5-2004

Vegetative Recovery of Military Vehicle Impacts at Fort Lewis, WA

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Recommended Citation

Simmons, Katie Jean, "Vegetative Recovery of Military Vehicle Impacts at Fort Lewis, WA. " Master's Thesis, University of Tennessee, 2004.
https://trace.tennessee.edu/utk_gradthes/2198

To the Graduate Council:

I am submitting herewith a thesis written by Katie Jean Simmons entitled "Vegetative Recovery of Military Vehicle Impacts at Fort Lewis, WA." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Paul Ayers, Major Professor

We have read this thesis and recommend its acceptance:

Daniel Yoder, Joanne Logan

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Joanne Logan________________________

Acceptance for the Council:

Anne Mayhew______________
Vice Chancellor and Dean of
Graduate Studies

(Original signatures are on file with official student records.)

VEGETATIVE RECOVERY OF MILITARY VEHICLE IMPACTS AT FORT LEWIS, WA

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Katie Jean Simmons
May 2004

ACKNOWLEDGEMENTS

This project has been completed as a result of the contributions of many people. I would like to thank Dr. Paul Ayers for providing the opportunity to work on this project as well as providing support and direction during the project. I would also like to thank Alan Anderson, Angel Lombardi, and Jeff Foster for making this project possible and helping it to go smoothly. Thank you to Dr. Daniel Yoder and Dr. Joanne Logan for serving on my committee and providing suggestions and support for the project. The University of Tennessee Department of Biosystems Engineering and Environmental Science provided me with the opportunity to use this project to further my education. My thanks are extended to Fort Lewis Military Installation, Fort Lewis, WA for providing a location for the project and to the U.S. Army Corp of Engineers for funding of the project. Thanks to Adam Fiscor for technical support with the equipment and data collection.

I would also like to thank my parents, Charles E. and Peggy Simmons, as well as my grandparents, Junior and Sylvia Simmons and George and Mertie Smith, for raising me to be hard-working with a strong set of morals and values. Thanks to my brother, Eric, who provided me with guidance and a good example to follow. I also thank my sister-in-law, Sarah Beth, who provided encouragement and support. I would like to extend my thanks to the people of Calvary Baptist Church who became my family away from home. I also received great support and encouragement from my friends—Karen Adams, Emily Hall, Susan Anderson, Jarrod Edwards, Tyler Hickman, Scott Parks, Aaron Matthews, and Kyle Reese. They have supported and helped me through many situations and difficulties and have helped me to keep my focus where is needed to be.

While all of these people have helped me to become who I am and accomplish all that I have, there is One who receives all of the credit and all of my thanks. Most importantly, I want to thank the Almighty God, my Savior Jesus Christ. Thank you for saving me and making me yours. Thank you for giving me the abilities I have and the desire to learn. And, thank you for providing me with the support of such wonderful family and friends.

ABSTRACT

Vehicles driven off-road damage the soil and vegetation on the terrain, which can cause soil erosion and degradation of the landscape. This type of damage occurs on military installations due to training. Military training lands must be managed in an attempt to minimize the overall impacts of training on the terrain. The Army Training and Testing Area Carrying Capacity (ATTACC) is a model used by the U.S. Army to manage their training lands. Methods of determining the impacts produced by a vehicle and subsequent vegetative recovery have been used at Fort Lewis, WA for the Light Armored Vehicle (LAV). The LAV is an eight-wheeled vehicle with a maximum curb weight of approximately 14,000 kg. In June of 2003, the vehicle was operated in spiral patterns (five high-speed and five low-speed), and the impacts of the vehicle were assessed at this time. Measurements were taken at 13-20 points along each of the 10 spirals. The impact measurements taken at each point were disturbed width and impact severity. The impacts were reassessed after six months and one year to determine recovery from the initial damage. Different types of impacts (imprint, scrape, combination, and pile) were determined based on the characteristics of the damage produced. The recovery of these different impact types was also assessed.

The study site at Fort Lewis was found to have an overall vegetative recovery of 43% after one year, but the different impact types varied in the amount of recovery. Imprint impact types had an almost complete recovery of 74%, while the scrape and combination showed little recovery (11% and 22%, respectively) after one year. The pile also showed a high recovery of 54%. Areas where the vehicle was operated at low speeds showed high recovery (78%). Recovery was much lower (29%) for areas where the vehicle was operated at high speeds. The damage produced was higher and recovery lower when the vehicle was turning sharply.

The data produced by this study will be useful in managing the training with LAVs at Fort Lewis by implementation into the ATTACC model. Further study must be done to determine when these impacts would be fully recovered from the damage. The results found in this study are only applicable to the LAV and Fort Lewis. Other vehicles produce different impacts, and other locations have different climates, soils, and vegetation types that would respond differently to vehicle impacts. The methods used in this study can be utilized at other locations and with different vehicles to provide applications to more sites and a wider variety of vehicles.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Vegetation holds soil in place and reduces erosion. When vehicles drive off road, they impact the soil and vegetation. The impacts left by the vehicles include shearing of soil and vegetation, compression of vegetation, compaction of soil, and removal of soil and vegetation from the vehicle track. The severity of these impacts is a result of many different factors such as type of vehicle, type of vegetation, soil type, and climatic conditions. Damaged or destroyed vegetation can result in increased erosion due to the reduced ability to hold the soil in place. As the vegetation recovers from the damage caused by the vehicle and regrowth occurs, the vegetation begins to regain its soil-holding ability. Vegetative recovery is influenced by climate (precipitation and temperature), the type of vegetation present, soil conditions, and the occurrence of further vehicle tracking.

The Army Training and Testing Area Carrying Capacity (ATTACC) is a land management model in use by the U.S. Army (U.S. Army Environmental Center, 1999). This model is used to manage the training areas on military installations. An understanding of vehicle impacts and vegetative recovery is necessary to utilize this model. This understanding can also be useful in reducing the subjectivity of some aspects of the model.

1.2 Vegetative Recovery Study Justification

A study performed on how vegetation recovers after disturbance by various military vehicles will provide information that can be implemented in the ATTACC model. It will help improve the model by producing a more accurate estimate of different vehicle impacts, how quickly terrain recovers from training, and how soon more training can take place. Recovery studies can be performed on many different military vehicles, but certain vehicles are of special interest due to the current Army transformation to a more easily deployed force, an approach the Army is taking to provide a quicker response to military threats around the world. This transformation includes the use of new 8-wheeled armored vehicles that are lighter and more easily deployed than tanks, such as the Light Armored Vehicle (LAV). The initial phase of the transformation involves two brigade units at Fort Lewis, WA that include LAVs. The LAVs are very similar to Strykers, which are the vehicles to be implemented in the final phase of transformation (U.S. Army Corp of Engineers, 2001). Recovery studies performed on these new vehicles will provide information needed in the ATTACC model for the further phases of the Army transformation.

Off-road vehicle traffic impacts both soil and vegetation. In the case of vehicle traffic at Fort Lewis, WA, impacts to vegetation appear to be more important due to a small amount of bare soil exposed. With the climate in Fort Lewis being favorable to vegetative growth, vegetation is likely to grow in areas where the soil has been severely impacted. The recovery of vegetation is more likely to reduce soil erosion than the recovery of impacted soil.

Vehicle tracking leaves impacts that can be divided into different impact types, which vary in associated characteristics. These characteristics include the severity of damage produced by the vehicle, and vehicle properties of velocity and turning radius, which represents the sharpness of the turn made by the vehicle. There is a need to look at not only the recovery from the general impacts left on the terrain by the vehicle, but also at the recovery of each of these different impact types. Understanding how these impact types recover and the turning radius in which they are found will be useful in the development of a land management tool involving prediction of impacts and subsequent recovery as a function of vehicle turning radius and velocity. Such an in-depth recovery study, which has not previously been performed on the LAV impacts, will be additional information useful in the ATTACC model for the Army transformation.

1.3 Objectives

The purpose of this study is not to determine the exact time of full recovery. The purpose is rather to determine the recovery in one year, both overall and for individual impact types, in order to provide an understanding of the recovery of the different impact types. The intention is that these data, supplemented by further study and data, can be used to better understand vegetative recovery rates. This can then be incorporated into the ATTACC model to reduce the subjectivity of some of the inputs to the model.

The overall objective of this project is to evaluate the impacts of a Light Armored Vehicle (LAV) on the terrain at Fort Lewis, WA, and how fully the vegetation recovers from these impacts within one year. This evaluation will provide information useful in the model used by the Army to manage their training events. The sub-objectives addressed in this thesis include:

1. Evaluate the vegetative impact type and quantity of a turning Light Armored Vehicle (LAV) at high and low speed in Fort Lewis, WA.
2. Determine the recovery of different impact types after six months and one year.

CHAPTER 2

LITERATURE REVIEW

2.1 Vehicle/Training Impacts

Vehicles driven off-road impact soil and vegetation in forms such as soil compaction, rutting, and vegetation damage and removal. Repeated use of vehicles in an off-road area increase these impacts left on the terrain. As described below, many studies have been performed that document the environmental impacts caused by off-road traffic and military training.

In the case of military training in off-road situations, there is a limited amount of land available for training exercises. This leads to the need for repeated use of the available training lands and their subsequent degradation. The U.S. Army Land Condition Trend Analysis (LCTA) Program was developed to monitor the environment on military lands, which is important in determining and monitoring training impacts (Diersing et al., 1992). This program is an installation wide impact and recovery evaluation that addresses general large-scale trends. Data collected from LCTA has been used to determine the allowable use of the land. The LCTA data helps determine the locations of areas that are in need of recovery or rehabilitation, and to determine the amount of training that can be done on a given parcel of land. LCTA monitoring of the military training lands finds areas of vehicle and training impacts. This monitoring helps determine the amount of damage caused by the off-road traffic and training.

2.1.1 Off-Road Vehicles

Off-road vehicles are a common cause of terrain damage. While off-road vehicles can be used for a variety of reasons, from industry to recreation, they all introduce impacts and damage to the environment. The types of impacts on vegetation caused by off-road vehicle use include shearing, root damage, crushing of foliage, and damage to seedlings (Webb and Wilshire, 1983). Other types of impacts seen are change in vegetation composition, soil compaction, and erosion. Varying types of impacts are also present in different climactic regions, and range from damage to permafrost in artic regions (Slaughter et al., 1990) to damage to desert pavements in arid desert regions (Wilshire and Nakata, 1976). Studies that on the impacts of off-road vehicles focused on different aspects of impact. Some studies focused on damage to soil, while others were concerned about damage to vegetation.

A study of off-road vehicle traffic in the Denali Highway region of Alaska found damage to soil and vegetation (Sparrow et al., 1978). Soils in the off-road trails showed increased bulk density with increased traffic. The bulk densities for moderate and highly disturbed areas were found to increase approximately 100% and 33%, respectively, from corresponding undisturbed soil. The degree of vegetation loss on the trails varied depending on the amount of traffic, with low-use trails having vegetation growing between the tracks, and high-use trails having no vegetation present.

Deserts are another region where off-road vehicles can cause damage to soil and vegetation. Desert pavements are a feature of some deserts that is also susceptible to damage by off-road vehicles. A desert pavement is a layer of stones covering the soil surface in a desert. These stones vary in shape and can be tightly or loosely packed together. The stones in the desert pavement provide a protective covering for the underlying soil, which helps reduce erosion (Webb and Wilshire, 1983). A study conducted in California's Mojave Desert examined the effects of a cross-country motorcycle race. Motorcycle use damages and destroys areas of desert pavement and vegetation and causes compaction of the soil. The race covered a distance of over 150 miles, and the starting line included a mile-wide front of contestants. Of the area used by the race, 2500 acres were no longer covered with desert pavement. Compaction of the soil and destruction of vegetation from motorcycle use left bare soil that is susceptible to erosion. The damage has increased wind erosion in the areas used for the race (Wilshire and Nakata, 1976).

2.1.2 Military Vehicles

The use of military vehicles off-road also causes damage to the environment. Military vehicles can crush and destroy vegetation and cause changes to soil conditions in the vehicle tracks due to compaction and shearing. Tracked vehicles, such as tanks, have been observed in several studies that often show significant damage to vegetation and soil.

Studies have been performed on an area of the Mojave Desert in California, Arizona, and Nevada that was used for training by General George Patton, Jr. in the 1940s (Prose and Wilshire, 2000). The specific locations observed in the study were areas where the tracks were still identifiable, which were the areas demonstrating the slowest recovery. Tank tracks were visible in the desert pavements, where the stones were crushed and broken into smaller pieces than those in the undisturbed areas. Penetrometer measurements showed values for the tracked areas 50% higher than those for untracked areas at a depth range of 0-20 cm (Prose, 1985). Vegetation, both in tracks and undisturbed areas, was measured and classified using the Daubenmire method along transects (Prose and Wilshire, 2000). The Daubenmire method consists of 20 x 50 cm plots used for sampling of shrubs, herbs, and other small plants (Daubenmire, 1968). The tracked areas had a lower overall plant cover than disturbed areas, due to smaller plant size and higher plant density than undisturbed areas. Total plant cover in the vehicle tracks was reduced by 7-16%, and total plant density increased by 13-66%. The tracked areas also showed a change in species composition (Prose and Wilshire, 2000). This damage caused by tracked military vehicles is similar to the types of impacts left by other off-road vehicles in desert regions.

Studies have also been performed on military vehicles in other areas. The impacts of tanks driven on prairies have been studied at the Canadian Forces Base at Shilo, Manitoba, Canada (Wilson, 1988). The tanks were driven across the prairie between May 1 and October 10 in each year. The study observed different frequencies and seasons of tank traffic, and determined the effects on common species of vegetation. Species frequency was determined by recording the presence of species in subquadrants of the plots. Three species showed a significant decrease in frequency with increased traffic. Two of these species showed a difference between spring and summer traffic. The species frequencies found with summer traffic were similar to the frequencies from occasional traffic. The frequencies for spring traffic were similar to those where traffic occurred in the spring and summer. Spring traffic caused more damage to the vegetation than did summer traffic.

The Pinion Canyon Maneuver Site in southeastern Colorado is an area that was studied to determine impacts of training involving various tracked military vehicles (Shaw and Diersing, 1990). Vegetation measurements were taken using the point intercept method. Traffic reduced basal cover by 8%, increased litter cover by approximately 20%, and caused a change in species composition. Shrubs, trees, and other woody plants also suffered a decrease in plant density due to traffic. These impacts are consistent with the types of impacts found for tracked vehicles in other studies.

Other studies looked at more details of vehicle impacts. A study by Braunack (1986) determined the effects of tracked vehicles on soil surface properties. This study was conducted at the Shoalwater Bay Training area in Queensland, Australia. Sampling sites were chosen where tracks could be seen and it was suspected that the tracks were from a single pass within the previous five years. Soil cores were taken in the middle of track ruts and between the ruts. Cone resistance measurements were also taken at sampling both in and out of the tracks. Bulk density and cone resistance were found to increase in the vehicle tracks when compared to the samples between the tracks. Saturated hydraulic conductivity decreased in the vehicle tracks due to the soil compaction. The conclusion of this study was that tracked vehicles traveling across the terrain damages surface soil structure, which can increase erosion and reduce the recovery of vegetation.

A study at the Orchard Training Area in Idaho consisted of plots that received varying numbers of passes from an M1A2 tank ranging from a control with no passes up to 8 passes (Grantham et al., 2001). Plots with any number of passes produced a less stable soil surface than the control plots. Vegetation in the plots receiving passes of the M1 was crushed, detached, and compressed in the tracks. Damage caused to the vegetation was assessed using the point-intercept method at one-meter intervals along plot transects. The amount of damage to the vegetation increased as the number of passes increased. A wind tunnel was set up over each plot and material removed by a simulated windstorm was collected. The material mass removed by the windstorm increased as the number of passes increased, indicating increased damage to the vegetation. While this study was focused on the multiple passes of the M1 in a straight line, it was also noted in the study that areas where the vehicle turned showed significant damage to the vegetation. The turns resulted in the stripping of vegetation and soil and the formation of ruts. The damage to soil and vegetation seen in a turn was greater than or equal to the damage occurring in the 8-pass plots.

Another study, conducted in Queensland, Australia with an M113 armored personnel carrier, also showed that turns produced more severe impacts than straight-line tracking (Ayers, 1994). Sharp turns were found to have greater widths of disturbance for the tracks and larger amounts of vegetative cover loss. In areas where the vehicle was turning very sharply (a turning radius of 4 m), complete shearing of vegetation was observed and disturbed widths of the tracks were found to be near three times the width of the pads on the vehicle. Soil disturbance was found to increase with an increased sharpness of the turn. The areas of straight tracking had vegetation that exhibited a spring-back effect. The only visible damage to this vegetation was a reduction in vegetation height and density. These areas also had less soil disturbance than did turns.

A study at the Yakima Training Center in Yakima, Washington looked at the vehicle impact relationships of a Light Armored Vehicle (Haugen, 2002). The vehicle was operated in spiral patterns, and the vehicle impacts were measured along these spirals.

Impact measurements included the disturbed width, or the distance across the vehicle track, and the impact severity. Impact severity, in this study, was a visual measurement of the disturbed percentage of vegetation within the vehicle track. A set of guidelines for impact severities ranging from 0-100% was established and followed for the impact evaluations. The disturbed width and impact severity measurements were used to calculate a measurement called the cumulative impact width, which is a measure of the actual vegetation disturbed. The vehicle was also tracked using the Global Positioning System (GPS), and the GPS information was used to determine the turning radius of the vehicle along the spiral tracks. This was used as a measure of how sharply the vehicle was turning. The results of this study showed that vehicles produced more vegetation damage at smaller vehicle turning radii (where the vehicle was turning more sharply). The damage was much more severe for turning radii less than approximately 30 m, indicating that the vehicle caused more damage when turning very sharply.

All of these studies showed that military vehicles driven off-road caused damage to the terrain. Protective plant cover and desert pavements were damaged or destroyed by vehicle traffic, leaving the soil vulnerable to erosion. The damage increased from slight to severe, increasing with the number of passes made by a vehicle and the sharpness of the vehicle turn, however, the speed of the vehicles was not addressed.

2.2 Vegetative Recovery

While determining the initial impacts of off-road traffic is an important part of maintaining the environment and military training lands, it is also important to understand how vegetation recovers from these impacts. The rate at which the damaged or disturbed vegetation recovers determines how quickly the land can sustain more off-road traffic. Determining recovery times is not an easy task. There is a certain amount of unpredictability in the amount of time required for vegetation to recover from impacts. Recovery depends on the amount of use the disturbed area receives. More use in an area introduces more damage to the vegetation and requires more recovery in order to reach initial vegetation levels (Webb and Wilshire, 1983). Recovery also depends on climate. Arid regions have less rainfall to promote plant growth, so slower plant growth leads to a longer recovery time. In comparison, areas with a climate that encourages rapid plant growth will have shorter recovery times.

Long-term studies of vehicle impacts and vegetative recovery have also been conducted in tundra regions. A study by Abele et al. (1984) observed some of the long-term effects of off road traffic on tundra in Alaska. This study involved air cushion, wheeled, and tracked vehicles. The vehicles made multiple passes over the test points, and measurements were made of surface depression, thaw depth, and impacted vegetation. Surface depression and thaw depth were found to recover after 10 years. At this time, both were found to be at the original levels displayed by the surrounding undisturbed areas. Vegetation was found to recover after in less than 10 years, with only aesthetic vegetation differences still visible.

Studies have also been conducted on revegetating areas disturbed by vehicle traffic. One such study focused on rangelands disturbed by Army maneuvers at Fort Carson, Colorado (Berlinger and Cammack, 1990). The revegetation treatments included pitting with a variety of seeding mixtures and fertilization. Vegetative measurements were taken using the first hit-point method. The results of the study showed that with moderate to light tank activity the various combinations of seeding and fertilization did not increase vegetative recovery compared to the control. Areas of high activity showed no difference in recovery between pitting alone and all of the pitting, seeding, and fertilization combinations. This lead to the recommendation that pitting alone be used to increase revegetation on the rangeland in highly impacted areas. While this study was specific to arid rangelands, more studies are available that provide specific information on recovery for other areas.

A study was conducted at Fort Lewis, Washington in which the impacts were observed after multiple passes of an M1A1 tank (CEMML, 2000). The numbers of passes included in the study were no passes (control), 1, 2, 4, and 8 passes. Measurements taken included soil type, moisture content, surface soil strength measured with a drop-cone penetrometer, plant cover and ground cover measured using the point intercept method, and plant species frequency using nested frequency frames. Impacts were observed at the initial tracking and 1 year later. The impacts increased in severity with the increase in number of passes. The initial impacts showed a significant reduction in total cover for 4 and 8 passes. Impacts after 1 year had no significant differences between the various passes and the controls. Total plant cover had almost completely recovered after one year, but the study also noted that the impacted area had a change in species composition.

Some studies compare recovery in different types of vegetation at a particular site such as a study performed in Dartmoor, southwest England (Charman and Pollard, 1995). This study looked at aerial photographs of off-road vehicle tracks taken in 1969, 1975, and 1989 to determine if sections of the tracks had been abandoned in the time periods between when the photographs were taken. Percent cover measurements were taken visually over transects of the tracks. The grassland site of the study showed little difference in vegetation between tracks abandoned since 1969 and 1975 and vegetation not in tracks (control). The only difference in vegetation seen was in the 1989 photographs with recently used tracks. The recovery from the earlier photographs suggests that grasslands recover quickly when the tracks are no longer used. Other sites consisting of a mixture of heath and grassland communities showed little difference between the 1969 tracks and the controls. The 1975 tracks were somewhat more apparent than the 1969 tracks, but not as apparent as the 1989 tracks. This shows that recovery is still occurring, but at a slower rate than on the grasslands. The last area observed in this study contained moorland-blanket bog vegetation. Tracks abandoned in 1969 were still completely visible and had very little, if any, recovery. This study shows general trends in recovery for various types of vegetation, but cannot provide specific recovery times because of the uncertainty in exactly when the tracks were abandoned.

Other studies looked specifically at the time required for vegetation to recover. One such study was conducted at Camp Atterbury, Indiana (Anderson et al., 2002). This looked at three different vehicles: the M88 tank recovery vehicle, the M35A3 cargo truck, and the M1009 Blazer. The M88 is a tracked vehicle, while the M35A3 and the M1009 are wheeled. In July, the vehicles were driven in spiral patterns, consisting of constantly decreasing the turning radius while the vehicles were moving. The tracks left by the vehicles were then evaluated to determine the severity of the impacts produced. The measurements taken included disturbed width (width across the vehicle track) and percent impact severity, a visual measurement of the damage to the vegetation. The tracks were reevaluated at the end of the growing season in December, and again the following July. Areas where the vehicle turned were found to have more damage than areas where the vehicle was driven straight. The results of the study found that the vegetation recovered for all vehicles within one year. There were also no differences in species composition found for the disturbed area after one year.

A study conducted at Schofield Barracks in Hawaii observed impacts and recovery of a Light Armored Vehicle (LAV) (Ayers et al., 2003). The LAV in this study was operated in spiral patterns, with impact measurements of disturbed width and impact severity being taken along the spiral tracks. A calculated measurement of cumulative impact width was determined from the data collected and related to the turning radius of the vehicle along the spiral tracks. The severity of the vegetative damage was reevaluated after approximately one year, and complete vegetative recovery was found.

Another similar study was conducted at Fort Collins, Colorado (Haugen et al., 2002). This study used the tracked M109 self-propelled howitzer, also driven in spiral patterns. Measurements were taken along the vehicle tracks and classified into various impact types with impact severities. The impact types were determined visually by classifying each point into a type with specific characteristics. Measurements of disturbed width and impact severity were taken as discussed in previous studies. The severity measurements were taken monthly at each point during the spring, summer, and fall. The more severe impact with a scrape classification was found at smaller turning radii. The vehicle tracks generally showed decreasing severity of the impacts over time, but impacts were still present for all impact types after one year. The variation in recovery times between this and the previous study are likely due to climatic and vegetation differences, and perhaps the type of impacts.

Impacts to terrain were determined in several studies using measurements of impact severity. This was the same measurement for all studies in which it was mentioned. Impact severity measurements were measured as described in guidelines found in Haugen (2002). These were measurements of the severity of damage to vegetation caused by vehicle traffic. Impact severity is a measurement that is also used in this study to describe the damage to vegetation and is further described later. It provides information that can be used in managing military training lands.

2.3 Army Training and Testing Area Carrying Capacity

Army training lands see impacts and need recovery to maintain sustainable conditions. The Army Training and Testing Area Carrying Capacity (ATTACC) is the methodology in use by the U.S. Army to determine a sustainable training land and the proper rehabilitation and maintenance requirements due to military training on the land (U.S. Army Environmental Center, 1999). ATTACC estimates the training land carrying capacity based on training load, land condition, and land maintenance practices. Training land carrying capacity is defined as “the amount of training that a given parcel of land can accommodate in a sustainable manner.” Training load, on which carrying capacity is based, is the collective impact of all activities on a given portion of land and is measured in terms of maneuver impact miles (MIMs). MIMs are the product of vehicle mileage and several other factors, which include the Vehicle Severity Factor (VSF), Vehicle Off-Road Factor (VOF), Vehicle Conversion Factor (VCF), Event Severity Factor (ESF), and Local Condition Factor (LCF).

For all of the vehicle factors, the standard to which vehicles are compared is the M1A2 tank. The Vehicle Off-Road Factor (VOF) represents the percentage of the mileage driven off improved roads. The Vehicle Conversion Factor (VCF) represents the width of the area impacted by a vehicle compared to that of the M1A2. The Event Severity Factor (ESF) represents the relative impact of an event on the condition of the land compared to the standard event of an Armor Battalion Field Training Exercise. The Local Condition Factor (LCF) represents the susceptibility of the land to impacts due to current environmental conditions at that location. The Vehicle Severity Factor (VSF) represents the impact of a vehicle on the condition of the land compared to the M1A2 (U.S. Army Environmental Center, 1999). The VSF is among the factors that are subjective and determined by expert opinion rather than based on data. It is based on the opinion of experts who assign a value based on their experiences. This subjective measurement provides an area where ATTACC can be improved.

Land condition in ATTACC is measured using erosion status and is divided into current land condition and predicted future land condition. The current land condition erosion status involves the use of the Revised Universal Soil Loss Equation (RUSLE) to determine soil erosion. The predicted future land condition is based on the current land condition, the change in land condition due to training, and the change in land condition due to natural recovery. The change in land condition due to training is based on maps showing training impact and training distribution over the installation. The most accurate estimates of recovery period are determined experimentally. When these data are not available, however, recovery period can be determined by expert opinion or personal experience (U.S. Army Environmental Center, 1999). Since some of these methods for determining the change in land condition due to natural recovery are subjective, additional experiments measuring the natural recovery of vegetation at different military installations would increase the ability of the ATTACC model to manage training lands.

2.4 Summary

Studies have been conducted that addressed the impacts left by vehicles driven off road. A variety of different vehicles have been observed, including wheeled and tracked, military, industrial, and recreational vehicles. Tests were performed in tundra, deserts, prairies, and other vegetative areas. All of these studies showed that vehicle traffic damaged the terrain, but some studies lacked a quantification of resulting damage. There were also some studies that addressed the recovery of the damaged vegetation, with a wide variety of techniques employed to measure and determine that recovery. These studies found that the vegetation did recover over time, but that the recoveries varied due to climate, vegetation, and impact differences.

While the issues of vehicle impacts on the terrain and the recovery of vegetation after damage have been addressed, there is still a need for further quantification in this area of study. There is a lack of consistency in the methods used for determining the damage caused by vehicle traffic and the subsequent recovery. Methods need to be developed that will allow consistency of measurement across a variety of climates and types of vegetation. This will provide measurements that can be related between initial vehicle impacts and subsequent vegetative recovery. Another potential improvement is the area of vehicles tested. Even though a variety of vehicles have been utilized in previous studies, there is little information on vehicles that are becoming of interest to the U. S. Army with the current Army transformation. Further study is needed on the vehicles involved in this transformation due to their increased use. There is also little study on the effects of factors such as velocity and turning radius on impacts and on subsequent recovery rates. Impact and recovery studies need to be conducted that address these influential factors.

CHAPTER 3

PROJECT SITE

3.1 Introduction

The site for this project was Fort Lewis, Washington. Fort Lewis, located in the western part of the state, covers almost 35,000 hectares of land approximately 56 km south of Seattle and 23 km south of Tacoma. Before it was established in 1917, most of the area was used for dairy farms and agriculture (ENSR, 2000). It was classified as gently rolling glacial outwash plain. The installation was largely dense forest dominated by Douglas fir but also contained a deciduous forest, prairies, and lakes (Goran et al., 1983).

3.2 Soil Characteristics

Soil samples were taken to provide background information of the soil present at the site. Samples were taken from the A horizon of the soil. The soil found at the site is classified as Spanaway gravelly sandy loam (A. Lombardi, personal communication, 1 March 2004). This soil is also classified taxonomically as a sandy-skeletal, mixed, mesic Typic Melanoxerands (NRCS, 2004). A particle size analysis found the soil to be 67% sand, 29% silt, and 4% clay. Moisture samples were taken at the center of each spiral. The gravimetric moisture content of the soil for the 10 study plots had a mean of 37.1% and ranged from 19% to 46.1% by weight dry basis. Upon analysis, the soil was found to contain 27.8% organic matter. The results of the nutrient analysis are shown in Table 1.

Table 1—Soil chemical analysis

	ppm
NO_3-N	12.0
P	0.5
K	94.8
Zn	6.5
Fe	143
Mn	34.1
Cu	1.4

3.3 Vegetative Characteristics

The project site contained sod-forming grassy vegetation. Most of these grasses were non-native perennials. The most common type of grass at the site was Colonial bentgrass (*Agrostis tenuis*) (A. Lombardi, personal communication, 1 March 2004).

3.4 Climatic Characteristics

The climate in Fort Lewis includs relatively warm, dry summers with mild, wet winters (Goran et al., 1983). The climate is highly influenced by the mountain ranges to the west and east. The average annual temperature at Fort Lewis is 11°C, and the area receives about 102 cm of normal annual precipitation. The winters are very wet, with over half of the annual precipitation falling between early November and late February. The initial impact study conducted at Fort Lewis occurred in June 2002. The average temperature in Fort Lewis in June of 2002 was 21°C, and the total rainfall for the month was 3.1 cm (Fort Lewis Military Installation, 2004). The total precipitation for each month from June of 2002 to June of 2003 is shown in Figure 1. From July 2002 to December 2002, when the six-month recovery study occurred, 28.1 cm of precipitation

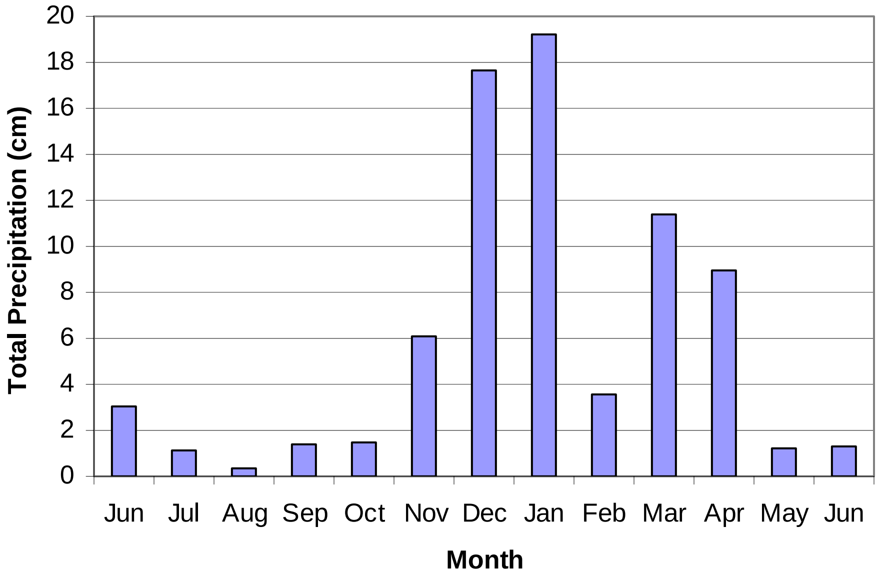

Figure 1—Total precipitation for each month from June 2002 to June 2003

occurred in Tacoma, WA. During the next time period, from January 2003 to June 2003, 45.7 cm of precipitation occurred in Tacoma, WA (AccuWeather, 2004).

CHAPTER 4

VEHICLE IMPACT RELATIONSHIPS

4.1 Introduction

A vehicle driven off road leaves impacts on the terrain. As the vehicle turns more sharply, the severity of the damage caused increases. Driving a vehicle in predetermined patterns containing varying degrees of sharpness provides an understanding of how the impacts on the terrain change as the vehicle turns. Measurements can be taken to quantify the types and severity of these impacts left on the terrain.

4.2 Vehicle Information

The vehicle used in this study was a Light Armored Vehicle (LAV). The LAV, shown in Figure 2, is a diesel fueled eight-wheeled vehicle. It has a maximum curb weight of 13,930 kg and a maximum curb weight of 13,930 kg. The length of the vehicle wheelbase from front to rear axle is 3.86 m, and the tread width, from center to center, is 2.3 m. The vehicle has four axles, with the front two axles steering and the rear two remaining straight. The tires tested were Michelin X, with a width of 27.9 cm and a diameter of 111.8 cm. These tires are also capable of being run at varying tire pressure, which, for this study, was set at 70 psi. The vehicle was operated in four-wheel drive mode, which is the mode that the driver would normally use while driving in the field where the study occurred.

4.2.1 Vehicle Tracking System

A Vehicle Tracking System (VTS) was mounted on the LAV on the longitudinal centerline to track the vehicle using a Global Positioning System (GPS). The VTS

Figure 2—Light Armored Vehicle (LAV)

included a Trimble AgGPS 132 12 channel receiver with Omnistar Satellite differential correction. Differential GPS data were collected every second.

4.2.2 Vehicle Dynamic Properties

Previous studies showed that vehicle dynamic properties such as speed and turning radius were influential in the amount of damage caused to the terrain. These dynamic properties were observed in this study to determine the resulting impacts using GPS data collected by the VTS. The calculation was made using the change in position over time.

The original GPS data were collected in degrees of latitude and longitude. These data were converted to Universal Transverse Mercator (UTM) coordinates using Blue Marble conversion software (Blue Marble Geographics, 2001). The data used for all calculations were in UTM coordinates. The vehicle velocity was calculated using the change in the vehicle's position, as

$$\text{Velocity} = \frac{\sqrt{(1_N - 2_N)^2 + (1_E - 2_E)^2}}{\text{Time Change(1 second)}}$$

where the Northing and Easting of the UTM coordinates are represented by the subscripts N and E, respectively. The vehicle was operated in spirals, as will be discussed in more detail later. The spirals were divided into high and low speeds. The low-speed spirals had an average velocity of 4.13 m/s, while the high-speed spirals an average velocity of 7.95 m/s.

The turning radius of the vehicle was also calculated using the vehicle position. Turning radius was defined as the distance from the center of the turn to the centerline of the vehicle. It was calculated from the three-point turning radius calculation method, which included the vehicle's current position and the positions immediately before and after the current position (Haugen et al., 2000). Each GPS data point thus had an associated calculated turning radius.

4.3 Data Collection

Initial vehicle impact data were collected for the LAV on June 11, 2002. Tracking data from the VTS provided velocity and turning radius data. Impact measurements were taken manually while walking along the vehicle tracks two to four hours after the traffic.

4.3.1 Spirals

The LAV was operated in spiral patterns formed by constantly turning the vehicle to the right. The spirals were begun with the vehicle driving straight and reaching the desired speed; then the vehicle began turning to the right, gradually decreasing the turning radius. This provided a constantly decreasing turning radius, to the right, for all spirals. The LAV made 10 spirals, 5 high-speed and 5 low-speed. The VTS mounted on the LAV collected GPS positions every second along the spirals. Figure 3 shows the vehicle track of positions collected by the VTS, and Figure 4 shows the positions collected for a single spiral.

4.3.2 Impact Measurements

After the tracking of the vehicle was completed, the spirals were walked, and impact measurements were taken. The vehicle impact measurements were taken at points every 4 to 7 m along each of the spiral tracks in an attempt to have a similar number of points per spiral. The points were determined by pacing along the spirals. GPS positions were taken at each of these points using the same equipment used to track the vehicle. The number of points per spiral ranged from 13 to 20 and can be seen, along with the speed of each spiral, in Table 2. Each point on both tracks was tagged and marked with a nail driven into the ground that was left in place to keep each point marked throughout the study.

As measurements were taken at each point, the impacts were classified as a specific type (Haugen et al., 2002). These types included:

- Imprint—soil and vegetation compressed in the vehicle track
- Scrape—soil and vegetation has been stripped away from the vehicle track
- Combination—a combination of a scrape and imprint having characteristics that are neither dominantly scrape nor imprint
- Pile—soil and vegetation that has been piled at the edge of the vehicle track.

Examples of these classifications can be seen in Figures 5-8. Some of these impact types can be found together. A pile is only found in conjunction with another impact type.

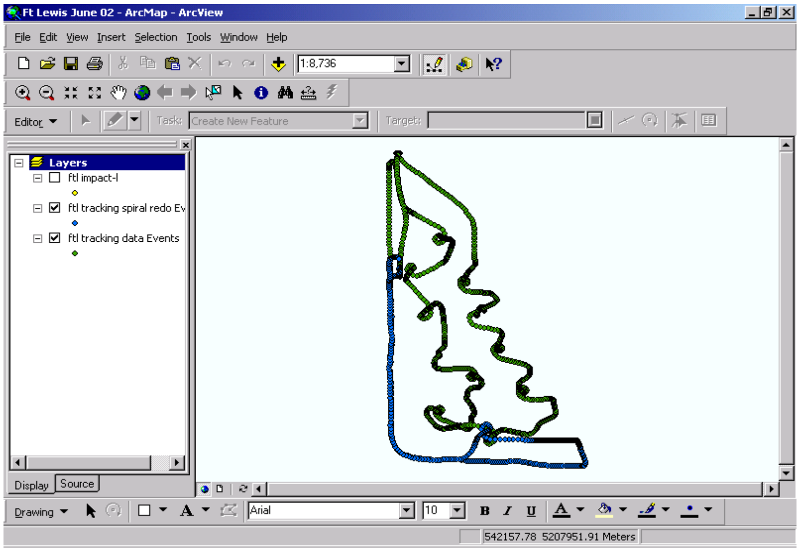

Figure 3—GPS data of LAV vehicle track collected by the VTS

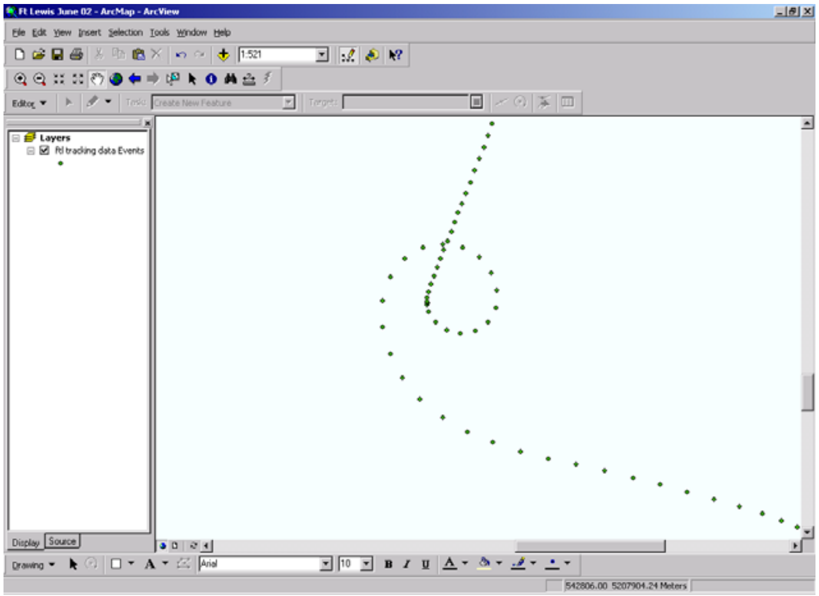

Figure 4—GPS data collected by VTS for a single spiral

Table 2—Spiral speed and number of points

Spiral	**Number of Impact Points**	**Vehicle Speed**
1	17	High
2	19	High
3	20	Low
4	17	High
5	16	Low
6	15	Low
7	15	High
8	13	Low
9	19	Low
10	18	High
Totals	86	High
	83	Low

Figure 5—Imprint

Figure 6—Scrape

Figure 7—Combination

Figure 8—Pile (next to scrape)

Because a pile is soil and vegetation that has been piled at the edge of the vehicle track, there must be disturbance within the track for this to occur. The other impact types are classifications of the disturbance within the vehicle track. If the impact within the vehicle track causes a removal and relocation of soil and vegetation out of the track, a pile is present. However, if soil and vegetation disturbed within any of the other impact types are not relocated outside of the vehicle track, there is no pile. When the classifications of impact type are made, the first question is whether the impact on the vehicle track is an imprint, scrape, or combination. Then it is determined whether a pile is present.

Once the impact type was classified, more specific measurements were taken. The measurements taken were an average over a length of approximately half a meter along the track. Disturbed width was a measurement of the soil and vegetation disturbed by the vehicle taken across the width of the vehicle track, as seen in Figure 9. Impact severity was a measurement taken visually of the percentage of soil and vegetation disturbed by the vehicle when compared to the undisturbed control of vegetation next to the track. The scale, from 0-100% was applied to each of the impact types. The guidelines used in determining impact severity are shown in Table 3. These guidelines are meant to work on a variety of different climates and vegetation types. Disturbed width and impact severity measurements were taken for both the left and right tracks left by the vehicle. The left track was the outside turn of the vehicle, and the right track was the inside turn of the vehicle. These impact measurements and classifications are the same methods of quantifying vehicle impacts used by Haugen (2002).

4.4 Data Analysis

Using the location collected by the GPS equipment, each impact point was associated with the closest vehicle tracking point. This provided vehicle velocity and turning radius data for each impact point along with the impact measurements. The data were then divided into individual impact types and separated for high and low-speed spirals. Distributions of the disturbed widths of the impact types were formed for various categories of turning radius. All of the impacts for the low-speed spirals were classified as imprints and were not further divided into turning radius categories. The high-speed spirals contained all of the different impact types, and the disturbed width impact distributions were developed based on turning radius. The categories of turning radius used were less than 20 m, 20-40 m, and greater than 40 m. These categories were chosen because they are ranges where the severities behaved similarly.

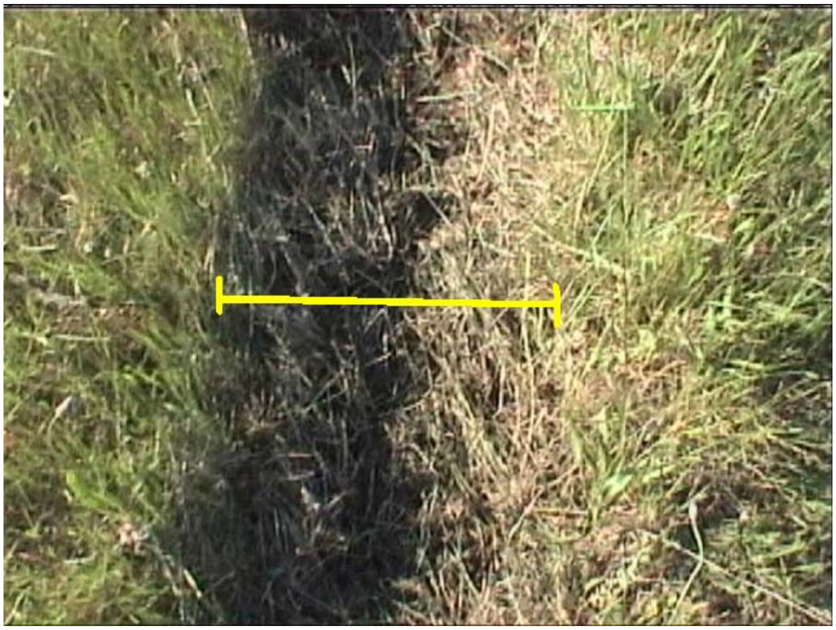

Figure 9–Disturbed width measurement

Table 3—Guidelines for assigning impact severity values (Source: Haugen, 2002)

Impact Severity (%)	*Guidelines*
0	No visible disturbance as compared to surrounding vegetation/area
10	Laying down of vegetation; will recover quickly; few, if any, broken stems; no evidence of vegetative shearing; very difficult to see impact after a few days
20	Some broken stalks/plants; no possibility of these stalks/plants straightening or returning to initial conditions within a few days; visible for a couple of months after impact; visible soil disturbance, possibly exposing bare soil, due to vehicle weight
40	Obvious depressed soil and vegetation with slight vegetation removal and significant vegetative damage; crushing, shearing and slight removal of vegetation likely; piling on track edge evident due to turning radius and weight of vehicle; movement of plants/soil towards the edge of vehicle track without completely shearing plant at roots; some bare soil exposed
60	About one third of vegetation still present and intact on the track; significant amount of bare soil exposed; larger piling of vegetation on edge of track due to shearing motion of the vehicle, fully removing species from the track; some of the pile has overturned, exposing some roots to air suggesting vegetation may not recover
80	Few vegetative species still intact on vehicle path; some vegetation has been sheared down to just above roots, so very little of plant remains above ground, while other vegetation has been fully sheared, removing roots; piling of vegetation and soil on the edge of the path; pile is completely overturned, exposing roots, suggesting the majority of species will not recover
100	Complete removal of vegetation and soil; shearing action of vehicle has left vehicle track bare; sheared vegetation and soil is piled on edge of track

Figures 10-12 show the disturbed width impact distributions for the high-speed spirals, including both the left and right tracks. These figures show the percentage of the total disturbed width found in each of the impact types. As the turning radius became sharper, the imprint impact type decreased in total percentage. The increase in the sharpness of the turn produced a transition from the less severe impacts of simple compression of the vegetation in imprints to the more severe removal of soil and vegetation in the scrape and pile impacts. Not only was there a transition in the impact type as the turning radius became sharper, but the disturbed width also increased. Sharper turns caused the vehicle to slide, leaving larger areas of vegetation disturbed. Figure 13 shows the average disturbed width for each of the impact types in each of the turning radius categories. High and low speeds showed similar disturbed widths but different impact types. Slight differences were seen in the impact distributions for left and right tracks. Figures showing these differences can be seen in the Appendix.

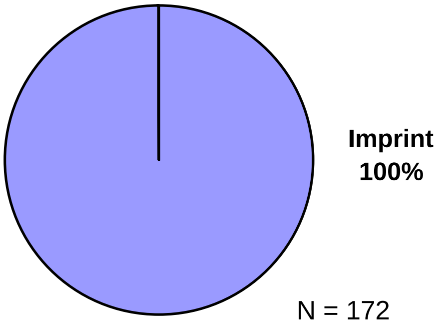

Figure 10—Impact distribution for high speed turning radius > 40 m

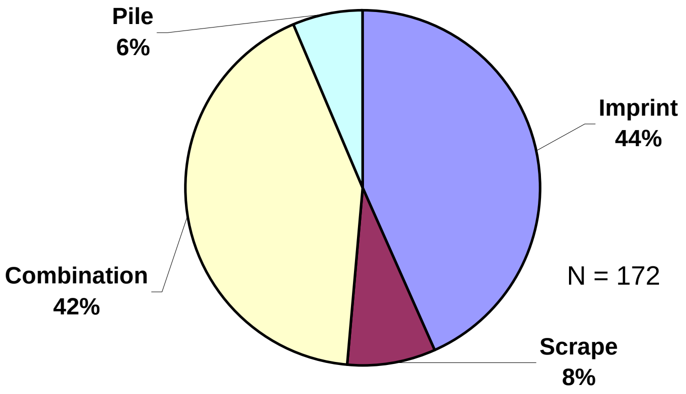

Figure 11—Impact distribution for high speed turning radius 20-40 m

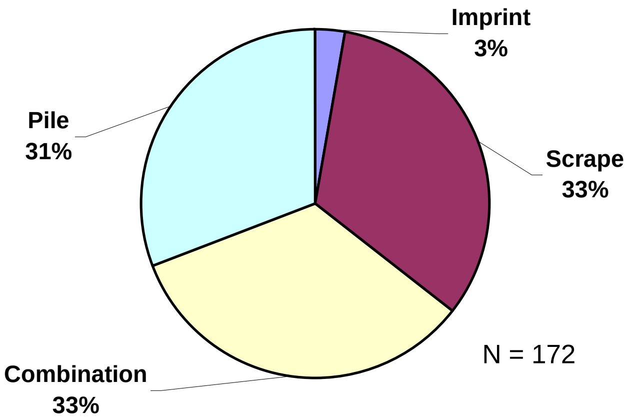

Figure 12—Impact distribution for high speed turning radius < 20 m

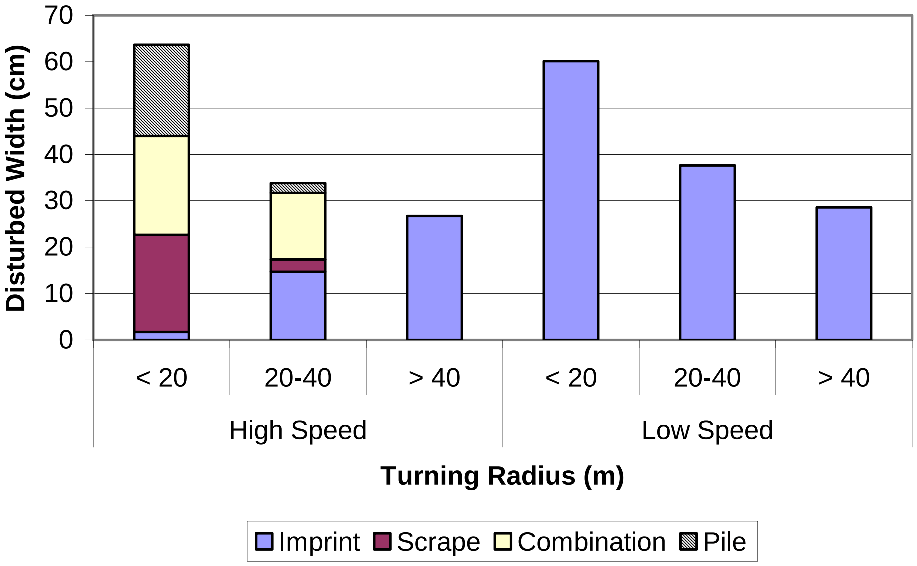

Figure 13—Average disturbed width for different turning radius categories

CHAPTER 5

VEGETATIVE RECOVERY

5.1 Introduction

The initial vehicle tracking was conducted on June 11, 2002. The vegetative recovery within the spirals was evaluated roughly six months and one year after the initial vehicle impact study, on December 17, 2002 and June 3, 2003, respectively. The original points were found and reevaluated to determine how the vegetative cover had changed over time. This change showed the recovery of the vegetation.

5.2 Data Collection

GPS positions were used to locate the beginning of each of the spirals in the field. Once the beginning of the spirals were found, the nails marking each point, both left and right tracks, were located. With the nails marking the original points, the reevaluation of vegetation was performed at the same points as the initial measurements. Data sheets used to collect the data contained only the disturbed width and impact type for each point. The original impact severities were not revealed at the time of the recovery reevaluations, removing any observer bias the initial impact severities might have on the new measurements. The original disturbed widths measured in the initial study were observed in the reevaluation. A new impact severity was measured over that disturbed width at each point for each impact type. Recovery impact severity guidelines were developed during this study based on the initial impact severity guidelines with adjustments made for recovery characteristics, and are shown in Table 4. Measurements taken in this way

Table 4—Recovery impact severity guidelines

Impact Severity (%)	*Guidelines*
0	No visible disturbance as compared to surrounding vegetation/area
10	Slight leaning of vegetation; vegetation may be leaning in the direction of the vehicle track instead of standing straight compared to surrounding vegetation; vegetation similar or same in size as surrounding vegetation; vehicle track only slightly visible
20	Leaning of vegetation, likely in the direction of vehicle tracking compared to surrounding vegetation; vegetation similar in size as surrounding vegetation; increasing visibility of track; little to no disturbance of soil visible
40	Depression of vehicle track; bare soil visible; over one third of the vegetation not present compared to surrounding; vegetation growing in track not as fully grown or as large as surrounding vegetation; if rocky soil, some rock visible in bare soil
60	About one third of the area with growing vegetation; vegetation smaller than surrounding vegetation; significant amount of bare soil still exposed; if rocky soil, rocks visible on soil surface; depression of track visible
80	Few vegetative species growing on vehicle path; vegetation present is much smaller and less developed than surrounding vegetation; depression of track visible; if in a rocky soil, increasing amount of rocks visible in track
100	Track is bare soil with no vegetation growing; depression of track visible; if in a rocky soil, rocks highly visible in track

provided an observation of the changes that occurred to the vegetation within the same area.

The impact severity guidelines used for the initial evaluation and the recovery evaluations were slightly different in their descriptions. The initial impact severity guidelines were a predictor of the resulting damage and die off, predicting the vegetative coverage. The recovery impact severity guidelines were an observation of the amount of vegetation growing back within the damaged area and were a measure of vegetative coverage. These recovery guidelines were observing what happened since the initial measurements and the amount of vegetation growing back in the area. Both sets of guidelines, however, were very similar. The recovery guidelines were derived from the initial severity guidelines, and the attempt was made to keep the guidelines on the same scale to allow the measurements to be compared. An initial severity measurement of 50% should have a recovery severity measurement of 50% if no vegetative recovery has occurred.

5.3 Data Analysis

The new impact severities for six months and one year of the different impact types were compared to the original impact severities to determine the recovery of the vegetation for each impact type. The vegetative recovery was analyzed by impact types, high and low speed, and an overall combination of the two. A single, representative impact severity for each time period, including the initial severity measurements, was determined as the impact severity weighted by disturbed width. These weighted severities were then compared to determine the change in severity and the recovery of the vegetation. All impact severity comparisons used the disturbed width weighted severities. Figures 14 and 15 show the comparisons of these impact severities for high and low speeds with their standard deviations. The severities compared include the initial impact severities and the recovery impact severities. These severities are the same types of measurements with the difference being some of the characteristics observed in assigning severity values.

5.3.1 6 Month Recovery

One measure of recovery used was the change in impact severity. This measure was simply the amount by which the width-weighted severity changed. As an example, an initial impact severity for an imprint was found to be 17%. After six months, the impact severity was found to be 20%. This produced an increase in impact severity of 3%. One year after the initial severity was measured, the imprint had a new severity of 5%. This was a decrease of 15% from the six-month severity and 12% from the initial severity. The changes in impact severity discussed here are differences in severities from one time of measurement to another. Percentage changes are later discussed as percent recovery.

The impact severities for all speeds and impact types showed an increase in severity of approximately 2-10% 6 months after the initial impact evaluation. This indicates a loss of vegetative cover since the original impacts. The combination impact type showed the largest increase in impact severity with 9.5%. The smallest changes were found in the pile, which increased by 1.7%. High speed spiral severities overall increased 6.7%, while low speed values increased by 1.9% overall.

This increase in severity after six months could be explained by the timing of the study. The initial measurements took place in June after the spring growing season. The December reevaluation did not allow for a growing season in between when the

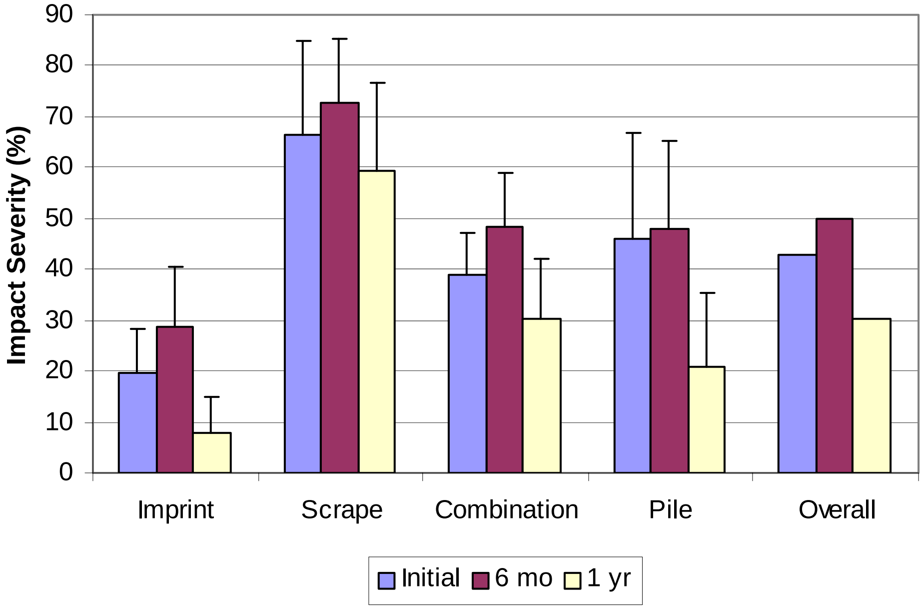

Figure 14—Impact severity comparison for high speed

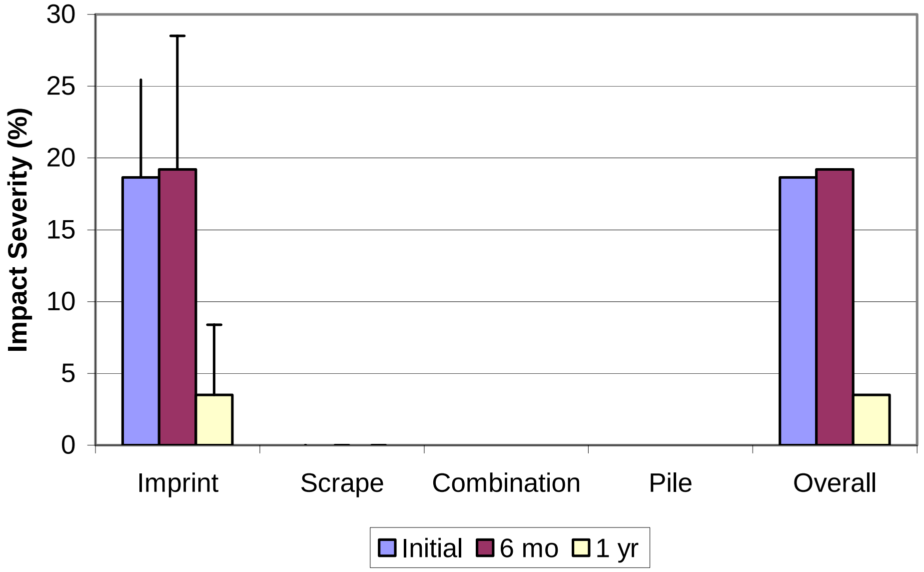

Figure 15—Impact severity comparison for low speed

vegetation could have recovered more. This time period was also one of very low rainfall, and the lack of rain could have caused some of the increased die off of the vegetation. It was also at a time when most of the vegetation was already dead for the winter. This combination of factors helped produce the higher severities after six months.

5.3.2 1 Year Recovery

Impact severities after one year decreased from the initial and six-month severities. Most severities decreased by approximately 7-15% when compared to the initial impact severities. The exception to this was the pile, whose severity decreased by approximately 25% from the initial measurements. These changes in impact severity can be seen in Figure 16. When compared to the six-month severities, the one-year measurements decreased by approximately 15-25%. The decrease in impact severity showed an increase in vegetative cover after one year. The increase in vegetative cover was present when compared to the initial and six-month vegetation.

Several example impact points illustrate the overall increase in impact severity after six months and subsequent decrease after one year. Figures 17-19 show the same point at the initial impact, six-month reevaluation, and one-year reevaluation, respectively. These pictures are from the same point, which was classified as a combination. The initial severity was 50%. After six months, the severity increased to 60%, and at one year, was 40%. This illustrated the increase in severity after six months but the overall decrease in severity after one year.

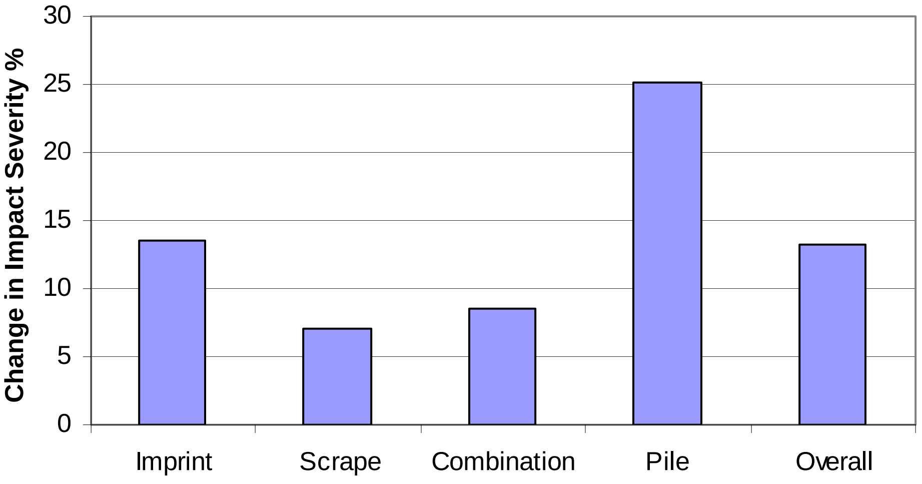

Figure 16—Change in impact severity % after 1 year

Figure 17—Initial impact severity of 50%

Figure 18—6 month impact severity of 60%

Figure 19—1 year impact severity of 40%

An overall evaluation of how the vegetation recovered and grew back in the vehicle tracks was measured as percent recovery. Percent recovery was calculated using the formula:

$$\%\text{Recovery} = \frac{IS_{initial} - IS_t}{IS_{initial}} * 100$$

In this equation, $\text{IS}_{\text{initial}}$ was the impact severity at the initial tracking and IS_{t} was the impact severity at the time of interest, in this case one year. Figure 20 shows the percent recovery for each impact type and overall, representing high and low speed combined. The imprint had the highest percent recovery with 74% (almost complete recovery) followed by the pile with 54%. The scrape and combination had much lower percent recoveries with 11% and 22%, respectively. The high-speed spirals had a percent recovery, with all impact types combined, of 29%. The low-speed percent recovery was 77%. Overall, Fort Lewis had an average recovery of 43% for this type of tracking one year after the initial tracking. The percent recovery was also broken down within the speeds for the different turning radius categories discussed earlier. These percent recovery values, which are divided for high and low speeds, are shown in Figure 21. High-speed turning radius categories showed slower recovery than low-speed.

The change in impact severity percentage can be used as an application to determine the amount of vegetation removed from the vehicle tracks. This was done by evaluating the area of vegetation removed at the initial tracking and the area of vegetation present at the time of recovery measurements. The area of vegetation removed at the initial tracking was calculated using the disturbed width, impact severity, and the distance between the impact points. The area of interest for each impact point was determined

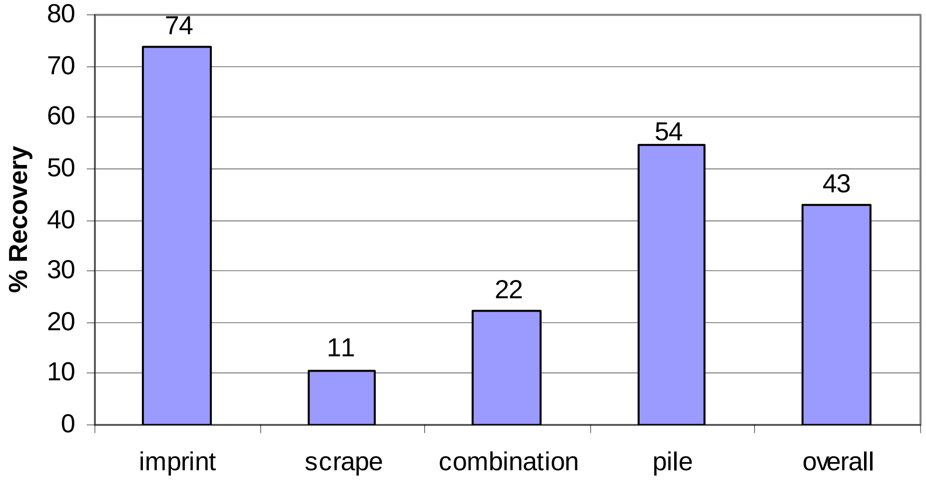

Figure 20—One year percent recovery values of impact types

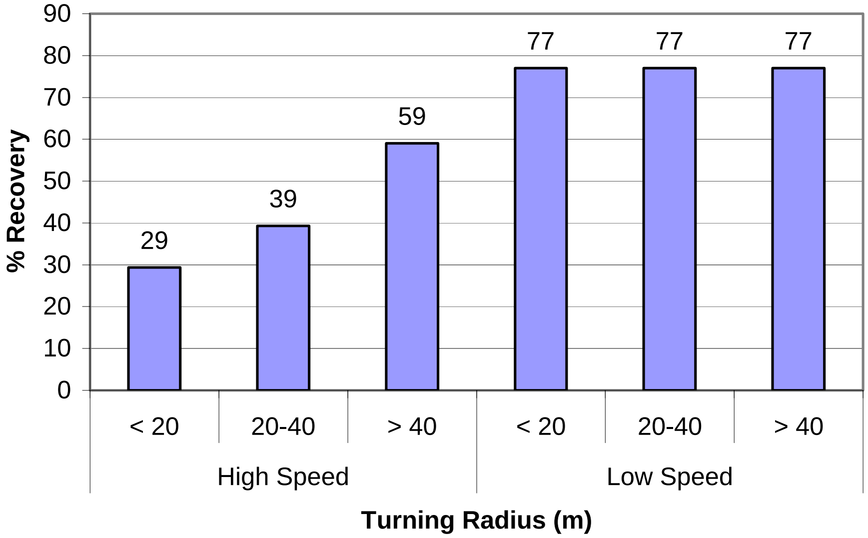

Figure 21—% Recovery for different turning radius and speed classifications

from the disturbed width and the length of track being affected. The length of track associated with each impact point consisted of half of the distance from the previous point and half of the distance to the next point. The impact severity provided a measurement of the amount of vegetation affected within the area of interest. The product of these three measurements provided an indication of the area of vegetation removed at the initial impacts. The same calculation using the recovery impact severities produced the area of vegetation remaining absent at the time of recovery. These values, shown in Table 5, were then used in the percent recovery calculation to determine the percent recovery based on the area of vegetation disturbed. As expected, the low-speed spirals, which consisted of only imprint impact types, recovered at a much higher rate than the high-speed spirals.

5.4 Summary

Overall, the recovery study showed that the disturbed vegetation was recovering one year after the initial vehicle impacts. While the impacts were more severe after only six months, within a year's time of the initial event, the vegetation was growing back and recovering in the vehicle tracks. The vegetative recovery was different for different impact types, but all types showed recovery.

Table 5—Area of vegetation initially removed and remaining absent after 1 year

	Low Speed	High Speed	Total
Initial (m^2)	75	145	220
One year (m^2)	16	100	117
Percent Recovery	79	31	47

CHAPTER 6

CONCLUSIONS

6.1 Project Conclusions

Light Armored Vehicle (LAV) tracking occurred at the site at Fort Lewis, WA. The vehicle was operated at high and low speeds in spirals that produced a varied turning radius. Impact types (imprint, scrape, combination, and pile) were determined for all of the impact points, as were the disturbed width and impact severity of each impact type. Measurements at 86 impact points were made along the 5 high-speed spirals, and measurements at 83 impact points were made along the 5 low speed spirals. The sharp high-speed turns produced more scrapes and higher impact severities. Impact severity was reevaluated after six months and one year to determine the recovery of the vegetation at each impact point. Recovery was then calculated for the different impact types.

Six months after the initial tracking, the vegetation had not begun to recover. The damage appeared more severe at this time than the initial impacts, with a severity increase of approximately 5-10% for all of the impact types and both speeds. It is suspected that the increase in severity was due to the death of vegetation damaged in the initial tracking. The initial severity measurements occurred several hours after the impacts and before the damaged plants died. The six-month severities showed the death of these plants that were highly damaged by the initial tracking. There is also suspect that since the initial tracking took place in June and the six-month recovery measurements occurred in December, with this period of time being very dry, the lack of a growing season and sufficient rainfall between did not allow for new growth to occur in the impacted areas. New growth would have decreased the severity and increased recovery.

The one-year recovery showed a decrease in impact severity from both the initial and six-month impact severities. Most of the one-year severities decreased approximately 10% from the initial severities and 15-25% from the six-month severities. The likely reason for such a great change in the severity from six months to one year is the presence of the spring growing season. This period of growth produced more vegetation and allowed growth in the impacted areas. This, in turn, produced a decrease in severity and an increase in recovery. Future studies should take into account the timing of initial tracking and recovery periods in relation to growing seasons. The timing of a growing season within the study effects the recovery time of the disturbed vegetation.

The change in impact severities differed for the various impact types. The pile had the largest decrease (approximately 25%) from the initial to the one-year severity. After one year, the pile appeared to be recovering more quickly than the other impact types. The imprint and combination were very similar in their change in impact severity. Both of these impact types decreased by approximately 10% from the initial to the one-year severity.

The scrape had the smallest change in severity of approximately 7%. This small decrease, in combination with the scrape having the highest severities of the different impact types, showed that the scrape was the most highly impacted area in the spirals. Since the scrape was more often found at higher speeds and smaller turning radii where the vehicle was turning more sharply, it could be concluded that the areas where damage is higher and recovery slower occur where the vehicle was moving at high speeds and turning sharply. These are the conditions in which the soil and vegetation cannot withstand the forces applied by the vehicle. More damage occurred to the vegetation in the scrape, and the scrape appears to have a slower recovery rate than the other impact types.

The decrease in impact severity showed an overall trend of increased vegetative cover and recovery from the initial impacts. Both speeds had an overall decrease in impact severity in the range of 12-14% from the initial to the one-year severities. The amount in which the severities changed indicates the amount of vegetation growing back within the area. However, this value alone does not fully describe the overall recovery of the impacted areas. The magnitude of the initial severity is also important in determining the overall recovery. Although two different points may have the same change in impact severity, if one point has a high initial severity and the other a low initial severity, the overall recovery of these points is not the same. Both values would be necessary in determining when the vegetation would fully recover.

While the six-month severities were greater than the initial severities, it is not likely that these measurements contained the peak of severity of the impacts. The severity likely slowly increased from the initial conditions to reach a peak of severity, where it slowly began to decrease due to plant growth. At the time of the spring growing season, the severity would decrease more quickly due to the dramatic increase in plant growth. After the spring growing season, the change in impact severity should level out again but still be slowly decreasing. This cycle of the severity is due to the change in seasons. The characteristics of this cycle are due to the timing of the initial study. If the initial tracking and impact measurements occurred at a different time of year, this cycle would be different. Tracking taking place in early spring would have a much faster decrease in the severity because the spring growing season would come much sooner in the reevaluation process.

This study showed the vehicle impacts and one-year recovery from the light armored vehicle (LAV) in Fort Lewis, WA. The analysis and results were specific to the LAV and Fort Lewis. The information provided could be used to design other studies for different vehicles and locations, but the specific results of this study could only be applied to this vehicle, location, and climatic conditions.

The data collected in this study was made available to the U.S. Army for use in the ATTACC model. The recovery data provided was information that could be implemented into ATTACC for use in management of training lands, with the recovery specific to Fort Lewis. Data provided could replace some of the expert opinion within the model. It could also be used to predict the time of full recovery, or be supplemented with continued recovery data to measure the time of full recovery. The methods used can be applied at other military installations to provide data from other locations to be used in ATTACC.

6.2 Comparison to Other Sites

The overall vegetative recovery at Fort Lewis, WA was 43%. This recovery value can be compared to annual recovery values derived from similar recovery studies. Other studies that addressed the recovery of disturbed vegetation were performed at different sites and utilized different military vehicles (Anderson, 2002; Haugen et al., 2002; Ayers et al., 2003). A comparison of percent recovery for these sites can be seen in Figure 22.

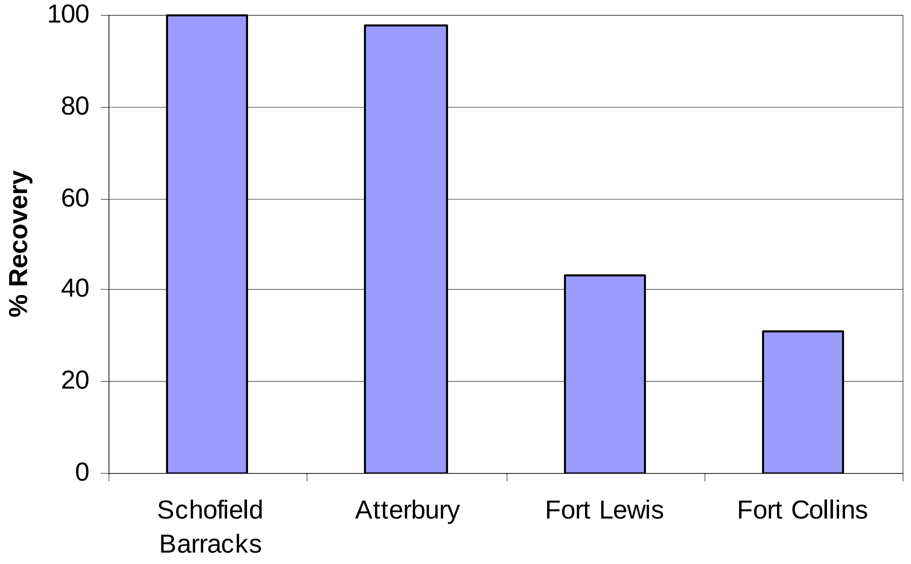

Figure 22—Percent recovery comparison for different sites

A recovery study performed at Schofield Barracks, Oahu, Hawaii also used a LAV and had a recovery of 100% after one year. Another study performed at Atterbury, IN used three different vehicles. The vehicles used included an M1009 CUCV Chevy Blazer, an M35A 2.5 ton cargo truck, and an M88 Recovery Vehicle. The vegetative recovery at this site was very high after one year and was combined into a single percent recovery for all of the vehicles at the site of 97.8%. A study performed at Colorado State University in Fort Collins, CO used an M109 Self-propelled Howitzer. After one year, the percent recovery of the vegetation was 31%.

This comparison of sites showed Fort Lewis to have a greater recovery after one year than Fort Collins, CO, but a far lower value than the high recovery in Atterbury, IN and the complete recovery at Schofield Barracks, Oahu, Hawaii. Similar methods were used at all of these sites, and the results found are expected. The sites in Hawaii and Indiana are areas of lush vegetation and climates favorable to growth of vegetation. These areas, expectedly, have higher recovery rates. Fort Collins is located in a dry area that does not promote as much vegetative growth. This location has an expected lower recovery rate than Fort Lewis, which has climate and vegetative conditions more suitable to recovery. This variation in percent recovery for different locations shows that these locations, with differing climactic and vegetative characteristics, do not behave the same. This produces the need for recovery studies to be performed in a variety of locations with differing characteristics to provide data representative of different areas. However, the methods used in this study appear to work very well at other locations. These methods, along with considerations for climate, should be able to explain percent recovery for a wide variety of locations.

6.3 Recommendations for Future Research

This study can be used as protocol for understanding some of the important factors influencing vehicle impacts and vegetative recovery at Army installations. The amount of recovery seen after one year helps determine when the terrain will be recovered to the point that it can sustain further training, and thus helps with training land management.

This data does, however, have limitations. It is only applicable to the vehicle used (LAV), the type of vegetation and soil present, and the climate in which it was performed. Varying the vehicle, vegetation, soil, or climate can change how the terrain recovers. Similar studies should be conducted in locations of different climates, soil types, and vegetation types and with a variety of different vehicles. The strategy used in this project can be used in other studies and applied to a variety of different locations.

The development of a method that would account for climatic and vegetative conditions at a given site would allow the methods used in this study to easily be transferred to other locations. This would provide a more representative data set that could be used in the management of different military installations scattered across the country.

Another limitation of this study is that it is looking at a single pass of a vehicle. When training exercises occur, vehicles do not always make a single pass over an area. A vehicle may circle around and drive over the same spot, or vehicles may travel in a line with several vehicles driving over the same spot. Each time a vehicle drives over the same place, it increases the potential for more impact at that location. This type of repeated tracking over the same area is becoming referred to as multipass. Further studies conducted on multipass tracking would provide information for another area of behavior vehicles exhibit during training exercises. An understanding of the impacts and recovery from this type of behavior would also be helpful in maintaining and managing training areas.

Improvement in this study can also be made in the impact severity measurements. These measurements are currently visual measurements based on a set of guidelines. Since they are visual measurements, they are somewhat subjective due to the person taking the measurements. There is the potential for variability in impact severity for different people taking the measurements. To remove this subjectivity, a more objective, quantifiable measurement system is needed, such as light reflectance measurements, weighing of vegetation, or a type of point count method. Some attempts have been made to create this type of objective measurement system, however, none have been found that are better than the visual system. Research in developing an objective measurement system should continue.

The factors that have been related in an attempt to explain impact severity are turning radius and velocity. While these factors are important, other factors may potentially be able to explain impact severity more accurately or add another element of explanation of impact severity. When a vehicle begins turning sharply, the weight of the vehicle begins to shift. The weight is no longer spread evenly on all tires or tracks. One side of the vehicle may be supporting more weight of the vehicle than the other. This shift in weight provides more energy in those areas of increased weight that can cause damage to the terrain. The impact severity will then change as a result of the shift in weight or the total acceleration of the vehicle as it is turning. A method could be developed to describe these changes in vehicle dynamic properties and relate them to the impact severity as another way to explain the damage caused to the terrain.

There are also other factors, such as tire pressure and mode of vehicle operation, specifically related to the vehicle that may be able to explain some of the impact severity. The LAV used in this study had a tire pressure of 70 psi, which was a high pressure that likely caused greater damage to the vegetation than a lower pressure. The LAV was operated in four-wheel drive mode and capable of other modes. The amount of wheels used to drive the vehicle could also have an effect on the damage caused to the vegetation. Future study looking at these aspects of a vehicle could provide more explanation of impact severity and its relation to vehicle properties.

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APPENDIX

LEFT AND RIGHT TRACK COMPARISONS

Differences appeared in the impact distributions for the left and right tracks of the high-speed spirals, shown in Figures A1-A6. The left track was the outside vehicle track in the spirals, and the right track was the inside track. Both tracks had all imprint impact types for a turning radius greater than 40 m. The tracks began to differentiate when the turning radius was less than 40 m. At a turning radius of 20-40 m, the right track was still largely imprint (65%), while the left track was only 24% imprint. With a turning radius of less than 20 m, the left track had no imprint and was dominated by scrape and pile. The right track still contained some imprint, and the most common impact type was combination. With the right track consisting of mostly imprint and combination, having more characteristics of compression of vegetation than removal, the overall impact appeared to be less on the right track than the left track. The left track contained a much higher percentage of scrapes characterized by more removal of vegetation and higher impact severities than a combination or imprint. This greater damage occurring in the left track was to be expected from the way the spirals were conducted. With the left track being the outside track in the spirals, the weight of the vehicle shifted to the outside as it turned more sharply. This increase in weight along the left track supplied the added force needed to cause greater damage to the terrain.

Impact severities were also different for the left and right tracks. These differences are shown in Figures A.7-A.10. Left and right tracks are shown for high and low speeds. Overall, the severities were higher for the left track. This was due to the way in which the vehicle was turning. With the vehicle turning to the right, the weight shifted to the left side of the vehicle and caused more damage on that side.

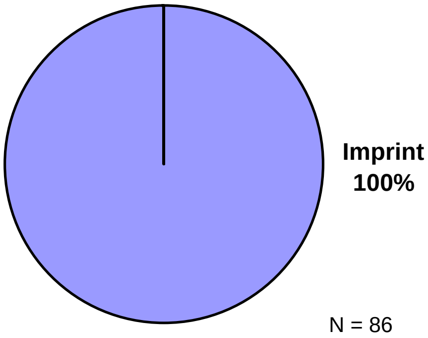

Figure A.1—Impact distribution for high-speed left track turning radius > 40 m

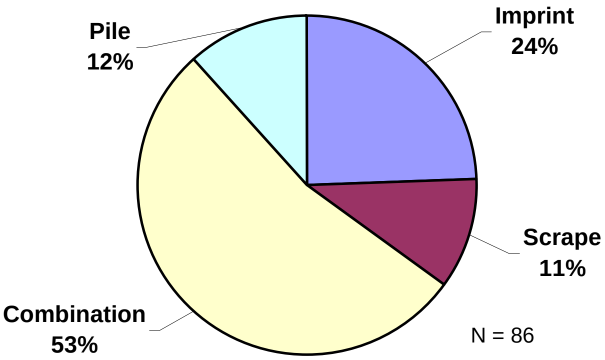

Figure A.2—Impact distribution for high-speed left track turning radius 20-40 m

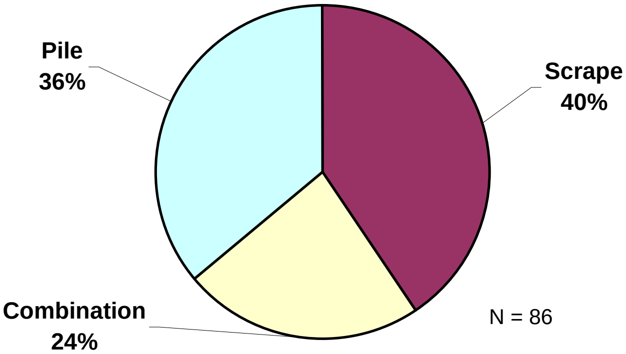

Figure A.3—Impact distribution for high-speed left track turning radius < 20 m

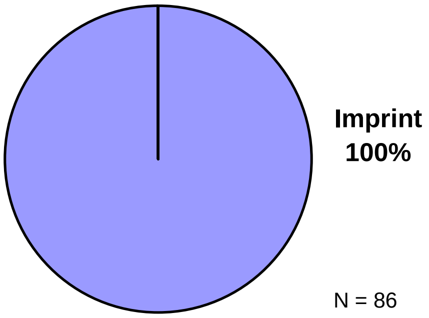

Figure A.4—Impact distribution for high-speed right track turning radius > 40 m

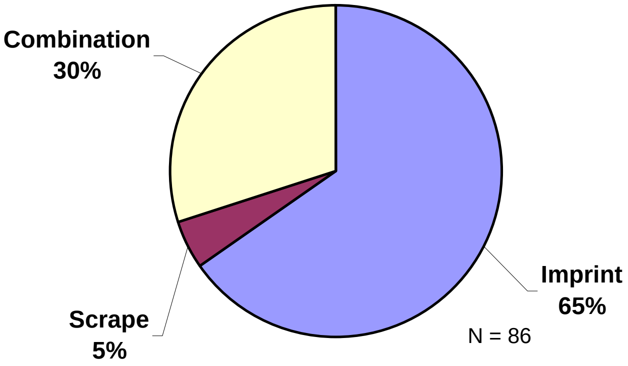

Figure A.5—Impact distribution for high-speed right track turning radius 20-40 m

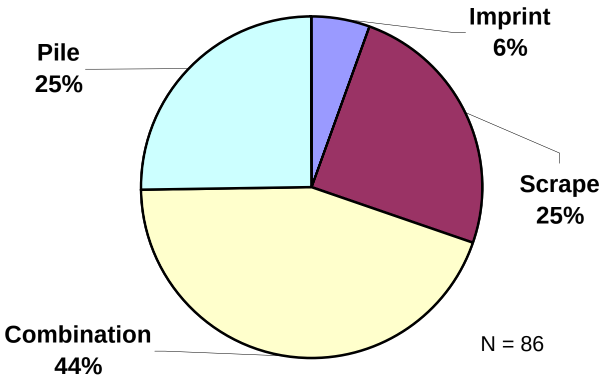

Figure A.6—Impact distribution for high-speed right track turning radius < 20 m

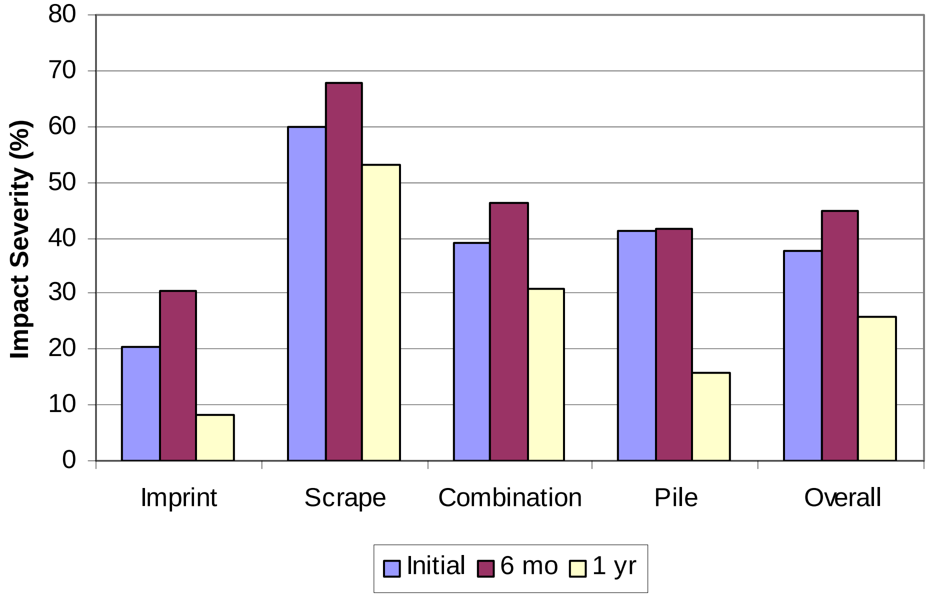

Figure A.7—Impact severity comparison for high-speed right track

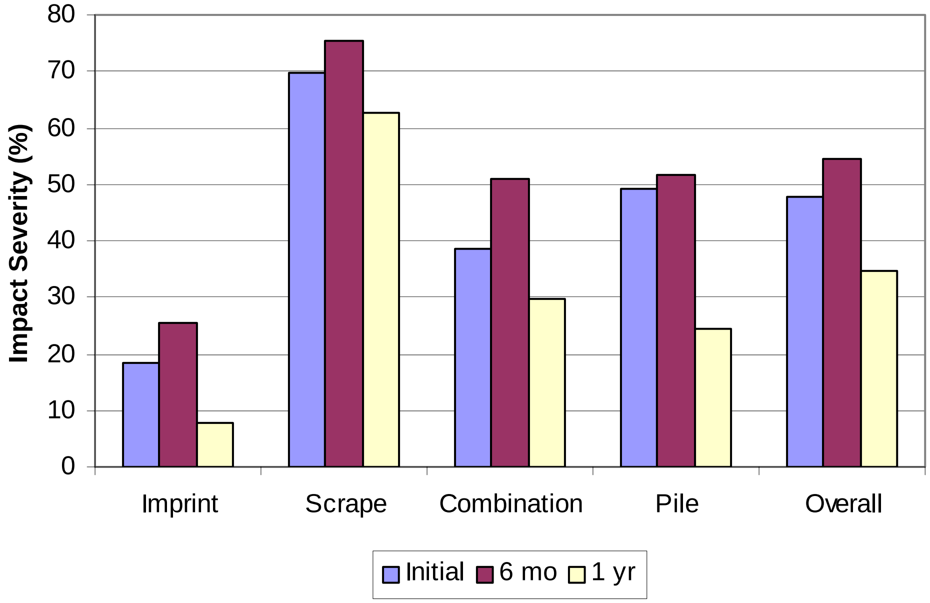

Figure A.8—Impact severity comparison for high-speed left track

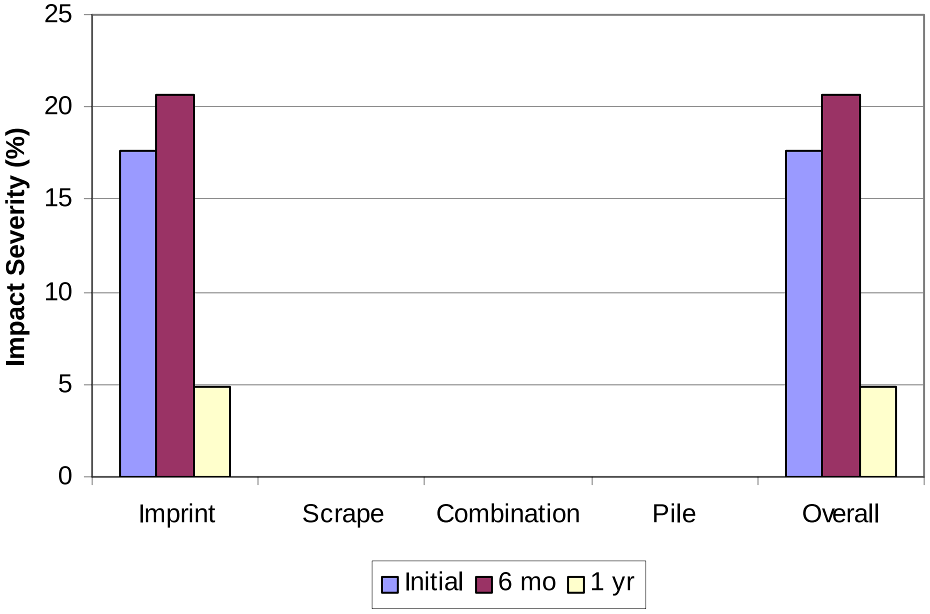

Figure A.9—Impact severity comparison for low-speed right track

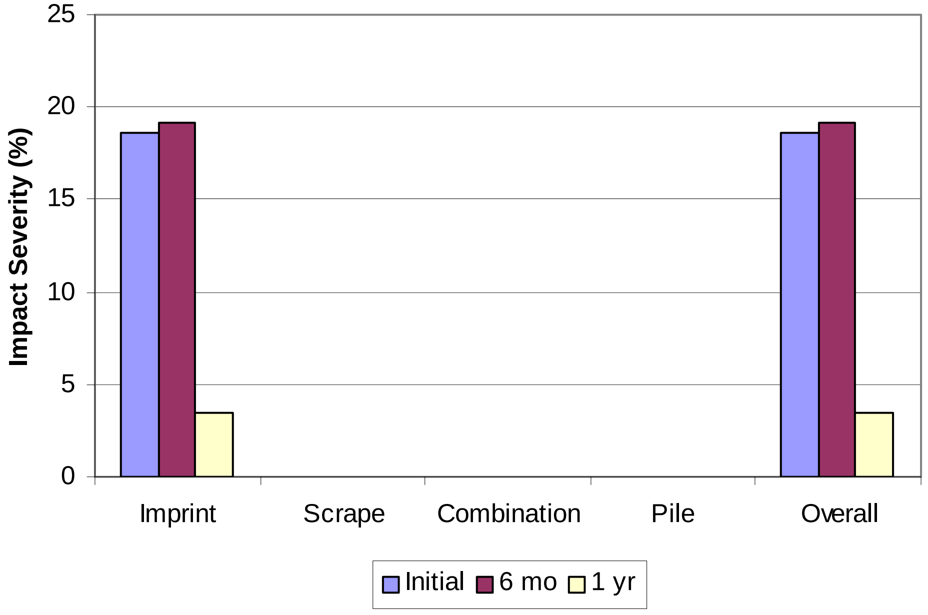

Figure A.10—Impact severity comparison for low-speed left track

VITA

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