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Integrating Remote Sensing and Field Data to Monitor Changes in Vegetative Cover on a Multipurpose Range Complex and Adjacent Training Lands at Camp Grayling, Michigan

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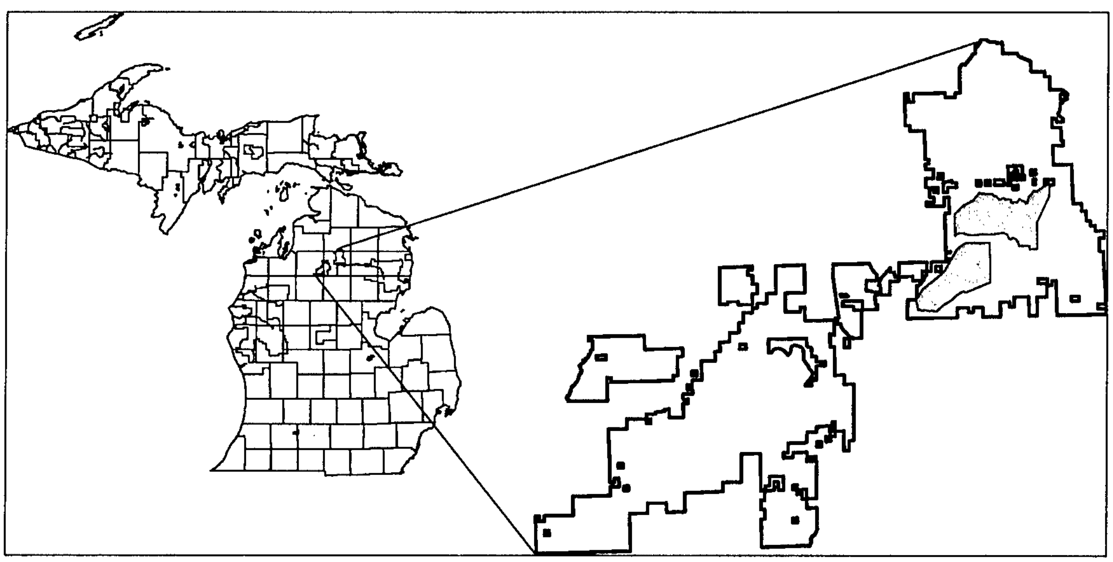

Construction Engineering
Research Laboratory

Foreword

This study was conducted for Commander, U.S. Army Garrison, Camp Grayling under Military Interdepartmental Purchase Order (MIPR) 448S2006597100, "Development and implementation of protocols to monitor changes in vegetative cover on a multipurpose range complex and adjacent raining lands at Camp Grayling, Michigan," Work Unit number NO7. The technical monitor was Mr. Greg Huntington, Manager, Environmental Section, Construction and Facilities Management Office, Michigan Department of Military Affairs.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Mr. Scott Tweddale. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Mr. Stephen Hodapp is Chief, CN-N, and Dr. John Bandy is Chief, CN. The associated Technical Director is Dr. William D. Severinghaus. The Acting Director of CERL is Alan W. Moore.

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1 Introduction

Background

Installation land managers are responsible for managing military lands in support of the training mission, while also complying with local, regional, and national environmental laws. Military training and testing affects the landscape in several ways. An impact of high concern to installation land managers is the reduction of vegetative cover resulting from tracked and wheeled vehicle training. The reduction of vegetative cover can negatively affect both the environmental integrity of Army installations and the ability of installations to provide a realistic training environment.

Camp Grayling, a U.S. Army National Guard installation in northern Michigan, was required to monitor changes in vegetative cover to fulfill obligations of the Environmental Impact Statement (EIS) covering the construction of a new Multi-Purpose Range Complex (MPRC). The new MPRC was built on the site of the old Range 30 Complex, and became operational during the summer of 1997. Activity on the new MPRC was expected to result in significant changes in the distribution and intensity of tracked and wheeled vehicle impacts at Camp Grayling (Mr. Greg Huntington, Manager, Environmental Section, Construction and Facilities Management Office, Michigan Department of Military Affairs, professional discussion, October 1996). Before construction of the MPRC, much of the area was used for various off-road maneuver training. Since the MPRC was constructed, tracked and wheeled vehicles have been restricted to several primary roads. As a result, impacts are expected to decrease within the new MPRC, but are expected to increase in some other areas of the installation, particularly in adjacent training lands north of the MPRC. The expected recovery of vegetation within the new range, due to a change in land use, was considered a mitigating factor in construction of the new range (National Guard Bureau and Michigan Department of Military Affairs 1994). The ability to monitor the changes in vegetative cover within the MPRC and training area immediately north (hereafter referred to as the Northern Training Area — NTA) is critical to fulfilling the intent of the EIS and training land management.

Objectives

The overall goal of this project was to develop a cost-effective method to detect and monitor spatial and temporal changes in vegetative cover within the MPRC and NTA. The first objective of this project was to gather data on vegetative cover within the MPRC and NTA from field surveys and remote sensing sources. The second objective was to use the field survey and remotely sensed data to develop spatially explicit baseline data on vegetative cover within the MPRC and NTA. The third objective was to design and provide a detailed description of monitoring methods that could be replicated in the future to assess changing conditions in relation to an established baseline survey of vegetation cover.

Approach

Study area boundaries and high priority regions at Camp Grayling were determined through consultations with natural resource personnel at Camp Grayling and the Michigan National Guard. Vegetative cover and physiognomic class were sampled in the field within the identified study areas during the peak growing season at Camp Grayling in 1997. A coincident Landsat Thematic Mapper (TM) satellite image was also acquired during the approximate time that the vegetation field survey was conducted. Relationships between field data and vegetation indices derived from satellite imagery were investigated to develop spatially explicit baseline vegetative cover data.

Method of Technology Transfer

The methodology, results, conclusions, and recommendations summarized in this technical report represent the primary mode of technology transfer to Camp Grayling, Michigan. The report contains a detailed description of the methodologies used for this initial baseline survey of vegetative cover, and therefore, will serve as a guide to subsequent monitoring activities. In addition to the technical report, all field survey data will be provided in a digital format. Hard copy maps and digital Geographic Information Systems (GIS) data layers that were created as a result of this analysis will also be provided.

2 Study Site

Physical Setting

Established in 1913, Camp Grayling (Figure 1) is an Army National Guard installation located in the rolling hills of the north central portion of Michigan's lower peninsula, approximately equidistant from Lake Michigan and Lake Huron.* The town of Grayling (population 2,745) is 2 miles (3.22 km) northeast of the cantonment area and approximately 200 miles (321 km) north of Detroit. Camp Grayling encompasses approximately 147,000 acres (59491 ha) and is divided into North and South Camps by Interstate 75. The Camp's acreage is spread over portions of Otsego, Kalkaska, and Crawford counties with the vast majority of lands occurring in Crawford County. The Camp is situated on lands leased by the Michigan National Guard from the State of Michigan.

Camp Grayling's primary mission is to serve as a Maneuver Training Center (MTC) for National Guard units from Michigan, Indiana, and Ohio. In addition, Active Duty, Army Reserve, Navy Reserve, and Marine Corps Reserve forces use the Camp for various training exercises. Visiting units of the Canadian Army and the Latvian National Guard also train at Camp Grayling.

Climate

Camp Grayling's climate is primarily continental in character; summers are warm and humid and winters are generally cold and snowy. The maximum/minimum temperatures for January are -3 °C/-13 °C and for July are 27 °C/12 °C. Yearly rainfall averages 81 cm. The climatic influences of Lake Michigan and Lake Huron are most pronounced throughout the late fall and early winter months. Camp Grayling receives a considerable amount of snowfall, averaging

* See http://www.michguard.com/grayling/default.htm and *Mission Expansion/Multiple Construction: Camp Grayling Army National Guard Training Site, Michigan - Final Environmental Impact Statement* (National Guard Bureau and Michigan Department of Military Affairs [1994]).

236 cm per year. This is due to Camp Grayling's proximity to the southeastern edge of the lake-effect snow belt, which is centered 30 miles (48 km) northwest of the installation.

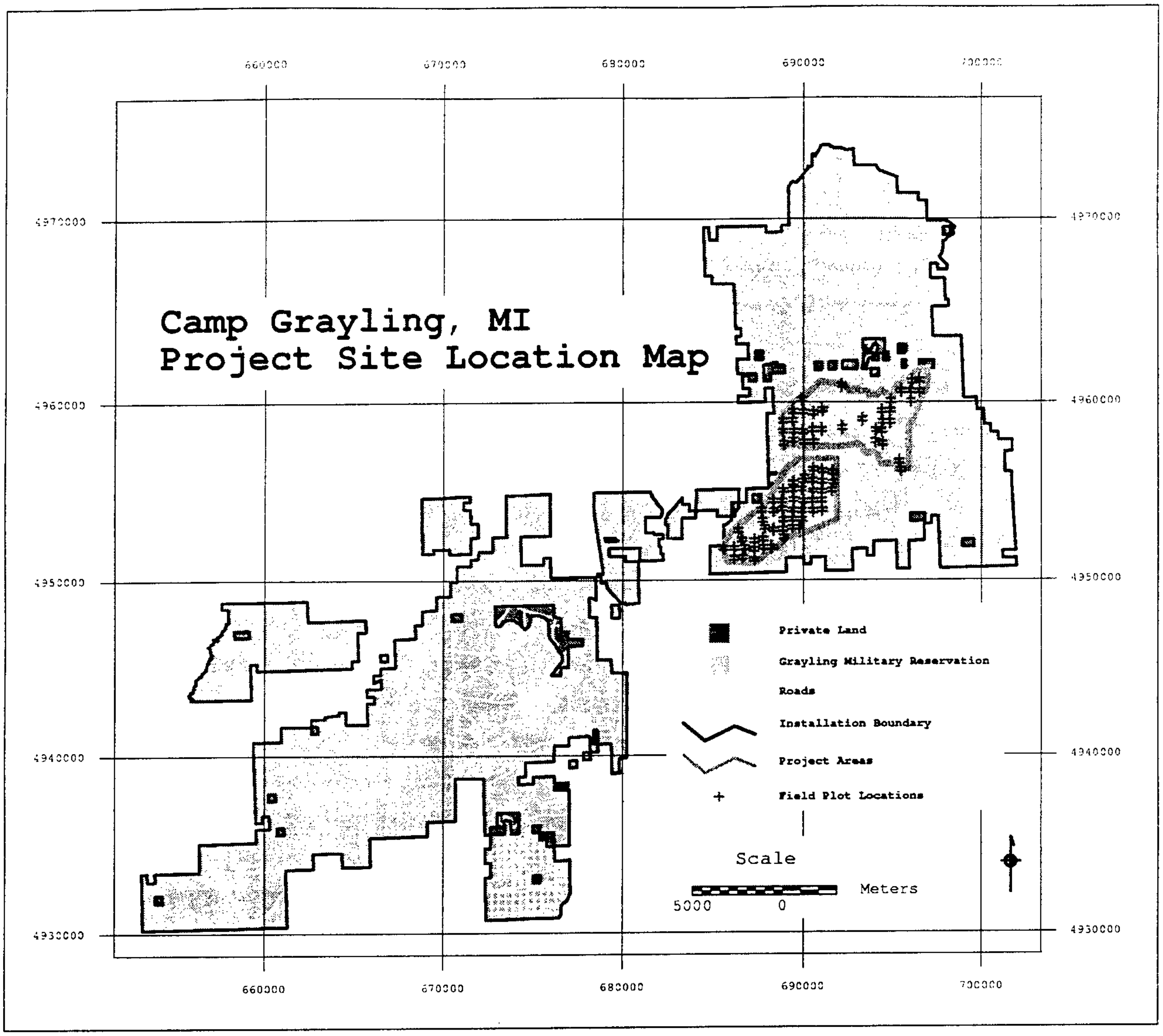

Figure 1. Map of Camp Grayling, MI.

Geomorphology and Soils

The geomorphology of Camp Grayling and the surrounding area is the direct result of the most recent episode of continental glaciation. The retreat of the glaciers during the latter part of the Wisconsin Period Glaciation resulted in ground moraines several hundred feet thick in the areas surrounding the Camp. Camp Grayling itself lies on portions of two of these moraines, separated by a low marshy plain, and roughly corresponds to the North and South Camps. The southern moraine (South Camp) is characterized by east to west tending ridges and valleys giving the south post more dissected topography. The north moraine (North Camp) is a gently rolling plateau that is cut by several streams. The retreat of the glaciers also resulted in many depressions in the landscape that have since become lakes and/or boggy wetlands.

Soils at Camp Grayling are largely derived from glaciofluvial parent materials. Most of the soils at the Camp are excessively drained sands. However, poorly drained, acidic soils occur in many of the wetland and low lying areas. The soils are differentiated primarily by their drainage characteristics. Three soil series: Rubicon, Graycalm, and Grayling, comprise a majority of the soils within the study area and throughout the installation. Many (40 percent) of the soils at Camp Grayling are within the Rubicon soil series, which consists of excessively drained soils found on glacial outwashes and moraines. Organic matter and clay content of soils in this series are low throughout all of the horizons. Soils found within the Graycalm series are also excessively drained sands. However, the organic and clay content of Graycalm soils is greater than that of Rubicon soils. Soils that comprise the Grayling soil series are excessively drained sands that contain virtually no organic matter or clay. Conditions for establishing vegetative cover are unfavorable for all soils within these three series because of low fertility and moisture availability.

General Vegetation

Camp Grayling is located within the oak/pine belt that extends eastward from Lake Michigan inland, and in the transition zone from the central deciduous hardwood region to the south, and the boreal forest to the north. Most (90 percent) of the upland areas at Camp Grayling are comprised of the following six major forest cover types:

1. Oak
2. Jack Pine
3. Aspen
4. Red Pine
5. Upland Hardwoods
6. Mixed Swamp Conifers

Study Areas

Two specific training areas, the MPRC and NTA, both located within the North Camp, were selected for monitoring and study (Figure 2). The MPRC essentially encompasses the old Range 30 Complex and now serves as a combined arms training and range facility. The MPRC is located within an area bounded to the south by North Down River road, to the East by Stephans Branch road, and to the north and west by Lake Truck trail. The NTA is used as a maneuver and bivouac area by various tracked and wheeled vehicle units that train at Camp Grayling. The NTA is a larger and more heterogeneous area than the MPRC. For the purposes of this study, the NTA was within an area bordered to the west and north by Jones Lake road, to the south by Bucks East and West Truck Trail, and to the east by Wakeley Bridge Road.

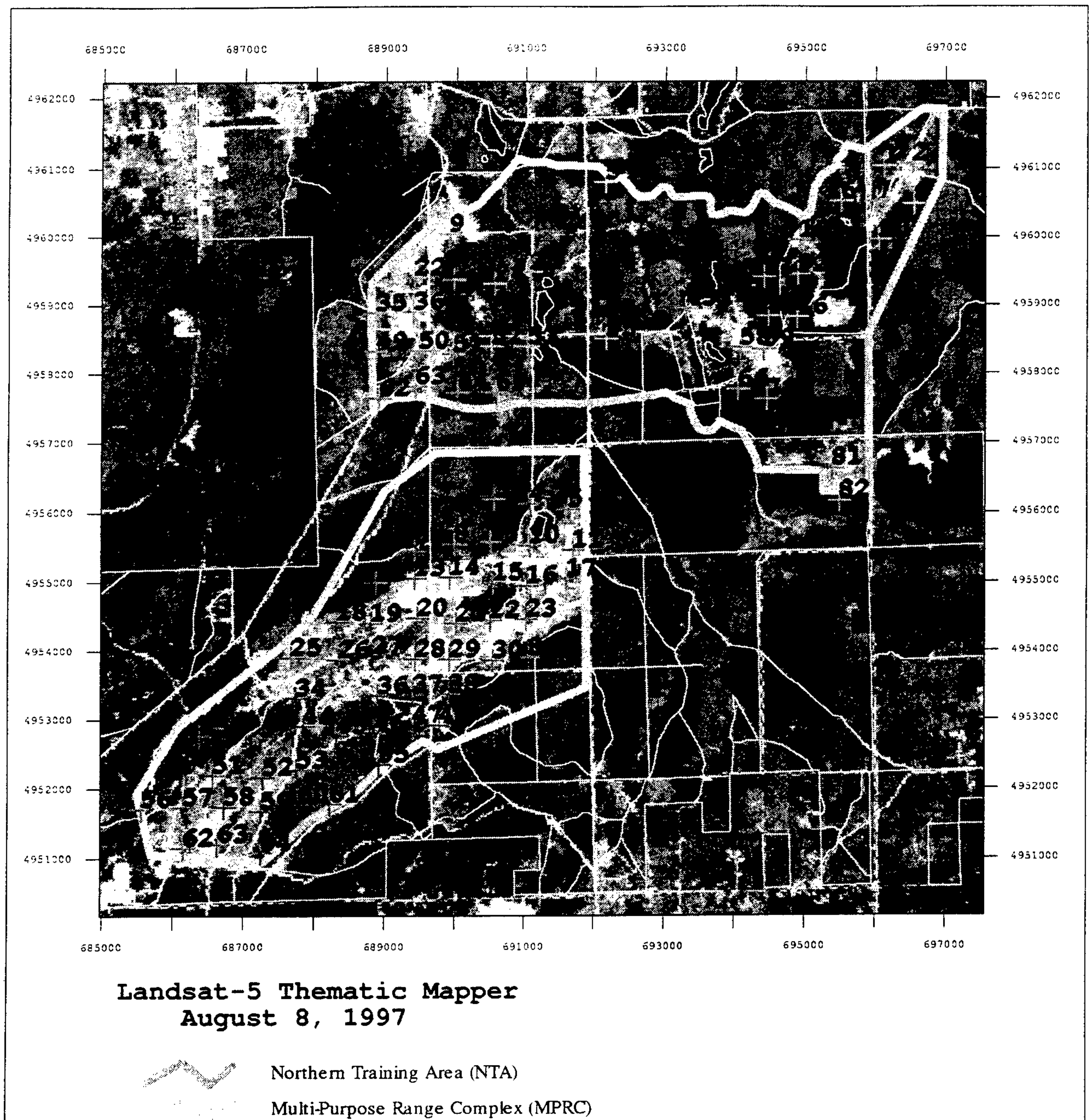

Figure 2. Study areas at Camp Grayling.

3 Methods

Remote Sensing

Image Pre-processing

Image acquisition

The original target date for image acquisition was coincident with field survey dates, which were 30 June 1997 through 11 July 1997. Header information for this image is included in Appendix A. However, three of the images (22 June, 8 July, and 24 July) were evaluated and determined to be unacceptable because of excessive cloud cover over the study site. The 8 August 1997 image was the closest available to the field collection dates without cloud cover and/or excessive haze over the installation.

Systematic noise correction

Periodic striping was apparent in bands 2 and 3 of the Landsat TM image, thus requiring correction. The correction was accomplished with a Fourier filter prior to georeferencing the image. The ERDAS Imagine Fourier correction routines were used to perform the corrections using the Fourier Editor and masking areas that showed frequency patterns determined to be those observed in the stripe pattern. A Gaussian filter was applied using a periodicity of 10, effectively correcting the striping without negatively affecting the original Digital Number (DN) values in the image (ERDAS Inc. 1997).

Georeferencing

The Landsat TM image was subsetted to approximate the installation boundaries and georeferenced to a previously acquired and georeferenced 25 August 1991 Landsat TM image. The scene was registered to (1) a Universal Transverse Mercator (UTM) coordinate system, (2) Clark 1866 Spheroid, and (3) NAD27 Datum, using a 1st order transformation, nearest neighbor resampling. The georegistration was accomplished with a sub-half pixel XY Root Mean Squared (RMS) error (< 15m). The georeferenced image was checked for accuracy by overlaying a vector roads layer, and by visually checking Global Positioning System (GPS) field plot locations with known natural and man-made geographic features.

Image Classification

The 8 August 1997 georeferenced Landsat-5 TM scene was subsetted to an area covering the entire geographic study area at Camp Grayling, MI (Figure 2). An ERDAS Imagine Area of Interest (.aoi) file, which delineated the MPRC study area and the NTA study area was used to create a separate subset for each study area. An unsupervised classification was performed on each of the subsetted areas using the ISODATA classification routine in ERDAS Imagine. The following parameters were used during the classification process:

Number of Classes: 5
Maximum Iterations: 6
Convergence Threshold: 0.950
Initializing Option Along: Principle Axis
Scaling Range: Std. Deviations: 1.00

Vegetation Index Calculation

Green healthy vegetation is characterized by strong chlorophyll absorption and low reflectance in red wavelengths (RED) and high reflectance in the near infrared wavelengths (NIR) of the electromagnetic spectrum (Kauth et al. 1978; Tucker 1979; Curran 1980). Therefore, spectral reflectance in the red region of the spectrum is inversely proportional to in situ chlorophyll density and biomass production of a plant. Conversely, spectral reflectance in the near infrared region of the spectrum is directly proportional to green leaf density and plant biomass (Curran 1980; Tucker et al. 1981; Walsh and Bian 1988).

Various ratios and linear combinations of reflectance in red and near infrared wavelengths are commonly used to calculate vegetation indices (Satterwhite 1984; Heilman and Boyd 1986; Lillesand and Kiefer 1987; Campbell 1987). Vegetation indices have been developed to reduce multispectral scanner data to a single number or index, for the purpose of qualitatively and quantitatively assessing vegetation conditions (Tucker 1979). Vegetation indices calculated from satellite imagery represent *relative* amounts of vegetative characteristics such as percent cover or biomass. To quantify an estimate of percent cover or biomass, an empirical relationship must be established between satellite-based vegetation index values and corresponding field measurements. Several empirical relationships between satellite image-derived vegetation indices and ground measures of vegetation and soil conditions have been identified. A Ratio Vegetation Index

(RVI), computed as NIR/RED, and a Normalized Difference Vegetation Index (NDVI), computed as NIR - RED/NIR + RED, have been highly correlated with vegetation parameters such as leaf area index (Richardson and Wiegand 1977; Law and Waring 1994), leaf water content (Dave 1980), and green leaf biomass and dry matter (Tucker 1979; Anderson, Hanson, and Haas 1993; Pickup, Chewings, and Nelson 1993). Similar relationships between vegetation index values and field surveys of vegetative cover have been established at several military installations in different ecological settings (Zhuang, Shapiro, and Bagley 1993; Wu and Westervelt 1994; Senseman, Bagley, and Tweddale 1996). Of these parameters, percent cover and biomass are of greatest interest and utility to military trainers and resource managers.

Vegetation indices analyzed in this study were calculated using spectral reflectance data recorded in the red (band 3) and near infrared (band 4) wavelengths of the TM sensor. The vegetation indices were calculated directly from the subsetted non-georeferenced TM subset, and therefore were not calculated using resampled pixels. The resulting vegetation index images were then georeferenced using the Transformation Matrix calculated previously. This procedure was followed to avoid a transformation of DN values in the image due to resampling that occurs during the georectification process.

Indices tested included: the NDVI (Rouse et al. 1973), the Transformed Normalized Difference Vegetation Index (TNDVI) (Deering et al. 1975), the Ratio Vegetation Index (Tucker 1979), and the Modified Soil-Adjusted Vegetation Index (MSAVI) (Qi et al. 1994). All indices appeared to detect the variability in vegetative cover across the study area, and each of the indices was determined to be equally suitable for the intended analysis. Therefore, the TNDVI was selected for further analysis. The TNDVI is a transformation of the NDVI, which is the most commonly used vegetation index. NDVI is a ratio vegetation index that exploits the differences in reflectance characteristics between green vegetation and other land cover components (Equation 1) (Rouse et al. 1973). TNDVI is simply a transformation of NDVI that adds 0.5 to avoid negative values and applies a square root function to stabilize variance (Equation 2) (Deering et al. 1975).

NDVI = TM Band4(NIR) – TM Band3(Red)/TM Band4(NIR) + TM Band3(Red) [Eq 1]

TNDVI = SQRT ((TM Band4(NIR) – TM Band3(Red)/TM Band4(NIR) + TM Band3(Red)) + 0.5) [Eq 2]

Field Data Collection

Before allocating plots for the collection of field data, the exact boundaries had to be established for the two training areas selected for study (MPRC and NTA). This task was accomplished through consultations with installation natural resource staff and a preliminary field reconnaissance. The fence that controls access to the MPRC was selected as the most logical boundary for the MPRC (Figure 2). The boundaries of the NTA were identified by Camp Grayling range control personnel and refined through preliminary field reconnaissance. The number of Land Condition Trend Analysis (LCTA) plots present within the study area was then determined. There were 12 LCTA plots within the NTA and 5 within the MPRC. The number of LCTA plots was considered insufficient for the purposes of developing a statistical correlation between imagery-derived vegetation indices and LCTA field measurements due to an insufficient sample size. Therefore, specific field survey methods were developed to accomplish the objectives of the study.

Plot Allocation

A systematic sample design was used to allocate field plots. Systematic sampling involves the placement of sample plots at fixed, regular intervals, originating from a randomly selected starting point (Thompson 1992). Systematic sampling is considered desirable for use in describing vegetation patterns because it samples evenly across populations (Krebs 1989). Plots were located at the intersections of a 550-m by 550-m grid within the boundaries of the two survey regions. This sample design resulted in 64 plots being allocated within the 2041-ha MPRC and 82 plots allocated within the 2567-ha NTA.

Plot Location

Vegetation data were collected for a 2-week period that commenced on 30 June 1998 and terminated on 12 July 1998. The field crew was provided UTM coordinates to the grid intersections and navigated to the approximate locations using GPS. (Due to the selective availability of the GPS satellites, navigation to plot locations was approximate.) Exact locations were to be determined by differentially correcting GPS coordinates collected in the field. However, there were difficulties associated with the base station files. Therefore, coordinates collected in the field were averaged to obtain the final plot locations. Each plot was permanently marked with an orange plastic stake to assist in relocating the plots at a later date.

Plot Survey Methods

Once the plot location was identified, the site was preliminarily classified based on the physiognomy of the surrounding vegetation. The preliminary classifications were based on The Nature Conservancy's (1994) *Standardized National Vegetation Classification System (SNVCS).* The physiognomic levels of the SNVCS have been adopted as the standard by the Federal Geographic Data Committee (1996). A forest was defined as having 60 percent or more total vegetative cover above 5 meters, a woodland as having 25 to 59 percent total vegetative cover above 5 meters, a sparse woodland as having 10 to 24 percent total vegetative cover above 5 meters, and a grassland/shrubland as having less than 10 percent total vegetative cover above 5 meters. The preliminary classification dictated which field methods were used. An expanded plant community classification key, based on the SNVCS and lifeforms of the dominant vegetation can be found in Appendix B.

Forest and woodland classes

The following data collection technique was used if the plot was physiognomically classified as a forest or woodland. Total vegetative cover was visually estimated, using a modified Braun-Blanquet cover abundance scale (Table 1) for the tree stratum (5 + meters), shrub stratum (1 to 5 meters), and herb stratum (0 to 1 meter) at four locations (Mueller-Dombois and Ellenberg 1974). These four locations were 5 meters from the permanent stake in each cardinal direction. In addition, cryptogamic cover (mosses, lichens, and liverworts), cover of organic debris (duff, leaf litter, roots, branches, etc.), and bareground (mineral, soil, and rocks) were visually estimated using the same cover scale. Dominant species, in terms of cover, in each stratum were also identified.

Table 1. Modified Braun-Blanquet cover abundance table used to estimate aerial vegetative cover.

Aerial Vegetative Cover	Cover Class	Class Midpoints
95-100%	6	97.5
75-95%	5	85.0
50-75%	4	62.5
25-50%	3	37.5
5-25%	2	15.0
1-5%	1	2.5
Several, cover less than 1%	+	1.0
Rare	r	0.5

Open and sparse woodland classes

The following data collection technique was used if the plot was physiognomically classified as herbaceous or sparse woodland. Military land mangers believed that the open and sparse woodland physiognomic classes would experience the greatest change in vegetative cover due to changes in training patterns. Consequently, a more detailed method of data collection was used. A 400-m^2 base plot was constructed and a 5-m by 5-m grid was superimposed on the base plot (Figure 3). At each grid intersection, including boundaries, a 1-m^2 quadrat was placed. The vegetative cover below 1 meter was estimated in each subquadrat using the Braun-Blanquet cover abundance scale (Table1). Total cover of cryptogamic flora, organic debris, and bare ground were also visually estimated in each subquadrat using the same cover scale. This data collection method is a more detailed version of the method described by Daubenmire (1959); similar methods have been used by Anderson, Hanson, and Haas (1993) and Dymond et al. (1992) to interpret remote sensing imagery. Total vegetative cover for the shrub stratum and tree stratum (if applicable) was visually estimated in the same manner as described for the forest and woodland physiognomic classes. Dominant species in each stratum within the base plot were also identified.

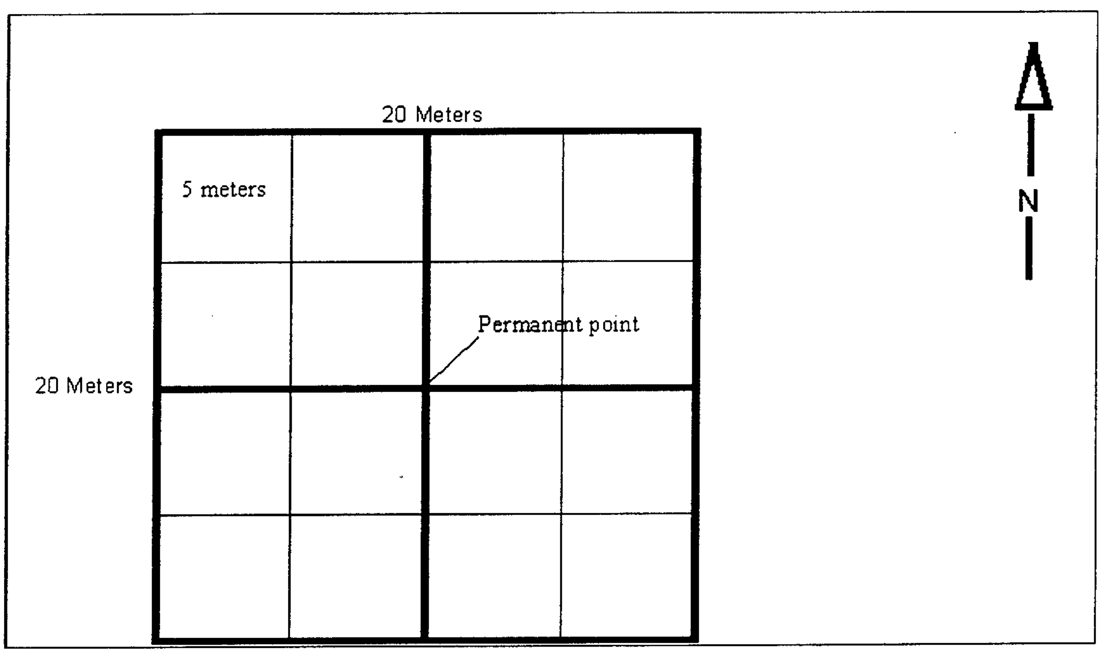

Figure 3. Plot layout used to collect data on plots classified as herbaceous or sparse woodland.

Field Data Summary

The relatively short time period that was available for the collection of field data (30 June through 12 July) did not allow sufficient time for the survey of all 146 allocated plots. Because the open and sparse woodland physiognomic classes were considered to be of higher priority, all of the plots located within these two physiognomic classes were sampled first. The remaining plots were surveyed as time allowed. The UTM locations of the allocated field plots that were not surveyed can be found in Appendix C. Appendix D provides the step-by-step procedures for constructing a field plot.

Forest and Woodland Classes

Plot data was summarized in the following manner. Arithmetic means were calculated for: tree stratum cover (TRC), shrub stratum cover (SC), herbaceous stratum cover (HC), organic cover (OC), cryptogamic cover (CC), and bare ground cover (BG) using the class midpoints of the corresponding cover class (Table 1) as data. Total vegetative cover (TVC) was subsequently calculated by summing mean vegetative cover of the tree, shrub, and herb strata. Visible bare ground (VBG) was calculated by subtracting total vegetative cover from 100. VBG represented bare ground that would potentially be visible if the plot was viewed from above (e.g., satellite imaging). Total cover (TC) was calculated by summing the mean values of all measured variables with the exception of BG. Two additional field variables, total vegetative cover + cryptogamic cover (TVCC) and total vegetative cover + organic cover (TVOC), were also calculated. Table 2 summarizes the methods used to calculate the various field variables in the forest and woodland physiognomic classes.

Table 2. Summary of the methods used to calculate the various field variables in the forest and woodland physiognomic classes.

Field Variable	Method of Calculation
Tree Stratum Cover (TRC)	$\sum(TRC_1 \ldots TRC_4)/4 =$ TRC
Shrub Stratum Cover (SC)	$\sum(SC_1 \ldots SC_4)/4 =$ SC
Herbaceous Stratum Cover (HC)	$\sum(HC_1 \ldots HC_4)/4 =$ HC
Organic Cover (OC)	$\sum(OC_1 \ldots OC_4)/4 =$ OC
Cryptogamic Cover (CC)	$\sum(CC_1 \ldots CC_4)/4 =$ CC
Bare Ground (BG)	$\sum(BG_1 \ldots BG_4)/4 =$ BG
Total Vegetative Cover (TVC)	TRC + SC + HC = TVC
Visible Bare Ground (VBG)	100 - TVC = VBG
Total Vegetative Cover + Cryptogamic Cover (TVCC)	TVC + CC = TVCC
Total Vegetative Cover + Organic Cover (TVOC)	TVC + OC = TVOC
Total Cover (TC)	TRC + SC + HC + OC + CG = TC

Open and Sparse Woodland Classes

Because of more intensive data collection techniques, data from the open and sparse woodland physiognomic classes were subjected to a more rigorous statistical examination than the forest and woodland physiognomic classes. Data from the shrub and tree strata within the open and sparse woodland physiognomic classes were summarized in the same manner as the forest and woodland physiognomic classes. The arithmetic mean of HC, CC, OC, and BG were calculated from the 25 subquadrats within each base plot. Total vegetative cover was subsequently calculated by summing the mean vegetative cover of the tree (if present), shrub (if present), and herb strata. Visible bare ground was calculated by subtracting total vegetative cover from 100. The field variables TVCC and TVOC were calculated in the same manner as described above. Table 3 summarizes how each field variable was calculated in the open and sparse woodland physiognomic classes.

Table 3. Summary of the methods used to calculate the various field variables in the open and sparse woodland physiognomic classes.

Field Variable	Method of Calculation
Tree Stratum Cover (TRC)	$\sum(TRC_1 \ldots TRC_4)/4 =$ TRC
Shrub Stratum Cover (SC)	$\sum(SC_1 \ldots SC_4)/4 =$ SC
Herbaceous Stratum Cover (HC)	$\sum(HC_1 \ldots HC_{25})/25 =$ HC
Organic Cover (OC)	$\sum(OC_1 \ldots OC_{25})/25 =$ OC
Cryptogamic Cover (CC)	$\sum(CC_1 \ldots CC_{25})/25 =$ CC
Bare Ground (BG)	$\sum(BG_1 \ldots BG_{25})/25 =$ BG
Total Vegetative Cover (TVC)	TRC + SC + HC = TVC
Visible Bare Ground (VBG)	100 - TVC = VBG
Total Vegetative Cover + Cryptogamic Cover (TVCC)	TVC + CC = TVCC
Total Vegetative Cover + Organic Cover (TVOC)	TVC + OC = TVOC
Total Cover (TC)	TRC + SC + HC + OC + CG = TC

Combined Remote Sensing/Field Surveys for Monitoring

Field surveys and remotely sensed imagery were used to develop an initial inventory of vegetation cover. Field survey information was used to quantify vegetation cover at individual sample sites. TNDVI values derived from TM imagery provided *relative* differences in vegetation cover across the study area. To increase the utility of TNDVI, vegetation index values were calibrated or correlated with ground-based sample data. Calibrating the vegetation index with ground data resulted in the transformation of each pixel value from a *relative*, dimensionless number to an absolute value of percent vegetative cover.

Spatial Coregistration

The accurate spatial coregistration of both data sets was critical to linking ground-based sample data with remotely sensed imagery. GPS technology was used to locate ground-based sample plots and spatially coregister these sample sites to corresponding pixels in the satellite imagery and TNDVI image. Ground-based sample sites and sizes were also designed to minimize spatial coregistration error to the extent possible. Sample sites were 20-m by 20-m, while TM pixels were 30-m by 30-m.

Due to difficulties with differential correction of sample site locations, there were some observed spatial misregistration errors. These known registration errors were assumed to have minimal effect on the correlation analysis because of sample design. In some isolated cases, a spatial misregistration error would occur in close proximity to an ecotonal boundary in the field. In these cases, there was potential for an incorrect pairing of field observations with corresponding vegetation index pixel values. Sample points at which this type of error occurred were easily identifiable and removed from further analysis. Several corrective measures were tested to ensure that spatial misregistration was not introducing any additional error into the correlation analysis.

GPS technology is sometimes prone to systematic error, either as a result of errors in initializing equipment in the field or problems with base station data. Systematic errors of this type cause all GPS coordinates to be shifted by a constant amount in one or both directions. Visual examination of ground-based sample sites displayed on top of satellite imagery, along with field notes and observations by the field crew, confirmed that this type of error did not occur. A neighborhood filter called Focal Analysis within ERDAS Imagine was also applied to the data to confirm this observation (ERDAS Inc. 1997). Focal Analysis within an image processing system involves the use of a moving filter or window that applies a neighborhood function to a small group of pixels within an image. For each iteration, the moving window is shifted one pixel, and the same neighborhood function is then applied to a new group of pixels. Focal Analysis was used for a 3-by-3 matrix or roving window (9 pixels). Focal Analysis allowed for "shifting" the field sample points in eight different directions when pairing that data with the corresponding vegetation index pixel. This test was conducted to determine if a constant shift in any given direction resulted in higher correlation between ground-based measurements of cover and vegetation index values. The technique tested is referred to as the Focal Analysis technique throughout this document.

A second potential source of spatial misregistration error results from simple differences between raster- and vector-based GIS and image processing software packages. GPS observations provide exact coordinates for a single observation point, while raster-based GIS and image processing packages spatially reference data by pixel location within a predefined grid. When importing field plot GPS point data to a raster GIS or image processing package, a shifting of some plot locations occurs when "fitting" GPS coordinates to a fixed raster grid of pixels, which in this case was a 30-meter grid (TM spatial resolution).

A Weighted Averaging method was developed and tested to mitigate this shifting effect. The plot identification number and XY coordinate for each ground-based sample point was imported to Arc/Info GIS (a product of ESRI, Redlands, CA) to create a points file in a vector format, which prevented shifting from occurring. A buffering routine was used to create a 10-meter radius arc around each point, effectively creating a vector polygon that matched the field sample size. The arc buffer polygon was overlaid on the TNDVI vegetation index image. Percent coverage of each pixel with respect to the total area of the buffer polygon was recorded. Based on the percent cover of each pixel within the buffer area, a weighted average was applied to the TNDVI values. The ground-based sample was not paired with a single TNDVI pixel value, but with a weighted average of all TNDVI pixels that fell within the actual sample point on the ground. In some cases, the GPS coordinate fell exactly within the center of a single pixel, and the weighted averaging had no effect on spatial coregistration. In other instances, the ground-based sample actually fell close to a corner of a pixel, and effectively overlapped as many as four different pixels in the vegetation index image (Figure 4). In this case, the weighted average of TNDVI values from each of the pixels effectively provided a single TNDVI value that represented the proportional variation in TNDVI values for all of the pixels involved. This method is referred to as the Weighted Averaging technique throughout this document.

A third method was also tested for the purpose of mitigating known spatial misregistration errors resulting from shifts while importing GPS coordinate data to raster-based systems. GPS coordinates were imported directly into ERDAS Imagine, resulting in "shifting" to fit GPS coordinates to a fixed raster grid of pixels. Instead of applying a weighted average to pixels within the sample area, a Focal Analysis routine similar to that described earlier was used to calculate local averages for TNDVI pixel values. In this case, a 3-by-3 matrix or roving window (9 pixels) was applied to the TNDVI image to calculate the local or neighborhood average within the roving window. The local average of 9 pixels within a roving window was applied to the center pixel of the neighborhood. For each iteration, the roving window was shifted 1 pixel and the same average was calculated and applied. The resulting output image from this analysis is a

TNDVI image with each pixel representing a local average of original TNDVI values for the surrounding 8 pixels. Similar in concept to Weighted Averaging, the Focal Analysis captures the variation in local TNDVI pixel values that were within the location of the ground-based sample point. This method is referred to as the Mean Filtering technique throughout this document.

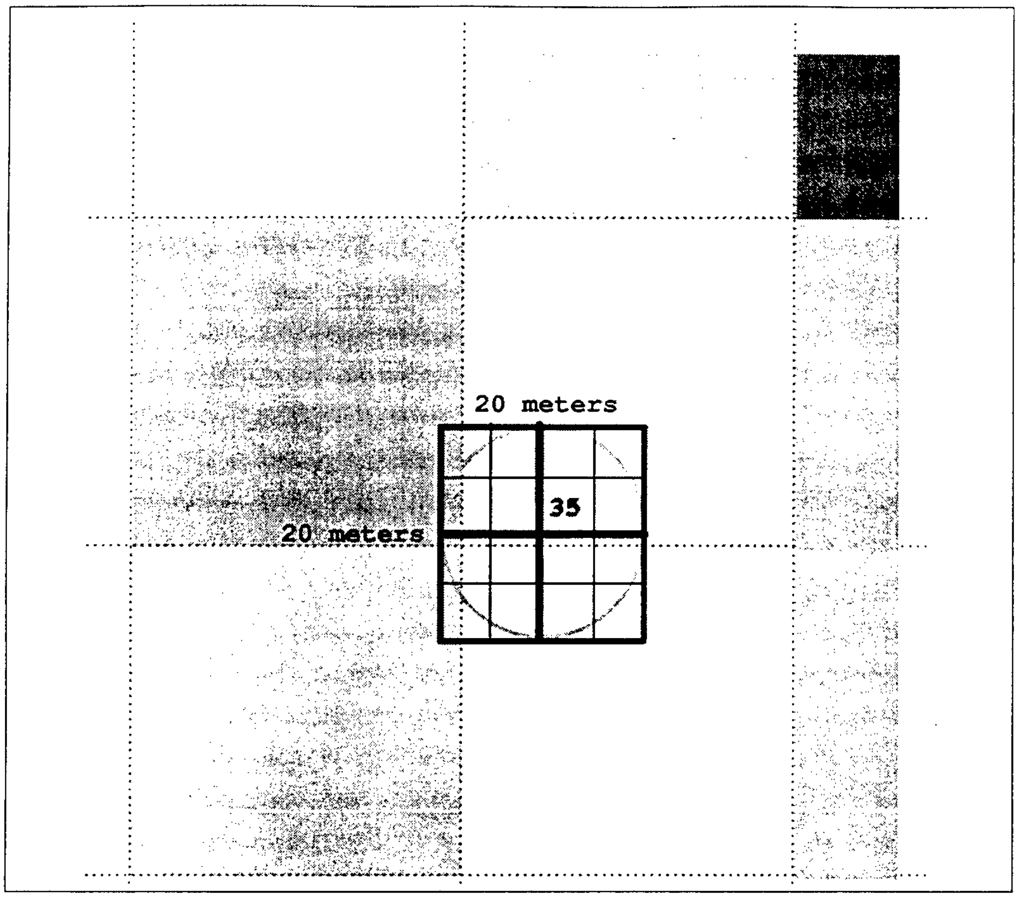

Figure 4. Example of spatial coregistration between the vector file of a field sample and the raster file of a satellite image.

Regression Analysis

Once several methods were tested to mitigate the effect of spatial misregistration errors, a simple statistical correlation was applied to imagery-derived vegetation indexes and paired field-based measures of the vegetation. This process was necessary to determine the direct relationship between TNDVI values derived from imagery and a number of field-based measurements of vegetative cover. The least squares fitting algorithm found in the MINITAB statistical software package (Minitab, Inc. 1992) was used for regression analysis. The relationship between TNDVI values and field-based measurements was then evaluated by determining the existence of linear relationships and evaluating coefficients of determination (R^2) between TNDVI values for a number of different field measurements. Ground-based samples within the MPRC and the NTA were first analyzed separately, and then were pooled together.

Once correlation analysis successfully identified a relationship between the vegetation index value (independent variable) and vegetative cover (dependent variable), the regression equation was applied to every pixel in the TNDVI image, resulting in new pixel values that were calibrated to ground-based vegetation measurements.

4 Results and Discussion

Remote Sensing

Image Classification

An unsupervised classification was applied to a subset of the 8 August 1997 Landsat-5 TM scene covering the MPRC and NTA study areas at Camp Grayling, MI. An Area of Interest file that outlined the MPRC and the NTA study areas was used to create a separate subset for each study area (Figure 2). An unsupervised classification was performed on each of the subsetted areas using the ISODATA classification routing in ERDAS Imagine, resulting in a separate land cover map for both the MPRC (Figure 5) and the NTA (Figure 6). Physiognomic class and subclass observations recorded for each field sample site were used to assign a land cover classification to each of the five land cover classes. The initial field classifications for each sample site were based on the SNVCS developed by The Nature Conservancy (1994) and adopted by the Federal Geographic Data Committee (1996). The five classes represent not only differences in land cover type, but also vegetative cover.

Vegetation Index

Spectral bands 3 (red) and 4 (near infrared) of the 8 August 1997 Landsat-5 TM subset were used to calculate TNDVI according to Equation 2. A TNDVI value was calculated for each pixel within the MPRC (Figure 7) and NTA (Figure 8).

The TNDVI images of both the MPRC and NTA clearly identify areas of varying vegetative cover amounts. Dark areas in these images represent areas of relatively low vegetative cover, while bright areas represent areas of relatively high vegetative cover. A gray scale is most commonly used to portray vegetation index values because they represent *relative* rather than *absolute* differences in vegetation cover between individual pixels in the image.

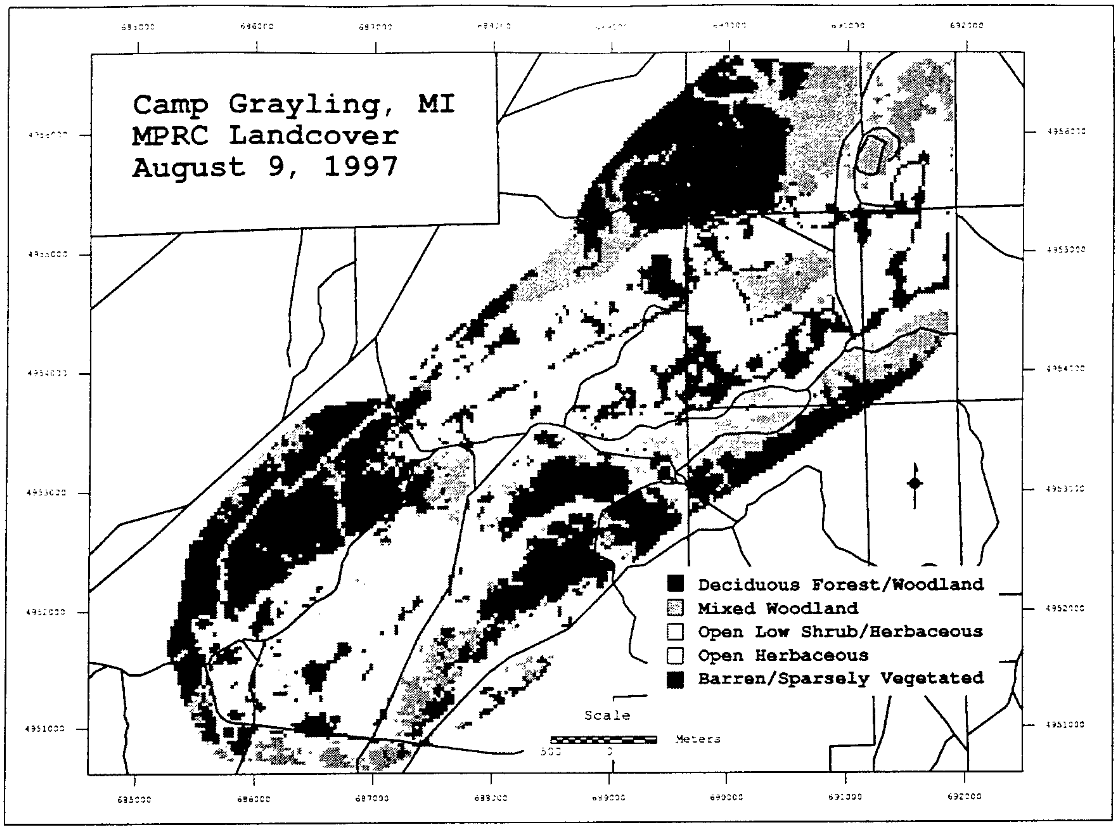

Figure 5. Land cover map for the MPRC.

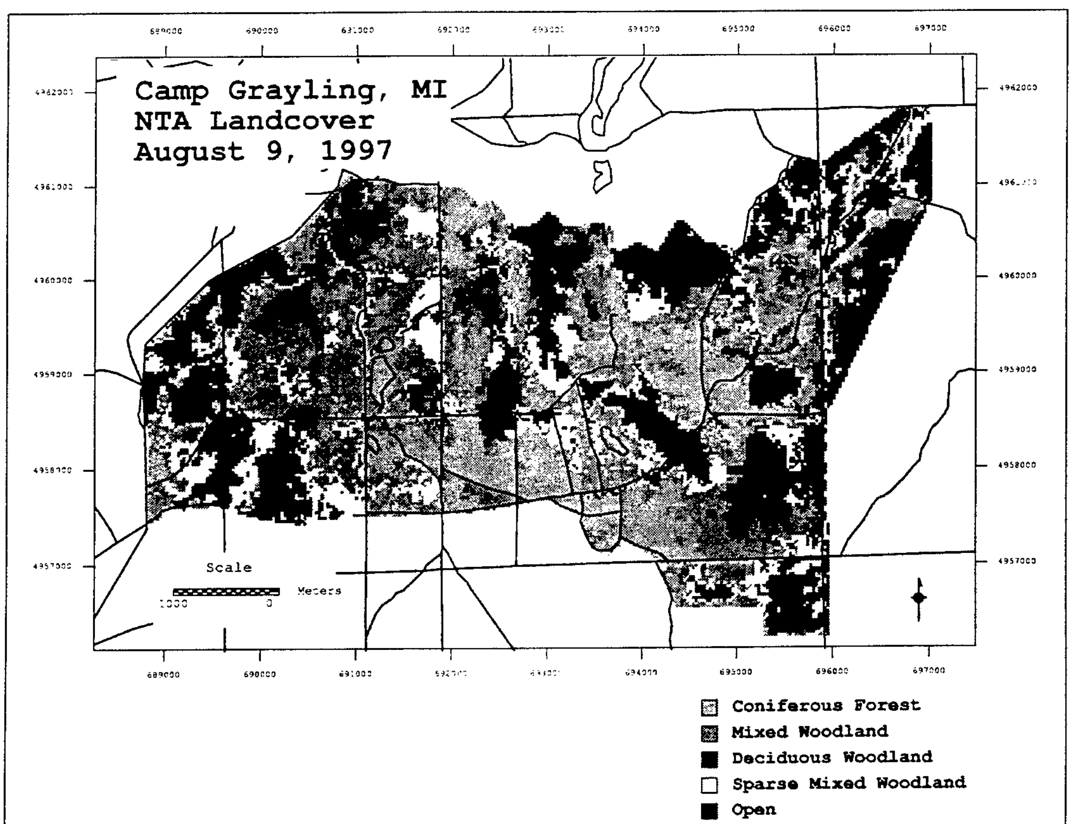

Figure 6. Land cover map for the NTA.

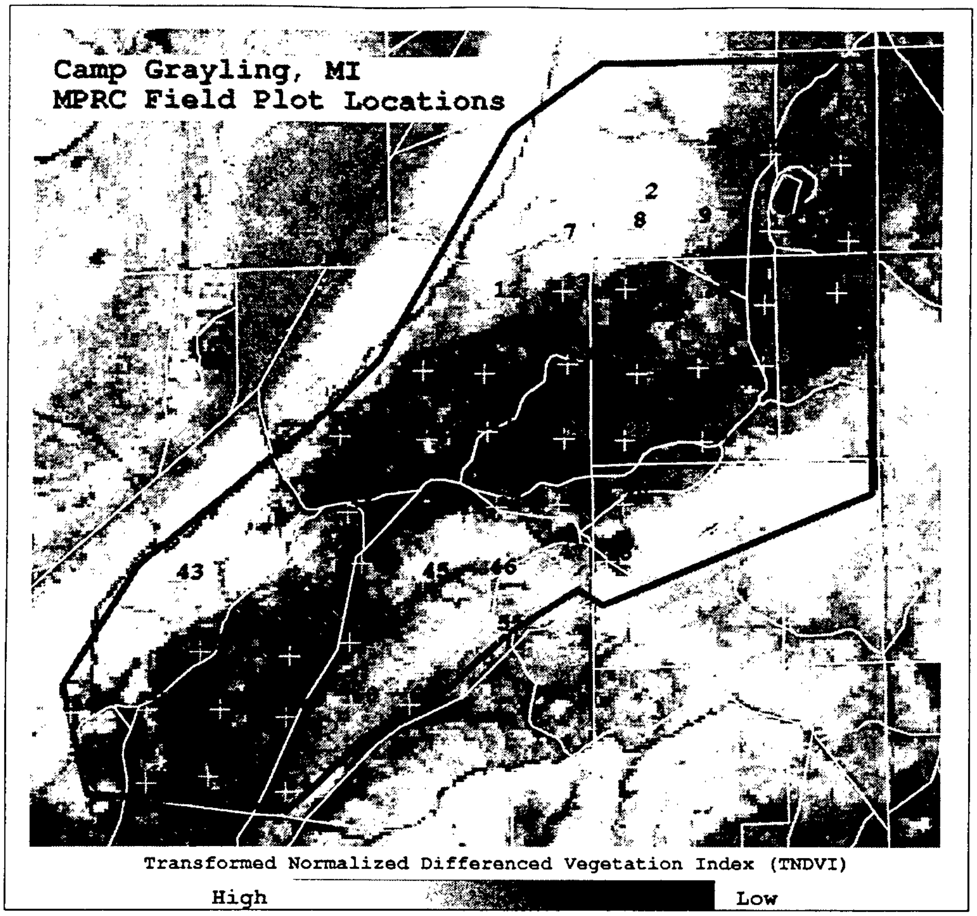

Figure 7. TNDVI map for the MPRC.

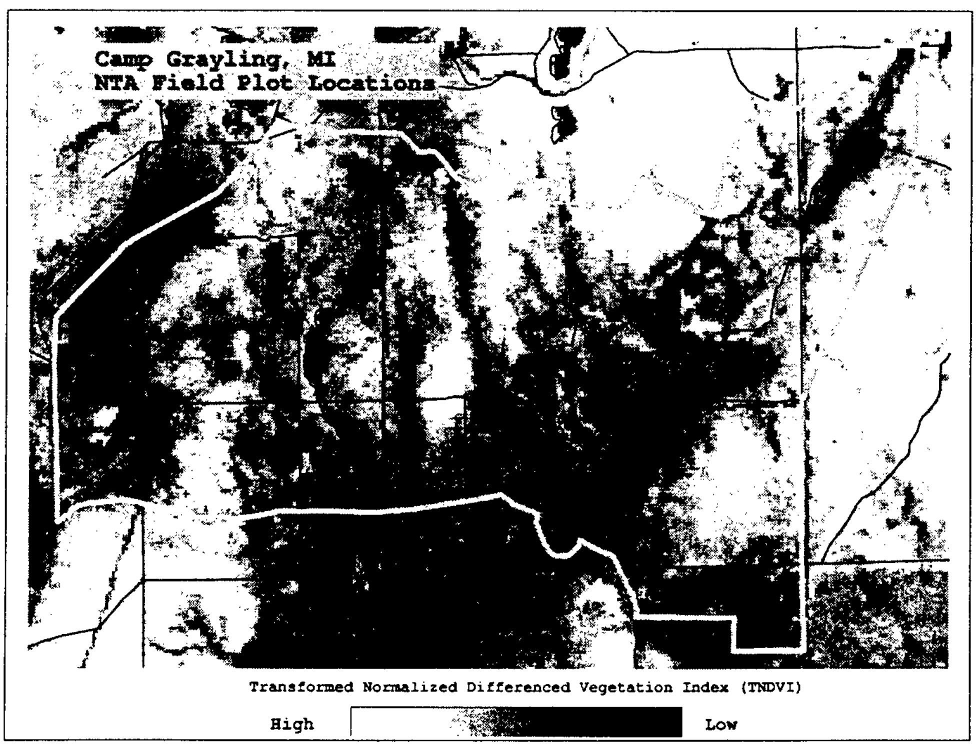

Figure 8. TNDVI map for the NTA.

Within the MPRC area, new roads and forest compartments are clearly visible as dark patterns in the TNDVI image, indicating relatively sparse cover, or in some cases, bare ground (Figure 7). Within the NTA, four highly disturbed areas are clearly visible as dark areas, indicating relatively low or sparse vegetation cover. Water bodies also typically result in low vegetation index values, and also appear as dark features in vegetation index images. Contrasting bright areas in the NTA clearly identify high vegetation cover in areas such as closed canopy deciduous and coniferous forests (Figure 8).

The TNDVI images provide a synoptic overview of current relative vegetative cover amounts for the entire study area. Compilation of a temporal sequence of future TNDVI images will provide a measure of changing patterns in relative vegetative cover.

Field Data

Table 4 lists the mean values* of the field variables with the exception of TVCC and TVOC. The results from the field data were what was intuitively expected. The forest and woodland physiognomic classes had the highest cover in all vegetative strata and very little BG and VBG. Conversely, the open and sparse woodland physiognomic classes had lower cover values and higher BG and VBG. Four field variables showed significant differences between the MPRC and the NTA. In the open physiognomic class there was significantly more HC in the NTA. This likely was the result of the activities associated with the construction of the MPRC and may be expected to change in the future. In addition, TVC was also significantly higher at the $P<0.05$ level in the open physiognomic class in the NTA. Conversely, OC was significantly higher for both the open and sparse woodland physiognomic classes in the MPRC. The high OC in the MPRC was the result of the tree-clearing activities associated with the construction of the MPRC that left branches and other woody debris. TC for all four physiognomic classes did not differ significantly between the NTA and the MPRC.

* TVCC = total vegetative cover + cryptogamic cover; TVOC = total vegetative cover + organic cover; BG = bare ground; VBG = visible bare ground; HC = herbaceous cover; TVC = total vegetative cover; OC = organic cover; TC = total cover; SC = shrub stratum cover; CC = cryptogamic cover.

Table 4. Comparison of mean values of the cover variables stratified by physiognomic class.

Field Variable		Open	Sparse woodland	Woodland	Forest
TRC	*MPRC*	0.000	24.687	43.333	70.938
	NTA	0.667	20.469	45.125	67.708
SC	*MPRC*	4.750	10.000	29.375	31.406
	NTA	4.000	18.125	32.000	32.292
HC	*MPRC*	32.147	46.400	58.400	61.875
	NTA	47.700 *	46.175	72.540	69.167
TVC	*MPRC*	36.897	81.088	131.108	164.219
	NTA	52.367 *	84.769	149.665	169.167
CC	*MPRC*	9.153	14.500	9.033	0.000
	NTA	10.613	7.500	35.320	30.000
OC	*MPRC*	49.033 *	60.125 *	72.633	85.00
	NTA	10.613	8.700	35.320	53.33
BG	*MPRC*	18.140	16.663	0.733	0.000
	NTA	11.316	7.650	0.013	0.000
VBG	*MPRC*	63.103	18.275	0.000	0.000
	NTA	47.633	19.913	0.000	0.000
TC	*MPRC*	104.896	155.467	212.775	249.219
	NTA	110.680	124.817	257.525	268.333

* Values are significantly different at $P<0.05$ level.

Regression Analysis

Initially, exploratory regression analysis was conducted to determine the effect and magnitude of potential spatial misregistration problems that could weaken the relationship between ground-based measurements of cover and vegetation index values derived from remote imagery. Four different methods of coregistration between field and image data were tested using regression analysis: (1) Pixel-to-Pixel, (2) Focal Analysis, (3) Weighted Averaging, and (4) Mean Filtering.

Coefficients of determination were analyzed for each of the four coregistration methods for all field measures (dependent variables) and the TNDVI (independent variable). The Pixel-to-Pixel method of coregistration involved no corrections for potential coregistration errors. This coregistration method resulted in R^2 values ranging from 1.7 for CC to 63.7 for TVOC. Most field measures exhibited a modest correlation with TNDVI using the Pixel-to-Pixel coregistration method. However, it was assumed that spatial misregistration had occurred to a certain extent, and acted to decrease the strength of the relationship between field measures of cover and image-derived estimates.

Focal Analysis results were analyzed to determine if there was a constant shift in GPS coordinates for sample site locations as a result of potential systematic error in differential correction. Results from the Focal Analysis did not indicate an increase in correlation between field measurements and image-derived estimates when shifting the field plot location by one pixel in all possible directions. If a systematic shift or error occurred while collecting GPS coordinates for ground-based sample sites, the corresponding Coefficient of Determination should have been consistently higher in one shift direction. Since this was not evident, it was assumed that a systematic error in GPS coordinate collection did not occur.

Although a systematic error most likely did not occur, there was still a possibility of random error in GPS coordinates for field sample sites, which would also cause spatial misregistration between data sets and would result in a decrease in the strength of the relationships between ground measures of cover and estimates derived from vegetation indices.

Weighted Averaging was also analyzed for all field measures (dependent variables) and TNDVI (independent variable). Coefficients of determination were actually lower for the Weighted Averaging method than for the Pixel-to-Pixel method. A possible explanation for this weak relationship may be that weighted averages were incorrectly applied due to human error in observation and estimation. Because of relatively weak relationships demonstrated by using the Weighted Averaging coregistration approach, this method was eliminated from further consideration.

Mean Filtering was also tested in a similar fashion and resulted in the strongest relationship between ground-based measures of vegetative cover and vegetation index values for the four coregistration techniques tested. Mean Filtering improved the strength of the correlation between all field measurements of cover and TNDVI values for the MPRC, with the exception of BG and CC (Table 5). Adjusted R^2 values ranged from 1.2 for CC to 70.5 for TVOC. These improvements in strength of correlation indicate that Mean Filtering was indeed mitigating the problem of spatial misregistration.

For some field measurements such as CC, the extremely low correlation between the field measure and TNDVI value can be attributed to the limitations of the Landsat TM sensor. Although variations in cryptogamic crusts were observed during field sampling, these same variations were not detectable with TM imagery. Within an individual TM 30-m data element or pixel, a single reflectance value is recorded for each wavelength. The 30-m area on the ground that is observed by the sensor for each pixel may be a heterogeneous mix of land cover types, each contributing a fraction of the total reflectance that is recorded by the TM sensor. Within any certain wavelength of the TM sensor, there may not be sufficient spectral contrast between land cover types within the same pixel, and therefore, it would be impossible to differentiate between land cover types using remotely sensed spectral information. In addition to a lack of spectral contrast, the spatial resolution of the TM sensor (30-m) may also be a limiting factor. Assuming that a heterogenous mix of land cover types exist within a single pixel, land cover types that cover the most geographic area within the pixel tend to dominate the spectral response recorded by the sensor. Plant communities are distributed spatially across the pixel area, but they are also stratified vertically. Therefore, due to the nature of the downward-looking TM sensor, those land cover or vegetation types that dominate the highest vertical strata within a pixel also tend to dominate the spectral reflectance recorded by the satellite. Since TNDVI is calculated directly from reflectance data, these same limitations also affect vegetation index values. Cryptogamic cover was typically sparse in comparison to cover of other lifeforms within the area of a single TM pixel and was always the lowest vertical strata of cover. For these reasons, essentially no relationship between vegetation index values and field measurements of CC was identified. In general, measures of cumulative cover, which represent a summation of cover at several different strata, such as TVOC and TC, exhibited higher Coefficients of Determination than those measures of a single cover type or strata, such as SC or TRC.

Table 5. Coefficients of Determination between all field variables and TNDVI for the MPRC using four coregistration methods.

	Pixel-to-Pixel n=51	Pixel-to-Pixel n=45*	3x3 Mean Filter n=51	3x3 Mean Filter n=48**
Field Measure	Adjusted R^2		Adjusted R^2	
VBG	50	64.3	59.3	65.6
BG	42.6	53	42.2	48.7
CC	1.7	0	1.2	0
OC	61.2	66.1	63.1	69.1
HC	40.7	42.1	42.5	46.2
SC	33.5	33.5	38.3	39.7
TC	61.2	74.5	68.1	77.6
TVCC	50.3	64.3	58.5	66.7
TVOC	63.7	75.1	70.5	79.2
TVC	54.5	66.5	62.5	70.4
TRC	29.8	32.9	38.4	39.7

* Less Outliers (plot ID = 8, 10, 12, 44, 47, 48)

** Less Outliers (plot ID = 47, 48, 12)

The influence of vertical stratification of cover on vegetation index values is particularly evident when comparing results between BG and VBG. The difference in strength of correlation between these two dependent variables and TNDVI can be attributed to vertical stratification of cover. Measurements of BG did not take into account cover at higher strata. Large amounts of bare ground may have occurred at some sample points, but vegetative cover may have existed at higher strata. Therefore, reflectance observed by the TM sensor, and the corresponding TNDVI values calculated from this reflectance data, were heavily influenced by cover at higher strata, and did not correlate well with measured BG on the surface. Conversely, VBG represented effective bare ground as observed from looking downward from above the canopy. In this case, vegetative cover at any strata that would tend to mask underlying bare ground was measured and used to calculate "visible" bare ground measurements. In essence, this measure represented the amount of bare ground that was observable by the satellite, which explains the higher correlation between TNDVI and VBG (R^2=59.3) versus BG (R^2=42.2).

Mean Filtering also was found to be the optimal spatial coregistration method for the NTA. Coefficients of Determination were consistently higher for the Mean Filtering method than for Pixel-to-Pixel and Weighted Averaging methods. However, the overall strength of correlations between the various field measurements and TNDVI were consistently lower for the NTA compared to results for the MPRC. Again, the influence of vertical stratification of cover on vegetation index values was particularly evident within the NTA. Unlike the MPRC, where there was minimal tree canopy, the NTA contains more forest and woodland cover types. The increased cover at higher strata within forest and woodland areas may have effectively masked understory and ground cover to the extent that correlations were not as strong. In addition, the NTA was more heterogeneous than the MPRC. As heterogeneity in cover types increases, the possibility of "mixed" pixels increases, which may also decrease the strength of correlation between field measurements and vegetation index estimates of cover. This would explain, to some extent, the lower Coefficients of Determination for all dependent variables in the NTA. Adjusted R^2 values for the NTA ranged from 0.0 for OC to 50.0 for TVCC (Table 6).

Table 6. Coefficients of Determination between all field variables and TNDVI for the NTA using four coregistration methods.

	Pixel-to-Pixel n=36	Pixel-to-Pixel n=34*	3x3 Mean Filter n=36	3x3 Mean Filter n=34**
Field Measure	**Adjusted R^2**		**Adjusted R^2**	
VBG	36.1	43.3	42.1	49.1
BG	19.8	19.4	26.4	25.7
CC	10.6	12.7	12.8	14.1
OC	0.0	0.0	0.0	0.0
HC	43.4	47.1	45.9	49.7
SC	29.3	37.5	32.9	39.8
TC	34.2	43.4	36.8	44.5
TVCC	46.7	54.5	50.0	57.1
TVOC	26.0	35.3	27.7	35.3
TVC	42.8	51.9	45.4	53.5
TRC	23.4	29.9	23.9	29.4

* Less Outliers (plot ID = 5, 20)

** Less Outliers (plot ID = 5, 20)

A final corrective measure was tested to ensure that spatial misregistration was not introducing any additional errors in correlation analysis. Included in the results of each regression was a list of outliers as identified by the MINITAB statistical package. For each outlier plot that was identified, a visual examination was conducted to determine geographic location of the plot with respect to any ecotonal boundaries that were evident in the satellite image. As mentioned earlier, some field plots were located in close proximity to an ecotonal boundary in the field. Any slight registration error for these sample point locations could result in an incorrect pairing of field observations with corresponding vegetation index values. Through visual examination of plot location and examination of field notes for respective outlier plots, those outliers that fit these criteria were identified and eliminated from further analysis.

A total of three plots were removed from the 3X3 Mean Filter analysis for the MPRC as a result of this examination (Table 5). Five field measures of cover (BG, CC, HC, SC, and TRC) exhibited relatively low Coefficients of Determination, even after removing outliers. However, as expected, the strength of correlation between all field measures and TNDVI increased after removing outliers. The largest increase in R^2 occurred for TC and TVOC. After removing these outliers, TVOC had the highest coefficient of determination.

A similar process was used to remove two outliers from the 3X3 Mean Filter analysis for the NTA. Again, removal of these outliers improved correlations for most field measures. However, all independent variables exhibited low coefficients of determination, even after removing the outliers. Coefficients of Determination ranged from 0.0 for OC to 57.1 for TVCC (Table 6).

Correlation between field measures and TNDVI values was also analyzed by combining data from both the MPRC and NTA for regression analysis. Similar to analysis for the MPRC and NTA data, several different coregistration methods were analyzed and are summarized in Table 7. Again, Mean Filtering produced the best results for all spatial coregistration methods tested. After removing outlier plots, three cumulative cover measures (VBG, TC, TVC) exhibited the highest correlation with TNDVI values.

However, due to distinct differences between the MPRC and NTA, it is recommended that field results for the MPRC and NTA be analyzed separately for the purpose of spatially extrapolating cover estimates across these two areas using remotely sensed imagery. Because there are distinct differences in the types of land cover and the relative homogeneity of cover types in both areas, extrapolation of cover estimates based on correlation between field and vegetation index values should be based only on field measures collected within each area, rather than on a pooled database of field measures for both areas.

Table 7. Coefficients of Determination between all field variables and TNDVI for NTA and MPRC using four coregistration methods.

	Pixel-to-Pixel n=87	*Pixel-to-Pixel n=84**	*3x3 Mean Filter n=87*	*3x3 Mean Filter n=84***
Field Measure	**Adjusted R^2**		**Adjusted R^2**	
VBG	47.9	53.4	56.8	61.4
BG	37.3	38.9	38.9	43.4
CC	3.4	4.9	4.8	4.9
OC	7.1	8.5	6.1	5.3
HC	44.4	47.9	47.9	51.3
SC	34.2	36.2	39.1	41.8
TC	49.2	53.0	55.0	60.2
TVCC	40.6	44.8	47.3	51.0
TVOC	49.1	51.7	53.2	56.9
TVC	50.3	54.8	56.9	60.9
TRC	30.6	32.1	36.3	38.1

* Less Outliers (Plot ID = 5, 10 (MPRC), 47 (NTA))

** Less Outliers (Plot ID = 5 (MPRC), 47, 48 (NTA))

5 Conclusions and Recommendations

Conclusions

The initial survey of vegetative cover for the MPRC and NTA at Camp Grayling, MI, was successfully completed using a combination of field surveys and remotely sensed imagery. Field survey data and remotely sensed spectral vegetation indices were correlated to develop spatially explicit baseline data on vegetative cover within these areas.

Four spectral vegetation indices were calculated from satellite imagery to determine which index exhibited the highest correlation with various measures of vegetative cover collected in the field. The Transformed Normalized Difference Vegetation Index (TNDVI) was identified as the best performing index.

A systematic field sampling method was designed and used, resulting in 64 established plots in the MPRC and 82 plots in the NTA. The location of each plot was recorded using differential GPS and permanently marked with an orange plastic stake. Each site was preliminarily classified based on the physiognomy of the surrounding vegetation based on The Nature Conservancy's Standardized National Vegetation Classification System (SNVCS). The preliminary classification dictated which field methods were used. Two different data collection and data summarization techniques were used, one for forest and woodland plots and the other for open herbaceous and sparse woodlands plots. A large number of cover variables were calculated from field measurements (Tables 2 and 3).

Vegetation index images were spatially coregistered with field plot locations to facilitate regression analysis. Four techniques were tested to mitigate potential spatial misregistration errors between imagery and field data. Mean Filtering was identified as the optimal spatial coregistration method.

Using Mean Filtering, a statistical correlation using a least squares fitting algorithm was applied to TNDVI vegetation index values and paired field-based measures of vegetative cover. Strong correlations between TNDVI values and several in situ vegetative cover measures were identified, including Organic Cover, Visible Bare Ground, Total Cover, Total Vegetative and Organic Cover, and Total Vegetative Cover. Once correlation analysis successfully identified a relationship between TNDVI (independent variable) and various vegetative cover variables (dependent variable), the regression equation was applied to every pixel in the TNDVI image, resulting in new pixel values that were calibrated to ground-based vegetation measurements. The resulting image provided a baseline survey of vegetative cover.

The combined remote sensing/field survey technique was designed so that it could be replicated in the future to assess changing vegetative conditions in relation to the baseline survey conducted during this research. This report provides a detailed description of the methods used to conduct the survey.

The completed survey now provides a baseline inventory of vegetative cover from which change can be assessed over time. Change in vegetative cover can now be assessed at varying levels of detail, ranging from relative changes in land cover type and/or percent cover, to estimates of absolute change to in situ measurement of absolute change in percent cover.

Changes in land cover can be detected by comparing land cover classifications developed from future imagery with the land cover classification provided in this report. Subtle changes in vegetation cover within land cover classes will be difficult to detect using this method. However, this method can identify areas where more notable changes in land cover composition and cover have occurred. The types of changes that potentially may be detected through comparison of land cover classifications are changes in species composition, such as a change from a woodland to grassland, or a change from barren to herbaceous, and significant changes (>20 percent) in cover. The amount by which land cover composition must change on the ground before it would be detected with remotely sensed imagery varies with land cover type. As a result, subtle changes in vegetation cover, such as a 5 to 10 percent increase in cover in a mixed woodland, or composition, such as a transition from open herbaceous to open low shrub/herbaceous, may not be detectable by this method. This method should not be used as a stand-alone method for change assessment, but rather as a supplement to other change assessment techniques.

Although subtle changes in vegetative cover may not be detectable by assessing changes between temporal land cover classifications, remotely-sensed vegetation indices have proven to be more sensitive to subtle changes. Assessment of changes in vegetation index values derived from multidate satellite imagery provides a method to monitor relative changes in percent cover for each pixel in the satellite image. Assessment of relative change only provides an indication of an increase or decrease in cover between two dates, but does not quantify change in absolute terms. An increase in vegetation index values between multidate imagery generally indicates a relative increase in vegetative cover or biomass over that time period. Likewise, a decrease in vegetation index values generally indicates a relative decrease in cover or biomass over that time period.

Recommendations

Empirical relationships established in this report provide calibrated baseline data from which absolute changes in vegetative cover and biomass can be estimated and spatially extrapolated. Assessment of absolute change allows for quantification of change. These same empirical relationships can be applied to future satellite images. However, an annual field survey should be conducted to recalibrate the relationship between vegetation index values and field measurements. Should annual field surveys become cost prohibitive, previously calculated baseline regression formulas can be applied to subsequent images. In this baseline study, strong correlations were discovered between TNDVI and number of field variables. However, there was variance associated with extrapolating point estimates across the entire study area using satellite imagery. As time passes between initial baseline calibration and subsequent uncalibrated estimates, the reliability of the empirical relationship decreases. Therefore, it is recommended that empirical relationships between vegetation indices and field data be recalibrated as often as possible. Ultimately, the level of accuracy and detail required to meet monitoring objectives, along with logistical and financial constraints should dictate how often a field survey is performed. However, if precise measures of change in vegetation cover are required, field surveys are necessary.

Because spatially explicit baseline data on vegetative cover now exist for both the MPRC and NTA at Camp Grayling, MI, several options for continued monitoring are possible, each varying in terms of cost and level of detail. These options are not intended to outline every possibility, but rather are intended to give a range of possibilities from which decisions can be made based on monitoring requirements and available funding. The following three options are provided as a guideline for future monitoring.

Option 1

The option providing the most general level of information on changing vegetation cover would involve acquisition of future satellite imagery with minimal ground surveys. Vegetation index values derived from future imagery can be subtracted from vegetation index values calculated for this baseline data set. Areas of increasing or decreasing vegetation index values between temporal images would provide a general survey of the *relative* change in vegetation cover. Because field surveys constitute the highest cost of any monitoring program, by minimizing the frequency at which field plots are surveyed, total cost of the monitoring program would be minimized. To minimize costs further, images could be acquired at longer time intervals, rather than annually. However, it must be noted that this technique would only provide a synoptic view of *relative* changes in cover.

Option 2

A second option would be to apply the same empirical relationships reported in this baseline survey to subsequent satellite images. Depending on the requirements for monitoring, field surveys should be conducted every 2 to 5 years. For interim years, the empirical relationships identified from the previous field survey could be applied to subsequent imagery. After each field survey is conducted, empirical relationships between vegetation indices and field data should be recalibrated. Therefore, as frequency of field surveys increases, the opportunity to recalibrate these empirical relationships will improve the accuracy of spatially extrapolated cover estimates. A 3-year interval for field surveys is recommended as a medium cost monitoring protocol.

Option 3

For the most precise monitoring, the techniques that were used to establish the baseline survey of vegetation cover should be repeated annually. The techniques would include a complete field survey, satellite image acquisition, and regression analysis. Although annual field surveys may be cost prohibitive, this option would provide the most accurate spatially extrapolated estimates of cover.

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Appendix A: Landsat Header Information

Header Information for August, 9, 1997 Landsat Thematic Mapper scene.

Scene Id :	LT5021029009722110
Acquisition Date :	1997/08/09
Northwest Latitude :	N45 30 07
Northwest Longitude :	W085 05 03
Northeast Latitude :	N45 09 50
Northeast Longitude :	W082 46 10
Southeast Latitude :	N43 41 46
Southeast Longitude :	W083 19 27
Southwest Latitude :	N44 01 32
Southwest Longitude :	W085 35 01
Center Nadir Latitude :	N44 36 10
Center Nadir Longitude :	W084 11 23
Satellite Number :	LANDSAT 5
Path :	21
Row :	29
WRS Type :	Landsat 4,5
Quality :	Fair
Cloud Cover :	1
Quad 1 Cloud Cover :	0
Quad 2 Cloud Cover :	0
Quad 3 Cloud Cover :	0
Quad 4 Cloud Cover :	2
Receiving Station :	EROS Data Center, SD, USA
Recording Technique :	TM Descending (Day).
BW Film Availability :	NO
Condition :	SpaceImagingEOSAT supplied nom.center coord.
Product Distribution Site :	USGS-EDC and EOSAT
Sun Elevation :	53
Sun Azimuth :	133
Spacecraft Start Time :	97221155301589
Spacecraft Stop Time :	97221155328630

Appendix B: Classification Key

Key to the plant communities within the NTA and MPRC at Camp Grayling based upon life form and physiognomy

- Vegetative cover less than 10% above 5 meters.
  - -Total vegetative cover less than 5% . . . . . Barren/Sparsely Vegetated
  - -Total vegetative cover greater than 5%.
    - -Total vegetative cover above 1 meter less than 10%.
      - -Vegetation primarily herbaceous. . . . . Open Herbaceous
- Vegetation mixture of woody perennials and herbaceous plants . . . Open Low Shrub /Herbaceous
  - -Total vegetative cover above 1 meter greater than 10%.
- Vegetation primarily deciduous angiosperms. . . . .Deciduous Shrubland/Dwarf Woodland
    - -Both gymnosperms and angiosperms present.
- Vegetation a mixture of gymnosperms and angiosperms . . . . Mixed Shrubland/ Dwarf Woodland
- Vegetation primarily gymnosperms. . . .Coniferous Shrubland/Dwarf Woodland
- Vegetative cover in greater than 10% above 5 meters.
  - -Vegetative cover greater than 60% above 5 meters.
    - -Vegetation primarily deciduous angiosperms . . . .Deciduous Forest
    - -Both gymnosperms and angiosperms present.
- Vegetation a mixture of gymnosperms and angiosperms . . . . Mixed Forest
- Vegetation primarily gymnosperms . . . . Coniferous Forest
  - -Vegetative cover 10% to 60% above 5 meters.
    - -Vegetative cover 10% to 25% above 5 meters.
      - -Vegetation primarily deciduous angiosperms . . . .Deciduous Sparse Woodland
      - -Both gymnosperms and angiosperms present.
- Vegetation a mixture of gymnosperms and angiosperms . . . . Mixed Sparse Woodland
- Vegetation primarily gymnosperms . . . . Coniferous Sparse Woodland
    - -Vegetative cover 25% to 60% above 5 meters.
      - -Vegetation primarily deciduous angiosperms. . . .Deciduous Woodland
      - -Both gymnosperms and angiosperms present.
- Vegetation a mixture of gymnosperms and angiosperms . . . . Mixed Woodland
- Vegetation primarily gymnosperms . . . . Coniferous Woodland

Appendix C: UTM Coordinates of Unsurveyed Plots

UTM coordinates of allocated plots not surveyed in 1997.

NORTHERN TRAINING AREA (NTA)

E:	N:	Plot ID#
691037	4960732	#3
691586	4960732	#4
691037	4960183	#10
691586	4960183	#11
692179	4960183	#12
692707	4960161	#13
693234	4960183	#14
693805	4960205	#15
694332	4960205	#16
695431	4960183	#17
696551	4960183	#19
691586	4959633	#26
692136	4959633	#27
692707	4959612	#28
693234	4959612	#29
693783	4959633	#30
695453	4959655	#33
695980	4959655	#34
689939	4959062	#37
690488	4959084	#38
691059	4959106	#39
691586	4959040	#40
692157	4959084	#41
692707	4959084	#42
693827	4959084	#44
695431	4959084	#47
695980	4959084	#48
691630	4958513	#54
692707	4958513	#56

693256	4958513	#57
694926	4958513	#60
695475	4958513	#61
691564	4957986	#67
692157	4958008	#68
692729	4957986	#69
693256	4958008	#70
694904	4957986	#71
695453	4958008	#73
693783	4957393	#74
694376	4957415	#75
694904	4957415	#76
695475	4957437	#77
694354	4956843	#78
694926	4956865	#79
695476	4956865	#80

MPRC

E:	N:	Plot ID#
689387	4956334	#1
689932	4956355	#2
688842	4955790	#6
691609	4954700	#24
691609	4954155	#32
691567	4953568	#41
691043	4953589	#40
690477	4953589	#39
690498	4953023	#49
688318	4953589	#35
687187	4953589	#33
686637	4953023	#42
686097	4952499	#50
688298	4952499	#54

Appendix D: Constructing a Field Plot

Field Procedures

1. Navigate to plot location utilizing GPS.

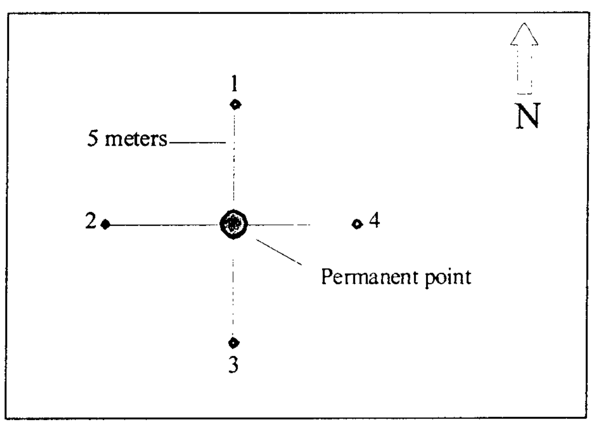
2. Establish center point with permanent stake and mark with pin flags.

3. Assess surrounding plant community and determine the physiognomic class of the community.

If the vegetative cover above 5 meters is:

- 60% - 100% the community is classified as a Forest.
- 25% - 60% the community is classified as a Woodland.
- 10% - 25% the community is classified as a Sparse Woodland.
- 0% - 10% the community is classified as Open.

4. If the community is physiognomically classified as a Forest or Woodland use the following procedures.



At each of the four points in the above figure total vegetative cover is estimated for the:

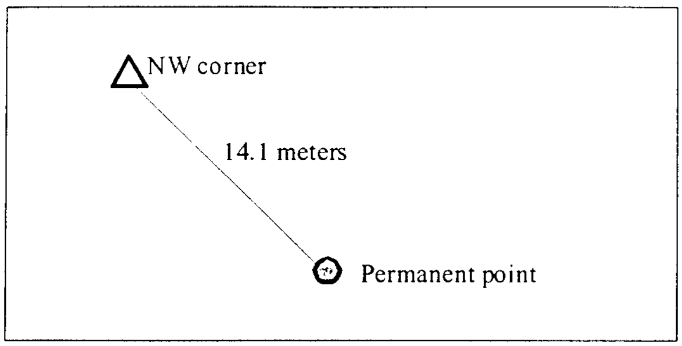
-Tree stratum (5 + meters)
-Shrub stratum (1-5 meters)
-Herb stratum (0-1 meter)
-Cryptogamic cover

-Organic debris
-Bare ground

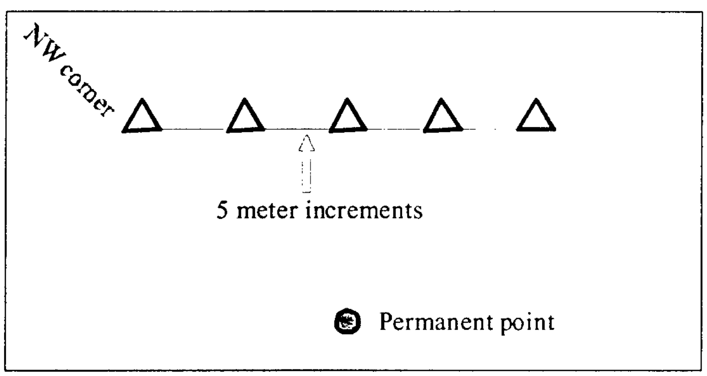
Vegetative cover is estimated using the Braun-Blanquet cover abundance scale.

5. If the Plant community is classified as a sparse woodland or open, use the following procedures:

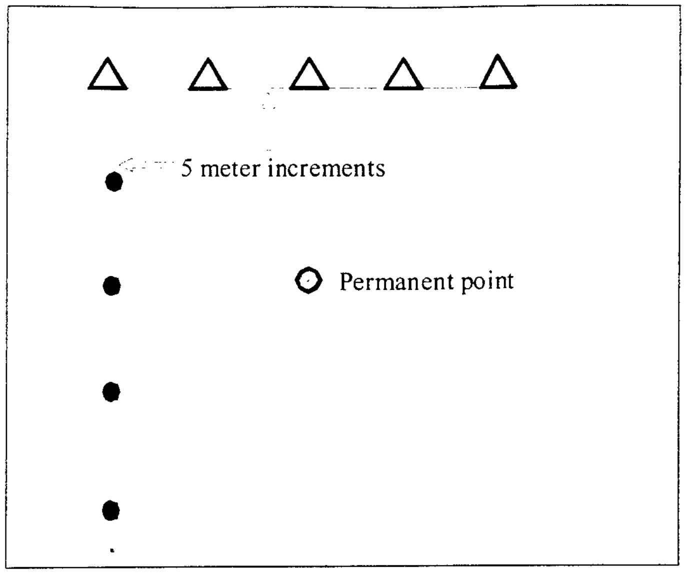
a. Establish the permanent point and then establish the NW corner of the plot 14.1 meters due NW (315 degrees) of the permanent point.



b. From the NW corner measure 20 meters due east and flag the 5, 10, 15, and 20 meter points.



c. Use a 20 meter rope (marked off in 5 meter increments) or tape measure to establish a line transect due south of the NW corner.



d. Place a 1m2 quadrat at the NW corner and each 5 meter point along the transect. Within each quadrat estimate the vegetative cover, cryptogamic cover, organic debris cover, and the amount of bare ground using the Braun-Blanquet cover abundance scale. Establish a new transect at each of the flags on the NW to NE line and repeat the data gathering procedures.

e. If applicable, estimate cover of the shrub and tree strata in the same manner as step 4.

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14. ABSTRACT
Vegetative cover was inventoried on a Multi-Purpose Range Complex (MPRC) and adjacent training area to Camp Grayling, MI. Camp Grayling, MI, is a U.S. Army National Guard installation located in the north central area of Michigan's lower peninsula. Remote sensing and field surveys were used to determine vegetative cover. In the field, vegetative cover data were collected on systematically allocated plots during the peak of the growing season in 1997. A Landsat Thematic Mapper (TM) image of the study area was acquired on 8 August 1997 that coincided with field data collection. A Transformed Normalized Difference Vegetation Index (TNDVI) image was derived from spectral information contained within the TM image. Analysis of correlation of vegetative cover measurements from field surveys and TNDVI values derived from satellite imagery were performed. Strong correlations between TNDVI values and several in situ vegetative cover measurements were identified, including Organic Cover (R^2=69.1), Visible Bare Ground (R^2=65.6), Total Cover (R^2=77.6), Total Vegetative and Organic Cover (R^2=79.2), and Total Vegetative Cover (R^2=70.4). Correlations were stronger within the MPRC than the adjacent training area (R^2 for Total Vegetative Cover; MPRC = 70.4, Adjacent Training Area = 53.5). Based upon these correlations, spatially explicit vegetative cover estimates were extrapolated across the two training areas. The resulting estimates provided a baseline survey of vegetation cover from which spatial and temporal changes in vegetation cover can be monitored.

15. SUBJECT TERMS
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