Numbers are used to distinguish between different plants with similar abbreviations. Because the alphacodes are accepted as U.S. national standards, they are consistent among federal agencies as well as many state agencies. The second parameter that is recorded is the assessment of the prior plant damage class. Figure 2 shows the four codes for damage classes typically used (low, moderate, high, and very high).

The basic principle is to get a quick estimate of the area of the shrub that has been run over. Adjust the size of the rectangle or square to best fit the shape of the shrub. Obviously, most shrubs are round or oval in shape so the rectangle needs to be adjusted to best approximate the area. A few limbs may extend beyond the symmetrical boundary of the shrub profile or there may be holes in the plant canopy. Consistency in how shrubs are measured is key to reliable measurements. The measurement of these variables will help in the estimation of the impacted area (length x width) and the impacted volume (volume = length x width x height).

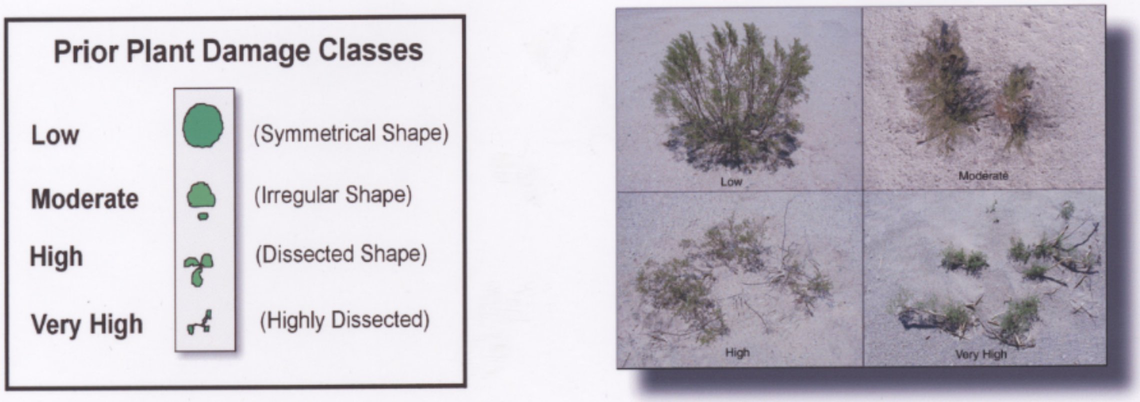


Figure 2. Prior plant damage classes.

The code is assigned based on evidence of prior damage from vehicular traffic. Plant symmetry is the major factor. Additional measured parameters to be recorded include: height of the plant (height in centimeters or the mean height of the majority of the branches), length of the impacted portion of the plant (in centimeters), and width of the impacted portion of the plant (in centimeters) (refer to Figure 1 for examples of shrub measurements).

Two other estimated parameters include an estimate of what percentage of the shrubs has been impacted by the vehicle and an estimate of what percentage of the impacted vegetation will survive based on green leaves, stems, or resprouts. Cover estimates can be recorded to the nearest 2 percent at the lower cover values and to the nearest 5 or 10 percent at the higher cover values. Charts that assist the visualization of percent cover are often useful. Charts can be laminated in plastic and trimmed to facilitate their use in the field. Figure 3 shows representations of cover from 1 to 50 percent.

Additional higher cover perceptions can be achieved by considering the cover of the white area. For example, a square with a 30 percent black cover can also be used to help visualize 70 percent cover of the white area in the same square. The cover of two charts can be mentally added into the same area to visualize cover percentages not shown in the charts (e.g., 20% + 3% = 23%). Frequent early reference to information in the chart can help reduce errors in visual estimates. Practice with other experienced scientists prior to collection field data can also help reduce such errors.

Once data are documented for the first plant, the scientist then locates the next plant. If it is in the same area as the first plant (e.g., an understory shrub), a linear distance of 0 is recorded for the number of paces. The measured pace for the second value begins at the precise point that the previous pace concluded. When the transect crossed barren areas like roads and tank trenches,

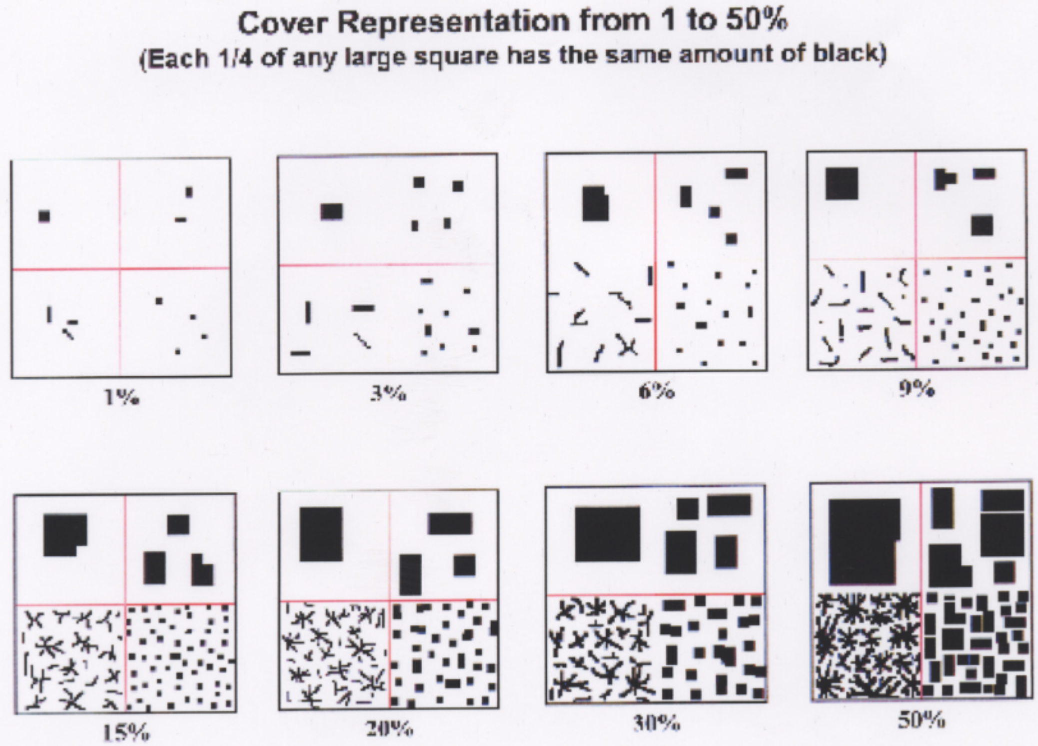


Figure 3. Visualization chart for cover representations from 1 to 50%.

the paces across these areas were ignored and the count continued where vegetated ground was reencountered. When the last pace distance is recorded, it can be added to the previous last pace value to complete the transect (e.g., if the last plant pace distance was 8 paces and the transect extends an additional 10 paces to the end of the transect, then the last value of 10 would be added to the previous value of 8 to obtain a new value of 18).

An example of a typical data form is shown in Figure 4. Users of palm-top computers would want to modify the header information and include them as five new columns to the left of the "Parameters" in the main lower body of the data form (e.g., include abbreviations for the column headings, location, grid, category, collector, and date). Headings can be "locked" in place so that they are always visible when scrolling up or down. The use of such computers minimizes transcription data errors. Most batteries last through a 10-hour day of data collection before they have to be recharged. Field supplemental power is also available as an accessory. The surface of the palm-top computers should consider using adhesive-back plastic overlays designed to protect the surface from scratching from blowing sand. Such covers last several days before they have to be replaced.

Formulas and variables used for calculating values associated with the plant damage assessment technique include:

$$C_T = \sum C_s$$

$$C_i = (\sum A_s)/V*100$$

where,

C_T = Total plant cover summed over all species (species *i* through species *j*), expressed as a percent of the total vehicular impacted area

= Total vegetative damage impact created by the vehicle, expressed as a percent of the total vehicular impacted area

C_i = Percent cover of the *i*th perennial plant species

$Species_i$ = The *i* th perennial plant species identified within the vehicular impacted area

V = Vehicle impacted area in square centimeters = $L_t * W_t$

L_t = Length in centimeters of the vehicular track that is sampled
W_t = Width in centimeters of the vehicular track

D_t = Distance in paces along L_t from the starting point or plant to the next plant or finish point

$\sum$ = Sum of the individual measurements for species *i* through species *j*

A_i = Area in square centimeters of the *i*th species = $L_i * W_i$

L_i = Length in centimeters of the *i*th species that was run over by the vehicular track

W_i = Width in centimeters of the *i*th species that was run over by the vehicular track

Other descriptive statistics and statistical tests can be used to stratify the data by site, species, prior damage class, and survival values.

In order to test the assessment technique, six different areas at Fort Irwin, California, were selected for sampling. Each area had slightly different soils and microclimate. Prior use varied among sites. Military training activities were sufficiently ongoing at each of the areas to yield numerous vehicular tracks across the sites. Severely impacted areas within these sites were

PLANT DAMAGE ASSESSMENT FORM

Training Center:		Location				Page(s)	Disruption Category
NATIONAL TRAINING CENTER		CENTRAL CORRIDOR				_1_ of _1_	Very Heavy [ ] Heavy [ ] Moderate [X] Light [ ] Very Light [ ] Other [ ]
		Grid Coordinates		GPS Coordinates			
Date	Collector(s)	E	N	Easting	Northing		
03/31/2000	Dennis Hansen Kent Ostler	5112					

PARAMETERS

Track Type (Code)	Track Width (cm)	Distance (paces)	Species (Alphacode)	Prior Damage (Code)	Damaged (% of plant)	Survival (% of damage)	Height (cm)	Length (cm)	Width (cm)	Area of Damage (L cm X W cm)
T	55	4	AMDU	H	80	25	20	90	45	4,050
T	55	2	AMDU	V	70	30	20	50	50	2,500
T	55	8	LATR	M	10	90	100	100	100	10,000
T	55	1	HYSA	H	70	50	60	80	50	4,000
T	55	3	AMDU	H	30	75	20	30	30	900
T	55	18	AMDU	V	30	70	30	60	40	2,400
T	55	1	AMDU	V	80	20	15	30	20	600
T	55	47	HYSA	V	90	20	25	40	30	1,200
T	55	12	AMDU	V	100	20	20	25	25	625
T	55	3	AMDU	H	95	5	6	32	29	928
T	55	11	LATR	H	90	60	32	56	63	3,528
T	55	47	AMDU	L	30	60	45	78	50	3,900
T	55	3	LATR	H	5	10	43	200	80	16,000
T	55	11	STPA	L	5	0	41	47	42	1,974
T	55	25	LATR	H	20	10	77	161	138	22,218
				TOTAL:	805	525	554	1,079	792	74,823
				MEAN	54	35	37	72	53	4,988

[TRACK TYPE CODES: T = tracked; W = wheeled; plus the width of the track in cm]; [ALPHACODE: National Plant Data species code species]; [PRIOR DAMAGE CODES: L = Light, M = Moderate, H = Heavy, V = Very Heavy]

Notes:

Figure 4. Example of a Plant Damage Assessment Form.

avoided because of the sparseness and lack of diversity of vegetation and the amount of time needed to encounter the next plant. Most areas would be classified as a mosaic of moderately to highly disturbed. Areas were sampled during a relatively dry spring from April 3 to May 31, 2000, and from June 30 to July 1, 2000, at the ends of training rotations (e.g., three weeks of training activities).

Data were collected into palm-top computers (3Com® PalmVx) running Quicksheet 4.0 (Palm Computing®) and later transferred to spreadsheet software on a desktop computer for analyses. Analytical packages used were: Microsoft® Excel 97, Microsoft® Access 97, and Minitab® Release 12.1.

Results

Approximately 20 tracks and nearly 500 shrubs were sampled at the six different areas at Fort Irwin to evaluate the plant damage assessment technique. The technique provided rapid and relatively comprehensive data upon which to evaluate the impacts to perennial vegetation. The technique was evaluated under conditions that provided a good test of the technique, because it was a relatively dry year with little precipitation. This was due to the fact that plant damage is greater under dry conditions than moist conditions and it is more difficult to determine survival of plant matter that is relatively dormant (i.e., living twigs without leaves). Additionally, resprouting after vehicular damage is also delayed more under dry conditions than during periods of adequate precipitation.

Vehicle tracks consisted of two types, those from wheeled vehicles such as rubber tires on humvees or trucks, and tracks from vehicles such as armored personnel carriers or tanks. Our analyses focused on impact damage from vehicles moving in a straight line, not during turns when soil displacement and damage is much greater, and more difficult to compare and assess. One-way analysis of variance for the mean percent survivability of vegetation after being run over by ten different tract or wheel widths suggests that there were significant differences ($p < 0.001$ level) in the mean survivability between track widths. In general the wider the track or wheel, the lower the survivability of the vegetation, probably suggesting that wider tracks support greater weights of vehicles resulting in greater damage near the root crown. A comparison of tracked vehicular damage versus wheeled vehicular damage using one-way analysis of variance suggest that there was a significant difference ($p < 0.001$) between the two types. Tracked types across all plant species had a mean percent survivability of 27 percent ($n=288$ observations) while wheeled types had a mean percent survivability of 39 percent ($n=188$ observations).

Survivability of individual plants varied by species with some species being more sensitive than others. A comparison of percent survivability using one-way analysis of variance suggests that there was a significant difference ($p < 0.05$) between plant species percent mean survival values. Percent mean survival is the estimated percentage of the vegetation that has been run over that is expected to survive. Field evidence of survivability included green stems still attached to the root crown, respouting of old stems or crowns, or remaining green, leafy plant parts. A ranking of the predominant shrubs and their associated mean survival values is shown in Table 1.

Prior damage to vegetation by vehicular traffic varied by site at Fort Irwin. The percent of all shrubs at each site falling into the four following prior damage classes - low, moderate, high, and very high - is shown in Figure 5.

Survivability following vehicular impact also appeared to be dependent on the physiological condition of the plant as determined by prior damage. Table 2 shows the differences in percent survival for different damage classes across all sites, species, and for all track types and widths.

Table 1. Comparison and ranking of plant species percent mean survival after vehicular impact.

Scientific Name	Common Name	Percent Mean Survival	Standard Error of the Mean ±	Number of Measurements
Lycium pallidum	rabbit thorn	12.8	4.4	15
Hymenoclea salsola	white burrobush	18.0	4.6	36
Cassia amata	spiny senna	32.1	8.3	17
Ambrosia dumosa	white bursage	32.5	1.9	293
Larrea tridentata	creosote bush	38.9	3.6	84

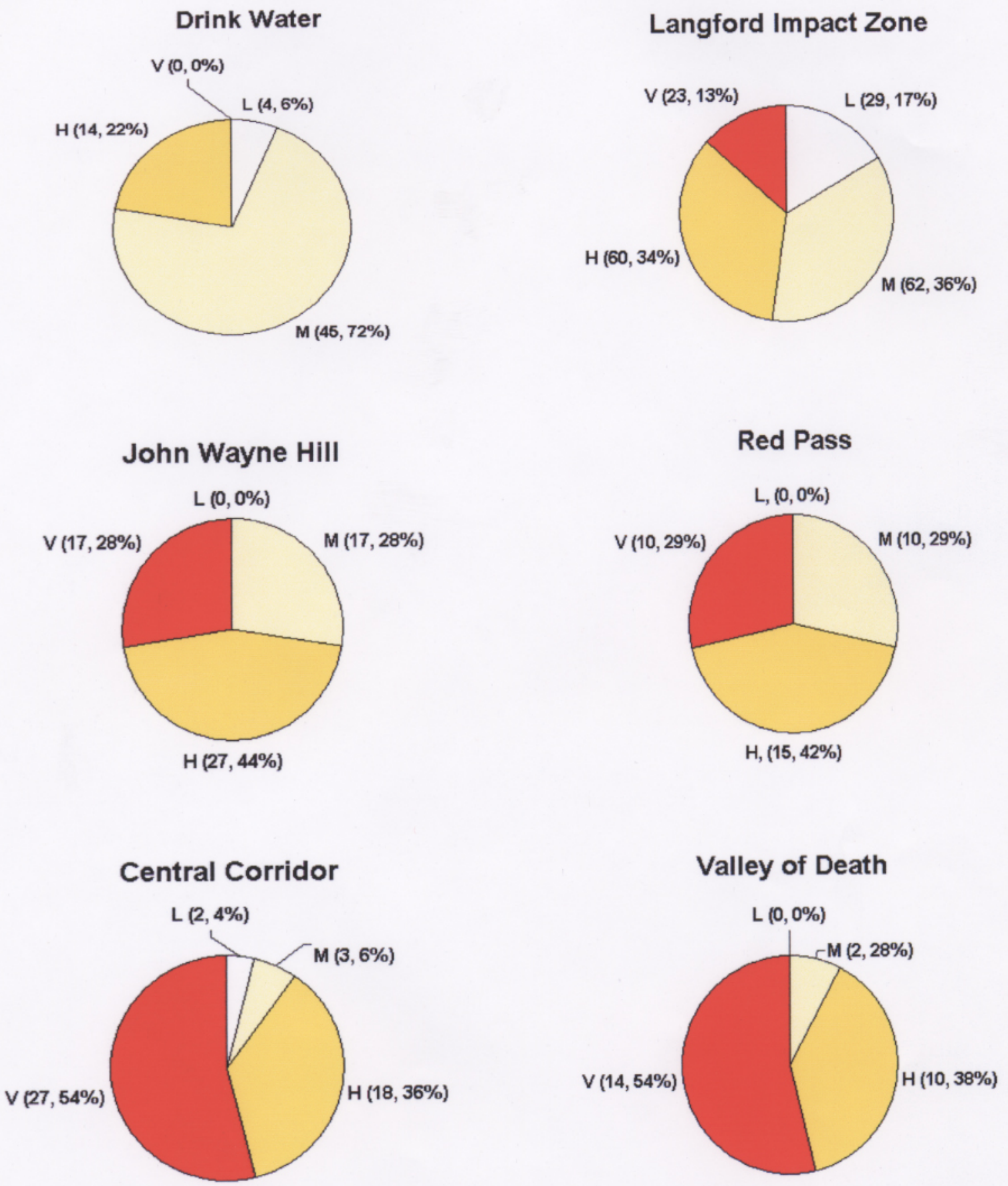
In general, plants that have little prior damage tend to have higher mean percent survival values than plants with higher prior damage. Plants with a better physiological status appear to be better able to recover after impact. An exception to this is with plants that have been very highly damaged previously. These plants are usually very small, with prostrate branches that resist further damage and result in a higher percent survival than larger plants with more upright branching patterns that are more susceptible to damage. Because they are very small, they often fit between the tracks escaping further damage completely.

When mean percent survival was considered at specific sites and for specific track types and widths, many specific patterns were observed. Some sites like John Wayne Hill, Red Pass, and Valley of Death are too disturbed by previous training activities to have any plants that fit into the "low" prior damage class.

Table 2. Mean percent survival for plants by prior damage class after vehicular impact.

Prior Damage Class	Mean Percent Survival	SE Mean (±)	N
Low	51.4	6.5	35
Moderate	29.3	2.6	139
High	25.9	2.5	144
Very High	32.8	3.7	91

Drink Water on the other hand had such low previous disruptions that there were no plants that fit into the "very heavy" prior damage class.



*** Codes for Prior Damage to Vegetation: L=Low, M=Moderate, H=High, V=Very High**
(Values in parenthesis: number of shrubs sampled, percentage of the total shrubs sampled)

Figure 5. Percentage of shrubs at Fort Irwin Sites by prior damage to vegetation codes.

It is apparent that the patterns described for each site reflect the past training levels and current plant community structure of the site. For example, Red Pass has been impacted so heavily in the past and has very sandy soils, making it more susceptible to damage, that the site is covered by a nearly complete monoculture of creosote bush. Certainly shifting sands created by secondary impacts once vegetative cover is removed tends to bury other shorter and smaller plants.

Reductions in shrub cover due to vehicular traffic is a function of the track type, the plant cover prior to disturbance, the survivability characteristics of the plant species, and the degree of previous plant damage. Mean reduction in plant cover per pass of tracked vehicles was 74 percent, while mean reduction in plant cover per pass of wheeled vehicles was 69 percent. In other words between 69-74 percent of all vegetation run over by vehicles was killed in the sampling transect. Percent mean reduction in plant cover per vehicle pass was also higher in areas of initial higher plant cover than in areas of initial lower plant cover. Regression analysis for percent reduction in plant cover versus percent plant cover for wheeled and tracked vehicles were both statistically significant ($p < 0.001$), although the amount of variation being accounted for was generally low ($r^2 = 23.3$ percent for wheeled and $r^2 = 70.3$ percent for tracked vehicles). The reason for this relationship appears to be that initial impact to relatively undisturbed vegetation is greater than impacts to vegetation that have been run over several times, thereby selecting for branching patterns and plant sizes that are better able to withstand vehicular traffic.

This plant damage assessment technique appears to provide a rapid means of assessing impacts of vehicular traffic in areas moderately to heavily disturbed. Its use is limited in areas where prior severe plant damage has occurred resulting in low species cover (i.e., less than 3 percent canopy cover) and large sampling distances required to provide statistically adequate sampling of the vegetation. Examples of additional plant community parameters are shown in Appendix A.

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APPENDIX A

Example of Possible Formats for Information Obtained Using the Plant Damage Assessment Technique

Appendix A - Fort Irwin Vegetation Damage Assessment Data

August 15, 2001 Location	Track Type cm	Track Width cm	Prior Damage Class	Number	Mean Damage (Percent)	Mean Survival (Percent)	Mean Height cm	Mean Length cm	Mean Width cm	Mean Volume cm^3	Mean Damage Area cm^2	Total Damage cm^2	Distance m	Impact Area Dam./Dist. cm^2/m	Plant Cover (Percent)	Reduction in Plant Cover/Pass (Percent)
Central Corridor	T	55	(Not Rated)	0	0	0	0	0	0	0	0	0	0			
		55	L	2	17.5	25.0	43.0	62.5	46.0	123,625	2937.0	5,874	58			
		55	M	1	10.0	90.0	100.0	100.0	100.0	1,000,000	10000.0	10,000	8			
		55	H	7	55.7	32.1	36.9	92.7	62.1	212,350	7374.9	51,624	50			
		55	V	5	74.0	32.0	22.0	41.0	33.0	29,766	1465.0	7,325	80			
		55	***All Classes***	***15***	***54***	***35***	***37***	***72***	***53***	***140,257***	***4,988***	***74,823***	***196***	***382***	***6.94%***	***65%***
	W	28	(Not Rated)	26	80.0	31.0	16.0	42.3	30.2	20,467	1952.7	50,769	329			
		28	L	0	0	0	0	0	0	0	0.0	0	0			
		28	M	2	20.0	40.0	16.0	45.0	25.0	18,000	1200.0	2,400	5			
		28	H	11	54.6	50.0	18.0	35.2	23.4	14,792	974.9	10,724	184			
		28	V	22	62.1	56.4	14.7	35.2	20.6	10,649	1021.4	22,470	294			
		28	***All Classes***	***61***	***67***	***44***	***16***	***39***	***25***	***15,604***	***1,424***	***86,891***	***812***	***107***	***3.82%***	***56%***
Central Corridor	***Combined***	***Combined***	***Combined***	***76***	***65***	***42***	***20***	***45***	***31***	***27,735***	***2,119***	***161,020***	***1,008***	***160***		
Drink Water	T	55	(Not Rated)	0	0	0	0	0	0	0	0	0	0			
		55	L	4	42.5	41.3	28.3	23.0	15.8	10,234	441.5	1,766	13			
		55	M	45	70.8	22.2	20.7	31.1	21.3	13,721	741.3	33,357	174			
		55	H	14	57.5	27.9	27.0	35.8	22.3	21,539	955.1	13,371	80			
		55	V	0	0	0	0	0	0	0	0	0	0			
		55	***All Classes***	***63***	***66***	***25***	***23***	***32***	***21***	***15,123***	***770***	***48,494***	***266***	***182***	***3.31%***	***75%***
Drink Water	***Combined***	***Combined***	***Combined***	***63***	***66***	***25***	***23***	***32***	***21***	***15,123***	***770***	***48,494***	***266***	***182***		
John Wayne	T	55	(Not Rated)	0	0	0	0	0	0	0	0	0	0			
		55	L	2	17.5	25.0	43.0	62.5	46.0	123,625	2937.0	5,874	58			
		55	M	12	49.6	28.8	31.7	38.3	20.0	24,285	471.0	5,652	115			
		55	H	13	40.5	11.9	38.5	45.7	22.08	38,856	588.3	7,648	101			
		55	V	4	63.8	18.8	37.3	39.0	26.3	38,135	526.0	2,104	15			
		55	***All Classes***	***30***	***47***	***19***	***35***	***41***	***21***	***30,666***	***518***	***15,548***	***237***	***66***	***1.19%***	***81%***
John Wayne	T	60	(Not Rated)	0	0	0	0	0	0	0	0	0	0			
		60	L	0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0			
		60	M	1	50.0	10.0	31.0	28.0	15.0	13,020	420.0	420	1			
		60	H	7	62.6	16.1	22.0	39.6	22.43	19,526	1180.3	8,262	126			
		60	V	8	72.5	9.4	29.3	42.5	31.1	38,698	1456.5	11,652	73			
		60	***All Classes***	***16***	***67***	***12***	***26***	***42***	***26***	***28,810***	***1,271***	***20,334***	***200***	***102***	***1.69%***	***88%***
John Wayne	W	60	(Not Rated)	0	0	0	0	0	0	0	0	0	0			
		60	L	0	0.0	0.0	0.0	0.0	0.0	0	0.0	0	0			
		60	M	4	58.8	6.3	37.5	43.2	27.9	45,194	1362.9	5,452	51			
		60	H	7	44.6	2.1	26.5	39.6	22.86	23,950	901.4	6,310	48			
		60	V	4	51.5	1.3	27.9	30.5	15.9	13,524	571.0	2,284	92			
		60	***All Classes***	***15***	***50***	***3***	***30***	***38***	***22***	***25,376***	***936***	***14,045***	***191***	***74***	***1.23%***	***97%***
John Wayne	***Combined***	***Combined***	***Combined***	***61***	***53***	***13***	***31***	***40***	***23***	***29,130***	***818***	***49,927***	***628***	***79***		

August 15, 2001	Track				Mean		Mean					Total		Impact Area	Plant	Reduction in
	Type	Width	Prior Damage		Damage	Survival	Height	Length	Width	Volume	Damage Area	Damage	Distance	Dam./Dist.	Cover	Plant Cover/Pass
Location	cm	cm	Class	Number	(Percent)		cm	cm	cm	cm^3	cm^2	cm^2	m	cm^2/m	(Percent)	(Percent)
Langford Impact Zone	T	18	(Not Rated)	13	45.2	42.3	24.5	55.3	43.9	59,419	4485.9	58,316	139			
		18	L	5	17.0	40.0	11.5	16.2	10.8	2,012	187.2	936	52			
		18	M	7	30.0	27.1	23.3	41.1	33.4	32,031	2512.3	17,586	54			
		18	H	5	60.0	26.0	44.0	72.0	55.0	174,240	460.2	2,301	27			
		18	V	2	50.0	0.0	3.0	3.5	3.0	32	11.0	22	13			
		18	***All Classes***	***37***	***42.0***	***30.2***	***13.0***	***28.5***	***19.5***	***7,243***	***1368.6***	***50,637***	***276***	***184***	***10.20%***	***70%***
	T	40	(Not Rated)	13	45.2	42.3	24.5	55.3	43.9	59,419	1011.7	13,152	139			
		40	L	6	48.3	50.8	16.7	20.8	19.2	6,657	516.7	3,100	34			
		40	M	7	55.0	26.4	30.7	55.7	43.6	74,542	3928.6	27,500	31			
		40	H	5	60.0	26.0	44.0	72.0	55.0	174,240	8425.0	42,125	27			
		40	V	1	20.0	0.0	35.0	40.0	30.0	42,000	1200.0	1,200	3			
		40	***All Classes***	***32***	***49.5***	***36.6***	***27.8***	***51.1***	***40.5***	***57,385***	***4132.5***	***132,241***	***234***	***565***	***14.12%***	***63%***
	T	44	(Not Rated)	0	0	0	0	0	0	0	0	0	0			
		44	L	0	0	0	0	0	0	0	0	0	0			
		44	M	14	52.5	28.9	26.0	44.8	33.9	39,495	1545.7	21,640	94			
		44	H	18	66.1	21.1	17.5	35.1	26.4	16,184	1043.5	18,783	120			
		44	V	4	100.0	23.0	15.9	19.1	14.0	4,226	111.8	447	23			
		44	***All Classes***	***37***	***65.5***	***23.8***	***20.3***	***36.6***	***27.7***	***20,611***	***1115.4***	***41,270***	***237***	***174***	***3.96%***	***76%***
	T	60	(Not Rated)	14	79.5	33.9	17.9	41.9	31.3	23,524	2478.9	34,704	35			
		60	L	8	68.8	50.0	20.0	26.9	27.5	14,784	1046.9	8,375	40			
		60	M	17	56.2	31.8	24.7	47.7	40.0	47,097	3019.1	51,325	60			
		60	H	3	100.0	8.3	18.3	25.0	25.0	11,456	641.7	1,925	5			
		60	V	7	95.7	6.3	21.4	45.0	35.7	34,437	2853.6	19,975	23			
		60	***All Classes***	***49***	***73.2***	***30.3***	***21.1***	***40.9***	***33.9***	***29,317***	***2373.6***	***116,304***	***162***	***718***	***11.97%***	***70%***
	T	***Combined***	***Combined***	***155***	***59.0***	***30.0***	***20.4***	***39.0***	***30.4***	***24,127***	***2196.5***	***340,453***	***909***	***375***		
	W	10	(None)	0	0	0	0	0	0	0	0	0	0			
		10	L	0	0	0	0	0	0	0	0	0	0			
		10	M	0	0	0	0	0	0	0	0	0	0			
		10	H	2	70.0	5.0	6.0	8.0	6.5	312	59.5	119	16			
		10	V	3	93.3	35.0	2.7	4.3	4.0	46	27.3	82	100			
		10	***All Classes***	***5***	***84.0***	***23.0***	***4.0***	***5.8***	***5.0***	***116***	***40.2***	***201***	***116***	***2***	***0.17%***	***77%***
	W	24	(None)	0	0	0	0	0	0	0	0	0	0			
		24	L	0	0	0	0	0	0	0	0	0	0			
		24	M	0	0	0	0	0	0	0	0	0	0			
		24	H	4	87.5	27.5	15.0	18.5	20.3	5,619	402.5	1,610	220			
		24	V	2	100.0	0.0	4.5	12.0	10.5	567	136.0	272	12			
		24	***All Classes***	***6***	***91.7***	***18.3***	***11.5***	***16.3***	***17.0***	***3,193***	***313.7***	***1,882***	***232***	***8***	***0.34%***	***82%***
	W	28	(None)	13	69.6	46.9	12.5	25.3	18.7	5,932	753.0	9,789	95			
		28	L	10	85.5	68.0	16.0	25.5	23.0	9,384	857.5	8,575	54			
		28	M	17	52.1	45.0	30.9	55.9	39.4	68,005	3079.4	52,350	122			
		28	H	7	38.6	22.9	32.3	55.7	42.9	77,100	2635.7	18,450	101			
		28	V	1	100.0	50.0	20.0	20.0	20.0	8,000	400.0	400	10			
		28	***All Classes***	***48***	***62.8***	***47.2***	***22.8***	***40.5***	***30.5***	***28,133***	***1865.9***	***89,564***	***381***	***235***	***8.40%***	***53%***
Langford Impact Zone	***W***	***Combined***	***Combined***	***59***	***67.5***	***42.2***	***20.1***	***35.1***	***27.0***	***18,966***	***1553.3***	***91,647***	***729***	***126***		

August 15, 2001	Track				Mean		Mean					Total		Impact Area	Plant	Reduction In
	Type	Width	Prior Damage		Damage	Survival	Height	Length	Width	Volume	Damage Area	Damage	Distance	Dam./Dist.	Cover	Plant Cover/Pass
Location	cm	cm	Class	Number	(Percent)		cm	cm	cm	cm^3	cm^2	cm^2	m	cm^2/m	(Percent)	(Percent)
Langford Impact Zone	***Combined***	***Combined***	***Combined***	***214***	***61.4***	***33.4***	***20.3***	***37.9***	***29.4***	***22,624***	***2019.2***	***432,100***	***1638***	***264***		
Red Pass	T	18	(None)	0	0	0	0	0	0	0	0	0	0			
		18	L	0	0	0	0	0	0	0	0	0	0			
		18	M	1	10.0	50.0	48.3	40.6	15.2	29,884	243.8	244	32			
		18	H	3	30.0	20.7	32.2	69.4	13.6	30,265	399.6	1,199	54			
		18	V	5	43.0	15.0	27.9	39.1	14.2	15,543	229.6	1,148	142			
		18	***All Classes***	***9***	***35.0***	***20.8***	***31.6***	***49.4***	***14.1***	***22,029***	***287.9***	***2,591***	***228***	***11***	***0.63%***	***79%***
Red Pass	W	18	(None)	0	0	0	0	0	0	0	0	0	0			
		18	L	0	0	0	0	0	0	0	0	0	0			
		18	M	5	22.0	36.0	41.0	13.7	11.6	6,474	238.8	1,194	99			
		18	H	6	48.3	46.7	30.7	21.3	21.5	14,052	568.9	3,414	77			
		18	V	4	23.8	66.3	28.8	16.7	11.4	5,478	238.2	953	60			
		18	***All Classes***	***15***	***33.0***	***48.3***	***33.6***	***17.5***	***15.5***	***9,107***	***370.7***	***5,560***	***236***	***24***	***1.31%***	***52%***
Red Pass	W	30	(None)	0	0	0	0	0	0	0	0	0	0			
		30	L	0	0	0	0	0	0	0	0	0	0			
		30	M	4	18.8	28.8	57.5	29.6	25.1	42,728	1258.9	5,036	79			
		30	H	6	36.7	18.3	40.0	23.5	24.4	22,840	848.8	5,093	50			
		30	V	1	10.0	50.0	19.0	9.9	3.0	564	29.7	30	33			
		30	***All Classes***	***11***	***27.7***	***25.0***	***44.5***	***24.5***	***22.7***	***24,660***	***923.5***	***10,158***	***162***	***63***	***2.09%***	***75%***
Red Pass Impact Zone	***W***	***Combined***	***Combined***	***26***	***30.8***	***38.5***	***38.2***	***20.4***	***18.5***	***14,472***	***604.6***	***15,719***	***398***	***39***		
Red Pass Impact Zone	***Combined***	***Combined***	***Combined***	***35***	***31.9***	***33.9***	***36.5***	***27.9***	***17.4***	***17,713***	***523.1***	***18,309***	***626***	***29***		
Valley of Death	W	18	(None)	6	28	40	25	28	17	11717	204	1224	212			
		18	L	0	0	0	0	0	0	0	0	0	0			
		18	M	2	75.0	45.0	14.0	16.5	15.2	3,515	102.9	206	37			
		18	H	10	48.5	38.0	26.7	27.1	15.4	11,145	250.4	2,504	143			
		18	V	8	48.1	50.6	25.4	17.1	21.0	9,130	357.5	2,860	275			
		18	***All Classes***	***26***	***45.8***	***42.9***	***25.0***	***23.4***	***17.4***	***10,172***	***261.3***	***6,794***	***667***	***10***	***0.57%***	***57%***

T = tracked, W = wheeled, L = low prior damage, M = moderate prior damage, H = high prior damage, V = very high prior damage, Not rated = plants recorded without a rating

7.0 INTERNET WEB SITES AND LINKS

7.1 Internet Web Sites for Remote-Sensing and Diagnostic Techniques

One of the valuable resources available to scientists today are the many World Wide Web Internet sites that post information and provide links to other related Web sites. The access of information on the Web is dynamic and nearly always in a state of change with new Web sites being added, old Web sites revised or moved, and links established nearly hourly. Anyone who has used the Internet has encountered links to sites that no longer exist. The best attempts to be current are often by using search engines on the Internet itself. Included here are a few key websites that may help users locate pertinent information it is not meant to be exhaustive nor complete, and while every attempt has been made to ensure that the sites listed here are active, it is likely that one or more of the sites will change during the next few months.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof or its contractors or subcontractors.

7.1.1 Strategic Environmental Research and Development Program (SERDP)

http://www.serdp.org/

7.1.3 SERDP Projects or Linked Web sites

Colorado State University's Center for Environmental Management of Military Lands
http://www.cemml.colostate.edu/

Utah State University's Remote Sensing for Ecosystem Assessment:
http://www.gis.usu.edu/~serdp.

University of Illinois's Spatial Data Analysis Laboratory:
http://www.sdal.uiuc.edu/

University of Nevada Reno: http://www.ag.unr.edu/serdp/

U.S. Army Corps of Engineers Engineer Research and Development Center, Construction Engineering Research Center:
http://www.cecer.army.mil/td/tips/index.cfm

7.1.4 Remote Sensing

U.S. Department of Agriculture's Forest Service Remote Sensing Applications Center:
http://www.fs.fed.us/eng/rsac/

Remote Sensing, WWW Virtual Library at:
http://www.vtt.fi/tte/research/tte1/tte14/virtual

American Society for Photogrammetry & Remote Sensing (ASPRS),
http://www.asprs.org

Color balancing and mosaicing software: DIME® software at:
http://www.possys.com/dime.html

Mosaicing software: Multiresolution Seamless Image Database (MrSID®) software at:
http://www.lizardtech.com

Military version of MrSID GeoViewer Version 2.1 at (note: https nor http):
https://trms.7atc.army.mil

7.1.5 Digital Photography

Flatbed scanning tips:
http://www.scantips.com

Digital Photography Tutorial by Norman Koren at:
http://www.normankoren.com

Digital editing software, Picture Window Pro, Digital Light & Color at:
http://www.dl-c.com

Technical information about digital photography at Computer-Darkroom:
http://www.computer-darkroom.co.uk

7.1.6 Kite Aerial Photography

Kite Aerial Photography E-Resources at:
http://www.fortunecity.com/marina/nelson/479/

Kite aerial photography:
http://arch.ced.berkeley.edu/kap/

7.1.7 Helium Blimps

Skyview blimp services:
http://www.skyview-usa.com.

7.1.8 Image Processing

Image Tool, University of Texas Health Science Center, San Antonio, Texas (UTHSCSA). Version 3.0 of UTHSCSA ImageTool at:
http://ddsdx.uthscsa.edu/dig/itdesc.html

Image Pro® Plus User's Group at:
http://www.solutions-zone.com/ipednld/subscriber.asp or http://www.mediacy.com)
Users may also search the archive files available at Image Pro® Plus User's Group Archives: http://www.mediacy.com/tech/ipts_ugml.html

SigmaScan® Pro: http://www.spssscience.com/SigmaScan/

Feature AnalystTM , Visual Learning Systems in Missoula, Montana
http://www.vls-inc.com/

Environment for Visualizing Images (ENVI®) can be reached at:
http://www.rsinc.com/envi/

Geomatica® can be reached at: http://www.pcigeomatics.com/

ERDAS Imagine® can be reached at: http://www.erdas.com/