Impacts of Deforestation and Land Cover Change on Mountain Soils in Hrazdan, Armenia

By

Jason L. Rhoades

A Report
Submitted in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE IN FORESTRY
MICHIGAN TECHNOLOGICAL UNIVERSITY
2008

This report: “Impacts of Deforestation and Land Cover Change on Mountain Soils in Hrazdan, Armenia” is hereby approved in partial fulfillment of the requirements for the Degree MASTER OF SCIENCE IN FORESTRY

School of Forest Resources and Environmental Science

Signatures:

Advisor ____

Dr. Blair D. Orr

Dean ____

Dr. Margaret R. Gale

Date ____

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acknowledgements

I would like to thank my advisor Blair Orr for his continuous and monumental assistance in every aspect of this study. Also, I would like to thank my committee members, Kurt Paterson, Andrew Storer, John Vucetich for their guidance and suggestions. A great debt is also owed to Scott Demyan, especially for his help in the field and in data analysis, without whom this project would not have been possible. For their tireless help in the field working from sunup to sundown on a 30% slope, many thanks to Jason Chandler and Michelle Bova. I am very grateful to the following people for their assistance in collecting background information: Artyom Alexanyan, Edit Mehdian, Anna Aghalaryan, Ray Reeder, Susanna Babaxanyan, Hrandt Alexanyan, and Stepan Margaryan. Thank you to Karen Aghababyan, and Thomas and Jennifer Lyman and the Acopian Center of the Environment at the American University of Armenia for their time and assistance. Thank you to Sergei Yeritsian, Armine Avagyan, and everyone at the State Agricultural Institute soils laboratory for their kindness, boundless generosity, and hard work. Many thanks to Christian Sewert in Germany for his generosity in performing the thermogravimetric analysis. For their advice and assistance in the writing of this paper, thank you to Patricia Butler, Chad Fortin, Max Henschel, Mike Hyslop, Marty Jurgensen, Cara Shonesy and Joshua Shields. Thank you to Michigan Technological School of Forest Resources and Environmental Sciences and the Peace Corps for the education, the experience, the support, and the opportunity. Finally, countless thank yous to my family for all their help and support.

Abstract

In this study, the impacts of deforestation and land cover change upon underlying soils were examined on one hillside in central Armenia. Soils characteristics in three land cover areas, forest, coppice, and pasture, were recorded and soil samples were analyzed. Deforestation and land cover change were found to increase erosion rates. From soil horizon and structural characteristics, it can be estimated that 40cm of soil have been lost in the pasture and 20cm have been lost in the coppice compared to the forest. Soil organic carbon was also affected by deforestation and land cover change. Compared to the forest (8.2% organic carbon), both the coppice (6.3%) and the pasture (5.9%) had lower values. Phosphorus, potassium, and nitrogen had varying levels and may have been affected by erosion, animal deposition, differing amounts of vegetative residues present, differing organic matter decomposition rates, and differing hydrological processes. Deforestation was also found to change the species composition of seedlings and saplings in the coppice in comparison to the forest; reducing oak numbers and increasing hornbeam recruitment.

Introduction

Armenia’s forests are an important resource for the country as a whole, the local forest communities, and the world at large (Moreno-Sanchez and Sayadyan, 2005; Boudjikanian, 2006; Sayadyan and Moreno-Sanchez, 2006). They should be managed sustainably in order to continue to provide important economic and ecological functions. Unfortunately, a long and complex history has resulted in extensive losses in forest cover and current pressures, especially illegal logging, threaten to further reduce this resource (Moreno-Sanchez and Sayadyan, 2005; Boudjikanian, 2006; Sayadyan and Moreno-Sanchez, 2006). While deforestation is a major concern within the Republic of Armenia, there has been little research conducted regarding the impacts it is having on Armenia’s ecosystems. Sustainable forest management decisions need to be based on an accurate inventory and with an awareness of the impacts that the harvest may have on the ecosystems involved.

The objective of this study was to examine the effects of deforestation and land cover change on one hillside in central Armenia. Chapter one begins with a general background of the modern Republic of Armenia. It then describes the current forest cover and composition within the country. It concludes by explaining the importance of forest ecosystems to Armenia in meeting economic and ecological needs.

Chapter two discusses the history of Armenia’s forests to better contextualize their current state and the current pressures that are acting upon them. The history is divided into three parts. It begins with the rise of incipient agriculture on the Armenian highlands continuing until Armenia joined the Soviet Union in 1920. This is followed by the period of Soviet rule in Armenia from 1920-1991. The final part covers from Armenian independence in 1991 until the present.

Chapter three reviews the literature concerning the impacts of deforestation and land cover change, especially in regards to mountainous areas. Chapter four presents a site description of the study area. Chapter five explains the methods of data collection and analyses that were employed in this study.

Chapter six discusses the results of the study. The discussion begins by looking at erosion, organic carbon and organic matter, phosphorus, potassium, nitrogen, and regeneration and species composition as distinct aspects of the results. Then, in chapter seven, conclusions are drawn about the impacts of deforestation and land cover change within the study area as a whole. Finally, suggestions are made regarding possible future studies concerning deforestation in Armenia and forest management in Armenia.

Chapter 1: Current Situation

Background Information

At 29,740km^2, the Republic of Armenia is one of the smallest of the former Soviet Republics. The 2008 population is estimated to be 2,968,586 people. It is landlocked, with Georgia to the north, Azerbaijan to the east, Iran to the south, and Turkey to the west. Armenia is located on the eastern edge of the Armenian plateau, which stretches westward through much of Turkey (Figure 1). Part of the Alp-Himalayan Mountain Range; the lesser Caucus Mountains run through the country. Tectonic shifts have created the country's mountainous terrain through folding ridges and volcanic activity. While the elevation ranges from 375m, at the Debed River, to 4095m, at the top of Mt Aragats, the average elevation is 1850m.

Climactically, Armenia is located in the sub-tropical zone and has arid and semi-arid conditions. Water resources and rainfall are limited. Rainfall averages 600mm/yr but can vary from 230 to 1000mm/year depending on the region. Armenia has six landscape types that are generally correlated with altitude: desert (below 900m), semi-desert (800 to 1200m), steppe (1200 to 2000m), sub-alpine and alpine meadows (above 2000m) and forests (500 to 2400m) (CIA, 2008; MNP, 2007).

Figure 1. Map of the Caucuses. The map prepared by Acopian Center for the Environment, American University of Armenia. Date of preparation unknown. Permission letter can be found in Appendix 1.

Current Forest Composition

Estimates place the current forest cover between eight and ten percent, roughly 283,000ha (Moreno-Sanchez and Sayadyan, 2005; Boudjikanian, 2006). Forests are generally located on north facing slopes steep enough to prevent logging and conversion to agriculture or to pastureland (MNP, 2007). The majority of Armenia's forests are located in the northeast (62%) and the southeast (36%) with a small area in the central region (2%) (Boudjikanian, 2006). Armenia's natural forests are 97% deciduous (oak, beech, hornbeam) with occasional forests of juniper, pine, and yew on drier sites. There are four major forest types found in Armenia. Oak forests, comprised mainly of

Georgian oak (*Quericus ibericum*), European ash (*Fraxinus excelsior*), European hornbeam (*Carpinus betulus*), Georgian maple (*Acer ibericum*), cork elm (*Ulmus suberosus*), and field maple (*Acer campestre*) make up about one-third of the total forest cover and are located primarily in the northeast of the country. Beech forests, comprised mainly of oriental beech (*Fagus orientalis*), littleleaf linden (*Tilia cordata*), Litinov birch (*Betula litwinow*), and spindle tree (*Euonymus europaeus*) also comprise about one-third of the total forest cover and are generally located in northern Armenia. Hornbeam forests, comprised generally of European hornbeam, Georgian oak, European ash, field maple, Caucasian pear (*Pyrus caucasicum*), and apple (*Malus orientalis*) are less common. Finally, dry scrub forests are located in the north and south and support about 80 species of trees and shrubs adapted to xeric sites (MNP, 2007).

The Importance of Armenia's Forests

The few remaining forested areas within Armenia, currently estimated to be between eight and ten percent of the total land cover, are of immense value to the country as a whole, to the local forest communities in particular, and to the larger ecosystems in which they play a part (Moreno-Sanchez and Sayadyan, 2005; Boudjikanian, 2006; Sayadyan and Moreno-Sanchez, 2006). First, a high percentage of Armenia's forests occur on steep slopes. The forests play a vital role in helping keep the mountain soils intact; landslides and erosion have occurred as a result of deforestation (Moreno-Sanchez and Sayadyan, 2005; Boudjikanian, 2006; MNP, 2007). Armenia's mountainous topography results in many rivers bordered on both sides by steep slopes. Removing forests from these mountains increases sedimentation of the waterways, increases stream temperatures, changes pH, and decreases the amount of organic matter inputs, all of which would have adverse impacts on the aquatic ecosystems (Hunter, 1990; Fretter, 1994; Xiubin et al., 2003; Abbasi and Rasool, 2005; Boudjikanian, 2006). In addition, Armenia needs to manage its forests sustainably in order to continue to be able to harvest trees for fuelwood and other timber products (Sayadyan and Moreno-Sanchez, 2006).

Armenia’s forests are also of great importance to the local populations that live near and in them. They provide herbs used in cooking and medicine. They provide mushrooms, fruits, and nuts which are used for food (MNP, 2007; UNEP, 2007). They have the potential to sustainably meet some of the villagers fuelwood needs in locations where gas is unavailable and to provide construction materials and other timber products (Sayadyan and Moreno-Sanchez, 2006). They provide habitat for game animals, which could be hunted for food (UNEP, 2007). They help keep streams and rivers habitable for fish populations, which are another food source (Boudjikanian, 2006). They offer a place for Armenians to go for recreation and relaxation (Sayadyan and Moreno-Sanchez, 2006).

Finally, the biodiversity of Armenia’s forests is important to the world at large. Armenia’s complex and mountainous terrain and resultant microclimatic diversity have yielded a great variety of flora and fauna, including many endemic species (Sayadyan and Moreno-Sanchez, 2006; MNP, 2007; CIA, 2008). Armenia’s location at the crossroads of four floristic regions (Near-east Asian, Old Mediterranean, Caucasian, and Iran-Turanian) further increases the level of biodiversity there. The forests of Armenia are often labeled a biodiversity hotspot due to this high biodiversity and high rate of plant and animal endemism found there (Sayadyan and Moreno-Sanchez, 2006). Habitat loss in Armenia has in turn resulted in many plants and animals being placed on threatened or endangered species lists. With the loss of more of Armenia's already diminished and fragmented forests, many endemic and rare species may become extinct (CEPF, 2003; MNP, 2003; MNP, 2007). Clearly, the continued and potential total loss of Armenia's forests would have many detrimental impacts for the country, the people, and the world in terms of monetary, societal, and ecological concerns. In order for Armenia's forests to continue to provide all of these important human needs and ecological roles and functions, it is imperative that they be managed in a sustainable manner.

Chapter 2: Armenia - A Brief Forest History

Prehistory to 1920

It is estimated that approximately 40% of the land located in present day Armenia between 550 and 2000m was forested at the beginning of the anthropogenic period (UNECE, 2007). Ancient Armenia and Mesopotamia were one of the first places to possess incipient agriculture and records show people on the Armenian plateau involved in agriculture as early as the 14th century B.C. (Bournoutian, 2003). While some forestland was cleared for agriculture, population density was low enough for an ecological balance to be maintained (MNP, 2007).

The Armenian people first came to power briefly in the aftermath of the Uratian kingdom around 585 B.C. (Bournoutian, 2003). Over the next two and a half millennia historic Armenia and the Armenian people suffered from great political instability and were under the rule of many invading powers including the Persians, the Greeks, the Romans, the Seljuk Turks, the Mongols, the Ottoman Turks, and Tsarist Russia (Bournoutian, 2003; Moreno-Sanchez and Sayadyan, 2005). The invading armies and wars resulted in some further deforestation (Moreno-Sanchez and Sayadyan, 2005).

Estimates put the forest cover in the geographical location of present day Armenia to have been about 18% during the seventeenth and eighteenth centuries. Beginning in the eighteenth century, the impact of human use upon the forests began to increase. Deforestation increased as fuelwood was needed for industrial purposes, such as copper production. Also, forest land was cleared for agriculture in the lower elevations and for pastureland in the higher elevations (Moreno-Sanchez and Sayadyan, 2005).

Soviet Armenia (1920-1991)

On December 2, 1920, under the pressure of the advancing Turkish military, Armenia joined the Soviet Union. Upon joining the Soviet Union, Armenia's forests fell under Soviet control with management decisions being made in Moscow. In the first half of the twentieth century, the Central Soviet thought that the forests of their republics were a limitless resource that should be fully exploited to create a strong Soviet state. Stalin's political and economic policies led Armenia to change from a predominantly agricultural economy to an economy primarily based on industry – growing the cities and factories and creating an urban workforce at great cost to the country's natural resources and environment (Bournoutian, 2003; Moreno-Sanchez and Sayadyan, 2005; Sayadyan and Moreno-Sanchez, 2006).

Population increased markedly, up from about 720,000 people in the 1920s to almost two million by 1960. The number of settlements also increased and spread, bringing with it the need for fuel, construction materials, road networks, pasture land, and land for agriculture, which all resulted in further deforestation. Growing copper and molybdenum mining demanded large amounts of timber. Emissions from these plants and, later, chemical plants resulted in substantial levels of air pollution, which affected the health of forests throughout Armenia (Moreno-Sanchez and Sayadyan, 2005). With this rapidly increasing industrialization, the Armenian environment became ever more polluted and degraded (Bournoutian, 2003). Logging from the 1930s to the 1950s resulted in the loss of nearly all mature trees within Armenia's forests (MNP, 2007). The intense levels of deforestation continued until the 1950s and the national forest cover had decreased to 9.6% (284,379ha) in 1941 and 8.5% (253,000ha) by the 1966 National Forest Inventory (Moreno-Sanchez and Sayadyan, 2005) (Figure 2).

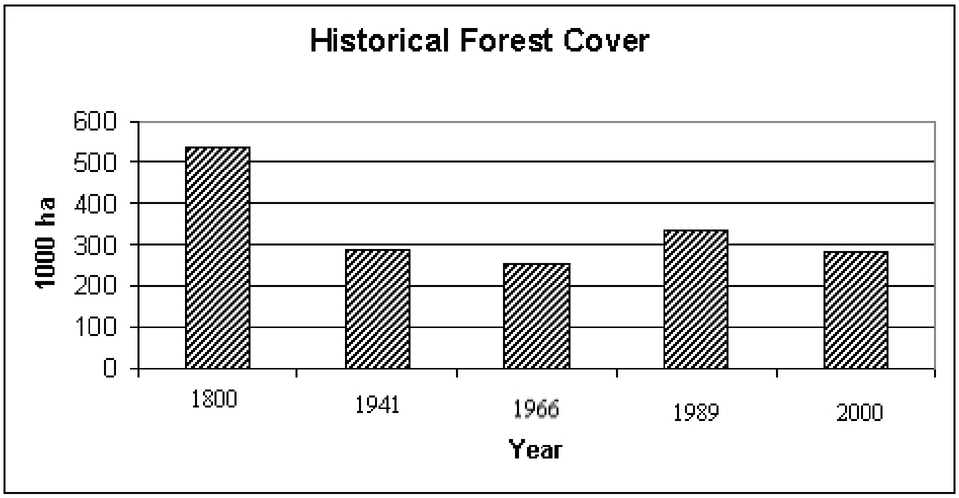

Figure 2. Historical forest cover in present day Armenia. Total ha in 1989 includes 90,000ha of pine plantation. An unkown portion of these plantations are also contributing to the 2000 totals. Source: Moreno-Sanchez and Sayadayan, 2005.

Ten-year management plans for Armenia's forests were created in Moscow (UNEP, 2007). Regional forestry offices were located as far away as the neighboring Republic of Georgia. During the 1950s, as the economy improved and the unsustainable environmental practices of the last thirty years became apparent, the Soviets began to put in place conservation policies and management practices for Armenia's forests. They reclassified Armenia's forests for protection and conservation purposes only, prohibiting all cutting except sanitary fellings and cuttings to promote regeneration. This policy continued until Armenia's independence in 1991 (Moreno-Sanchez and Sayadyan, 2005; Sayadyan and Moreno-Sanchez, 2006).

While World War II and a post war boom in industry and agriculture resulted in further deforestation, the amount of regulated and unregulated logging greatly decreased as timber imports from Russia increased. The Soviets also began to plant pine plantations around Lake Sevan, Armenia's largest body of water, and major cities such as Yerevan, the capital. Approximately 90,000ha of pine plantations were created between the 1950s and the 1980s. During the 1980s, there were almost no commercial cuts conducted within Armenia and 90% of the country's need for wood products was satisfied by imports from other Soviet Republics. As a result of these conservation measures, the forest cover rose to 11.2% (334,100ha) by the 1986-1989 National Forest Inventory (Moreno-Sanchez and Sayadyan, 2005; Sayadyan and Moreno-Sanchez, 2006).

Independence to Present

On September 21, 1991, Armenia declared its independence from the USSR (Bournoutian, 2003). Upon independence, all forests became property of the Armenian state and eventually fell under the management of Hayantar, the forestry branch of the Ministry of Agriculture within the Armenian government. Hayantar developed a forest code that continued forest management for conservation purposes, only allowing for sanitary and regeneration cuttings to promote forest health. Hayantar and Armenia as a whole, however, were immediately faced with a series of problems that made forest management difficult and resulted in great damage to Armenia's forests (Sayadyan and Moreno-Sanchez, 2006).

First, upon independence, the timber imports, which had been satisfying Armenia's wood product needs, decreased dramatically. A black market timber economy developed within Armenia to meet its internal wood product needs (Moreno-Sanchez and Sayadyan, 2005). Furthermore, while Armenia now needed to manage its forests for multiple use, there were no trained personnel and no institutes within the country for educating and training foresters. During Soviet times, everything was centralized and the nearest forestry schools were in Moscow, Georgia, and the Ukraine. These schools focused training and research on the coniferous production forests stretching across Siberia and the Eastern USSR; little attention was given to conservation management of mixed species deciduous forests, such as were found in Armenia (Sayadyan and Moreno-Sanchez, 2006).

Then, to compound the problem, in 1991, war broke out with Azerbaijan over the territory of Nagorno-Karabakh. In November of that year, Azerbaijan shut down the gas pipeline supplying gas to Armenia. In addition, Azerbaijan and Turkey blockaded their borders with Armenia resulting in terrible fuel and food shortages (Bournoutian, 2003). The transportation, economic, and energy blockade caused great pressure to be put on the forests as a source of fuel (Moreno-Sanchez and Sayadyan, 2005). It is estimated that 50% of household energy, heating and cooking, for communities living near forested areas came from fuelwood during the first half of the 1990s. During this time, legal and illegal forest cutting is estimated to have been about 600,000m^3/yr. A ceasefire was declared in 1994 but the blockade continues to this day (Boudjikanian, 2006). During the worst years, 1991-1993, the GDP fell by 60% and Armenians were forced to cut forest trees to cook food and heat their homes through the long and brutal Armenian winters (Bournoutian, 2003). Sixty-thousand to eighty-thousand trees were cut around the capital city of Yerevan alone (UNEP, 2007).

The situation gradually improved after the cease-fire. Natural gas began to reenter the country via Georgia and the ageing nuclear power plant reopened, both alleviating the pressure on the forests to provide fuel for heating and cooking (Bournoutian, 2003). Unfortunately, a great toll had already been taken on Armenia's forests. After those few years of intensive logging, experts estimate that the forest cover decreased from the 11.2% of the 1986-1989 National Forest Inventory to only about seven or eight percent - a loss of one-quarter of Armenia's total remaining forest cover (Moreno-Sanchez and Sayadyan, 2005).

An extensive illegal market for timber had developed during the early 1990s energy crisis to supply fuelwood. During this time, 70% of timber from forest cuts was used domestically to meet this need. The illegal logging was generally poorly organized and scattered in a few rural areas. With growing profits, the illegal loggers became better coordinated, accumulated machinery, and gained influence through bribes over more forestry officials at local and regional levels. They expanded the range and scope of their logging activities, executing illegal forest cuts in highly visible areas, such as near roads and cities, and within the boundaries of forest preserves and parks (Sayadyan and Moreno-Sanchez, 2006). With the return of alternative energy sources in the mid-1990s, these operations shifted their focus from cutting trees for fuelwood to cutting larger, higher value species of trees for export to Europe, Turkey, and Iran (Moreno-Sanchez and Sayadyan, 2005). This high-grading leaves behind forests comprised mostly of low value species and with a degraded genetic stock for regeneration (Sayadyan and Moreno-Sanchez, 2006). Studies suggest that the recent rates of combined legal and illegal logging is higher than recent estimated forest growth rates (600,000m^3/yr in cutting compared to 450,000m^3/yr in growth) (Moreno-Sanchez and Sayadyan, 2005). Because the logging operations are carried out illegally, they are done without using proper extraction methods in order to minimize the environmental impact (Sayadyan and Moreno-Sanchez, 2006). Armenia's forests are on steep slopes with soils that are prone to erosion and it is estimated that two-thirds of Armenia's soil already suffers from moderate to heavy erosion (Moreno-Sanchez and Sayadyan, 2005; MNP 2007). Harvest methods are not appropriate for the mountainous topography. Unplanned logging roads have led to accelerated erosion, sedimentation of streams and rivers, and landslides in some locations (Sayadyan and Moreno-Sanchez, 2006). It is estimated that the central office of Hayantar only detects and records 11% of the total amount of illegal logging (UNECE, 2007). In addition, corruption of forestry officials and the low priority given to forest management at the national level have prevented any successful efforts to more effectively implement, enforce, or update the forest code (Sayadyan and Moreno-Sanchez, 2006).

Currently, Armenia's forests are in a desperate situation. Few skilled forestry personnel exist within the country and there is only one fledgling program offering forestry training (Sayadyan and Moreno-Sanchez, 2006). No forest inventory has been conducted since the last Soviet National Forest Inventory in 1989 and local forestry branches lack the personnel, funds, and equipment to conduct surveys (Sayadyan and Moreno-Sanchez, 2006). Management decisions, therefore, are still based on the 1989 data (Sayadyan and Moreno-Sanchez, 2006). After years of centralized conservation management that did not allow for the input of local forest communities in management decisions or for those communities to make any use of the forests in gaining their livelihood, local forest communities feel disconnected from their forests as a sustainable resource and turn instead to illegal logging and also clear forest land for grazing (Sayadyan and Moreno-Sanchez, 2006). Illegal logging operations only grow in size and the response of the Armenian government has been nowhere near sufficient to fight this problem. With the continued loss of forest cover, Armenia's other environmental problems, primarily erosion and water supply depletion, will increase and some experts warn that, at the current rate of deforestation, by 2050 the remainder of Armenia's already fragmented forests will be gone (Moreno-Sanchez and Sayadyan, 2005; Boudjikanian, 2006).

Chapter 3: Literature Review

Deforestation can impact soils in multiple ways including reducing organic carbon and nitrogen (Pennock and Kessel, 1997). Mroz et al. (1985) showed that whole tree harvesting of northern hardwoods in the Upper Peninsula of Michigan resulted in losses of nitrogen and soil exchangeable potassium. These impacts can be increased when regeneration following the cut is suppressed (Bormann et al., 1968). Deforestation and regeneration suppression can increase soil erodibility and erosion (Bormann et al., 1974; Cebecauer and Hofierka, 2008). It has also been shown to reduce the cation exchange capacity of the soil and the levels of soil nutrients such as calcium, magnesium, potassium, sodium, aluminum, nitrogen, chlorine, iron, and phosphorus (Likens et al., 1970; Dominski, 1971; Bormann et al., 1974; Eden et al., 1991). Deforestation and conversion to pastureland can increase bulk density (Eden et al., 1991; Desjardins et al., 2004).

The detrimental impacts of deforestation and subsequent regeneration suppression due to land cover change are amplified when the cutting occurs on steep mountain slopes due to the increased risk of erosion, the accompanying loss of nutrient capital, organic and inorganic material, as well as degradation of the soil structure (Bormann et al., 1974; Cebecauer and Hofierka, 2008). In the hilly region between the Dongzhi Plateau and Louchan Plateau in China, Zheng et al. (2005) found erosion from deforestation to have reduced organic matter, total nitrogen, and available phosphorus by nearly half or more. Sanchez et al. (2002) found soil losses in the Venezuelan Andes to be about 40 times higher in cultivated land than in native forests and pasture land to have double the soil losses compared to native forests. A study in the mountainous area of the Wolong Nature Reserve in Sichuan Province, China showed soil quality to be highest in natural forestland compared to secondary forest land and still lower in grassland. The study also showed organic matter to be highest in the natural forestland and to decrease respectively in the secondary forestland and grassland with bulk density showing the opposite trend (Fu et al., 2003). Khresat et al. (2008) showed that in the mountainous region of northwestern Jordan, converting native forests to agricultural uses decreased organic matter and cation exchange capacity while increasing bulk density and contributed to increased erosion and a loss in soil fertility. A study in the Alay Mountain Range of Kyrgyzia by Glaser et al. (2000) showed that the conversion of native juniper forests to pastureland resulted in a 20% increase of nitrogen due to deposition of animal excrement and a decrease in total organic carbon by 30%. Similarly, a study in the hilly area of Rawalakot Azad Jammu and Kashmir found native forests to have higher levels of organic matter and nutrients such as nitrogen, potassium and phosphorus, and lower levels of bulk density than forestland that had been converted to grassland (Abbasi and Rasool, 2005; Abasi et al., 2007).

Some studies have been conducted in the Armenian highlands, comprising eastern Turkey, Armenia, and northern Iran, and the surrounding area looking at the impact of deforestation and land cover change on soils. Basaran et al. (2008) found that the conversion of native woodlands and grasslands to plantations, recreation land, and cropland had an impact upon soil organic carbon, bulk density, and pH in Indagi

Mountain Pass, Cankiri, Turkey. In the Tarus Mountains of Turkey, Celik (2005) showed cultivated soils had a higher bulk density and lower levels of soil organic matter compared to adjacent forests. To the south of Armenia, in the Lordegan area of Iran, Hajabbasi et al. (1997) found that cutting of the native oak forests and subsequent tillage of these soils resulted in increased bulk density and decreases in organic matter, total nitrogen, and soluble ions. In central Iran, Nael et al. (2004) showed that soil organic carbon and microbial respiration decreased following cutting of native oak forests.

The importance of Armenia's forests, the erodibility of Armenia's mountain soils, the recent rate of legal and illegal logging (600,000m^3/yr), and, with only eight percent of fragmented forest cover remaining, deforestation and soil degradation are issues of major concern within the Republic of Armenia. Despite this concern, few studies have quantified the effect deforestation has on the soils there. With this quantitative data and an accurate forest inventory, Armenia could begin to develop silvicultural management plans that allow for some degree of legal, regulated logging in areas of the country where it may be carried out sustainably and could also begin to reduce the amount of illegal logging that is currently occurring. This study looks at the impacts of deforestation and subsequent land use upon the underlying soils on one hillside in central Armenia.

Chapter 4: Site Description

The study site was located in Kotayk Marz, in the town of Hrazdan, 45km north of the capital city of Yerevan, southwest of the village of Djurarat and the road that travels west into the Hankavan Valley (N 40^o 32’ 36.8”, E 44^o 44’ 53.0”) (Figure 3). The site is on the northern aspect (20^o) of a hill with a 28% slope that is situated at the easternmost extent of the Tsaghkunyats Mountain Range. The highest elevation within the study site was 1890m. The soil found on the site formed in place from parent material. The area was then uplifted and has since undergone colluviation (Edilyan and Petrosyan, 1976). The soils in the immediate area are Ustepts, Ustolls, Orthents. As in much of Armenia, the climate of the study site is semi-arid and prone to desertification (MNP, 2007). The average rainfall is between 600 and 800mm per year with May and June being the rainiest months of the year. In the winter, up to two meters of snow can accumulate. In the summer temperatures can rise to above 20^{o}C and fall to below -10^{o}C in the winter (Susanna Babaxanyan, environmental expert for Kotayk Marz, personal communication, July 2008). On the hill is the easternmost edge of a natural Georgian oak/Caucasian hornbeam (*Quericus iberica* and *Carpinus caucasica*) forest that extends into the mountains behind the village of Tzakadzor and into the Hankavan Valley (Figure 4). This forest comprises the majority of the two percent of forested land found in the central region of Armenia. The area of the study site on this hill was approximately 190ha.

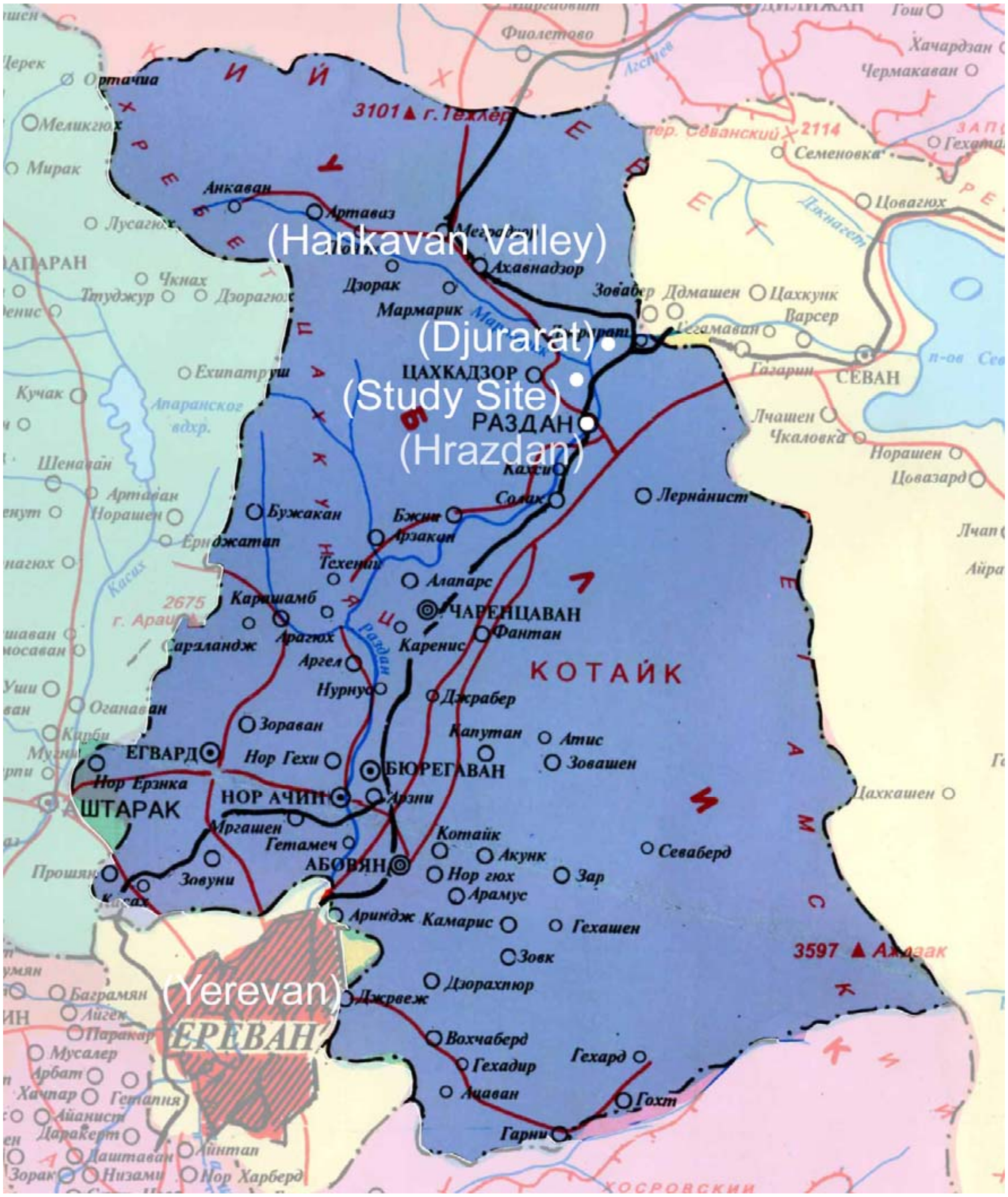

Figure 3. Map of Kotayk Marz with referenced areas labeled in white. The map prepared by USSR. The map is in the public domain. Documentation can be found in Appendix 1.

Figure 4. Natural oak/hornbeam forest extending into Hankavan Valley. Photo by Jason Rhoades.

While the study site currently has three distinct areas of vegetative cover, within the past two centuries, the entire north face of the hill was covered in the same natural oak/hornbeam forest (S. Margaryan, District Forester, personal communication, July 2008). At the farthest eastern edge of the hill, the forest was cut and the land was converted to pasture by local shepherds to graze their sheep, goats and cows (Figures 5 and 6). The clearing of the forest and its conversion to pasture land probably began shortly after the arrival of the first settlers in 1828, who founded what would soon become the village of Djurarat (H. Alexanyan, Hrazdan Historian, personal communication, July, 2008). A few remnant oaks from the original forest still exist scattered within the pasture area and increment borings from a few of the trees show their ages to be 186, 168, and 127 years (Figure 7). The land is still used for grazing livestock. It is owned by the state and the villagers are allowed to pasture their animals on it without regulation (S. Margaryan, District Forester, personal communication, July 2008). The current area of land under pasture cover is approximately 40ha.

Figure 5. Transition from forest to pasture. Photo by Jason Rhoades.

Figure 6. Pasture area. Photo by Jason Rhoades.

Figure 7. Remnant trees in pasture with the village of Djurarat in the distance. Photo by Jason Rhoades.

Adjacent to the western edge of the pasture begins the natural oak/hornbeam forest (Figure 8). This forest was last heavily logged about 87 years ago and then allowed to naturally regenerate (S. Margaryan, District Forester, personal communication, July 2008). Presently, it has a well developed overstory of Georgian oak, Caucasian hornbeam, Norway maple (*Acer platanoides*), European ash (*Fraxinus excelsior*) and apple (*Malus*), with an understory comprised of Georgian oak, Caucasian hornbeam, Norway maple, European ash, European mountain ash (*Sorbus aucuparia*), Caucasian pear (*Pyrus Caucasica),* and wild cherry (*Prunus avarium*).

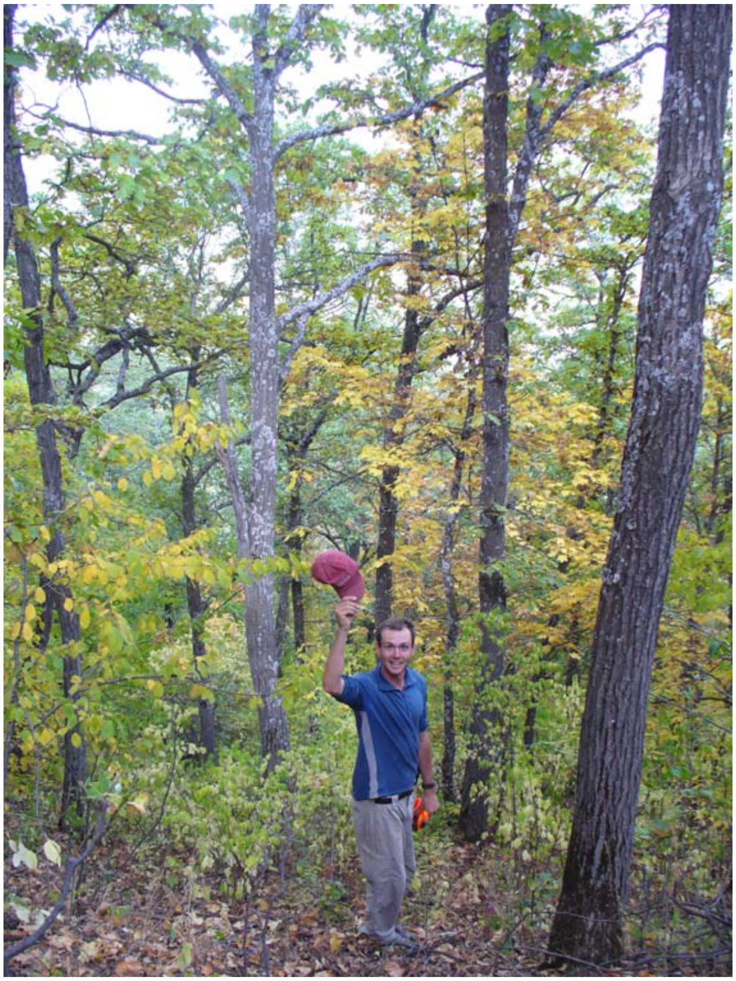

Figure 8. Interior of forest. Photo by Jason Rhoades.

Adjacent to the 87 year old forest is a similar forest tract that was cut by local residents for fuelwood during the energy crisis. From 1992 to 1994, the unplanned and unregulated harvest resulted essentially in a clear-cut of the area, with nearly every tree being removed from the site (S. Margaryan, District Forester, personal communication, July 2008) (Figure 9). The forest was allowed to naturally regenerate following the cut and the oaks and hornbeams have since stump-sprouted but have been left untended resulting in a bushy coppice regeneration (Figures 10 and 11). There is also prolific hornbeam regeneration in areas of the coppice receiving more light (Figure 12). The area of coppice forest is approximately 110ha.

Figure 9. Transition from forest to coppice with remnant trees. Photo by Jason Rhoades.

Figure 10. Stump-sprouting of cut tree in coppice. Photo by Jason Rhoades.

Figure 11. Bushy coppice regeneration in coppice area. Photo by Jason Rhoades.

Figure 12. Hornbeam seedling regeneration in coppice. Photo by Jason Rhoades.

The portion of forest that went unlogged during the energy crisis was spared because a church and cemetery lie at the bottom of the hill and the villagers did not want to disturb those sites (Figure 13). This area of unlogged forest covers approximately 40ha. Both forest stands are owned by the state and managed by Hayantar. As in the rest of Armenia, the only logging permitted is sanitary cutting, but some small scale illegal logging does occur in the form of high grading (Figures 14 and 15). No forest inventories have been conducted since the 1989 National Forest Inventory, but the local branch of Hayantar hopes to begin surveying again within the next few years. Hayantar also plans to thin the coppice forest stand within the next four years but has no other management plans for either stand (S. Margaryan, District Forester, personal communication, July 2008).

Figure 13. Forest with church and cemetery at base of hill. Photo by Jason Rhoades.


Figure 14. Illegal logging in forest. Photo by Jason Rhoades.


Figure 15. Illegal high-grade cut in forest. Photo by Jason Rhoades.

Chapter 5: Methods

This study looked at soil characteristics and nutrient levels within the pasture, the forest, and the coppice. The development of these three land cover areas is a result of various stages of Armenia's historical development and the pressures that have been placed on the forest ecosystems therein. The easternmost edge of the forest was cut and converted to pasture around 180 years ago as a result of settlement expansion and the concurrent need for grazing land. The coppice was cut in the mid 1990s as a direct result of the energy crisis. The central portion of forest escaped this recent cutting due to the location of a church and graveyard below it at the base of the hill. It is a unique opportunity to find these three land cover areas adjacent to each other on the same hillside with the same parent material and subject to the same environmental conditions. It would be difficult to find other hillsides with similar conditions and infeasible to try to artificially replicate the land cover areas. Therefore this study has only one replication of each land cover area from which to draw its conclusions. While it would be desirable to have multiple areas of each land cover type from which to sample and analyze and thereby avoid the problem of pseudoreplication, it is a common problem in experiments and studies occurring on a large scale in the natural world and many other experiments and studies have been conducted with the same constraint. Experiments and studies with pseudoreplication can still yield valuable results as long as the implications of inferential statistics performed on the data are not overestated (Hurlbert, 1984; Oksanen, 2001; Wu and Hobbs, 2002; Oksanen, 2004).

An area measuring 140m across by 125m down the slope was established in each of the three land cover areas - pasture, forest, and coppice (Figure 16). A ten meter buffer was created along the borders. Three transects were randomly located within each land cover area. Transects ran down the slope. Sampling sites were located along the transects at 25m intervals beginning 25m from the top of the slope. Four sampling sites were located on each transect yielding twelve sampling sites in each land cover area (Figure 17).

At each sampling site, the latitude, longitude, elevation, slope, aspect, and topography were recorded. Then an inventory of the vegetative cover was conducted. Overstory was measured using point sampling with a 10 BAF prism and DBH and height were recorded by species for every in tree (Avery and Burkhart, 1983). Around the center point of each sampling site, all of the seedlings and saplings were recorded within a 1/100acre subplot. Also, the percent cover by species was recorded for herbaceous vegetation within a one square meter subplot located over the center point. The inventory of seedlings, saplings and herbaceous cover was repeated in radial subplots located twelve meters away from the center point in the semi-cardinal directions (NW, NE, SE, SW) (Figure 17).

At the center of each sampling site, a soil pit was dug to a minimum depth of 24cm. The soil characteristics were recorded and 200g of soil were collected. Then at a distance of one meter in each of the cardinal directions, a soil probe was used to collect another 200g of soil to a depth of 24cm. The five separate soil samples were then combined to form one composite sample. Three bulk density soil samples were taken using a bulk density sampler from the area immediately around the center point. The samples were divided into zero to five centimeters in depth and five to ten centimeters in depth.

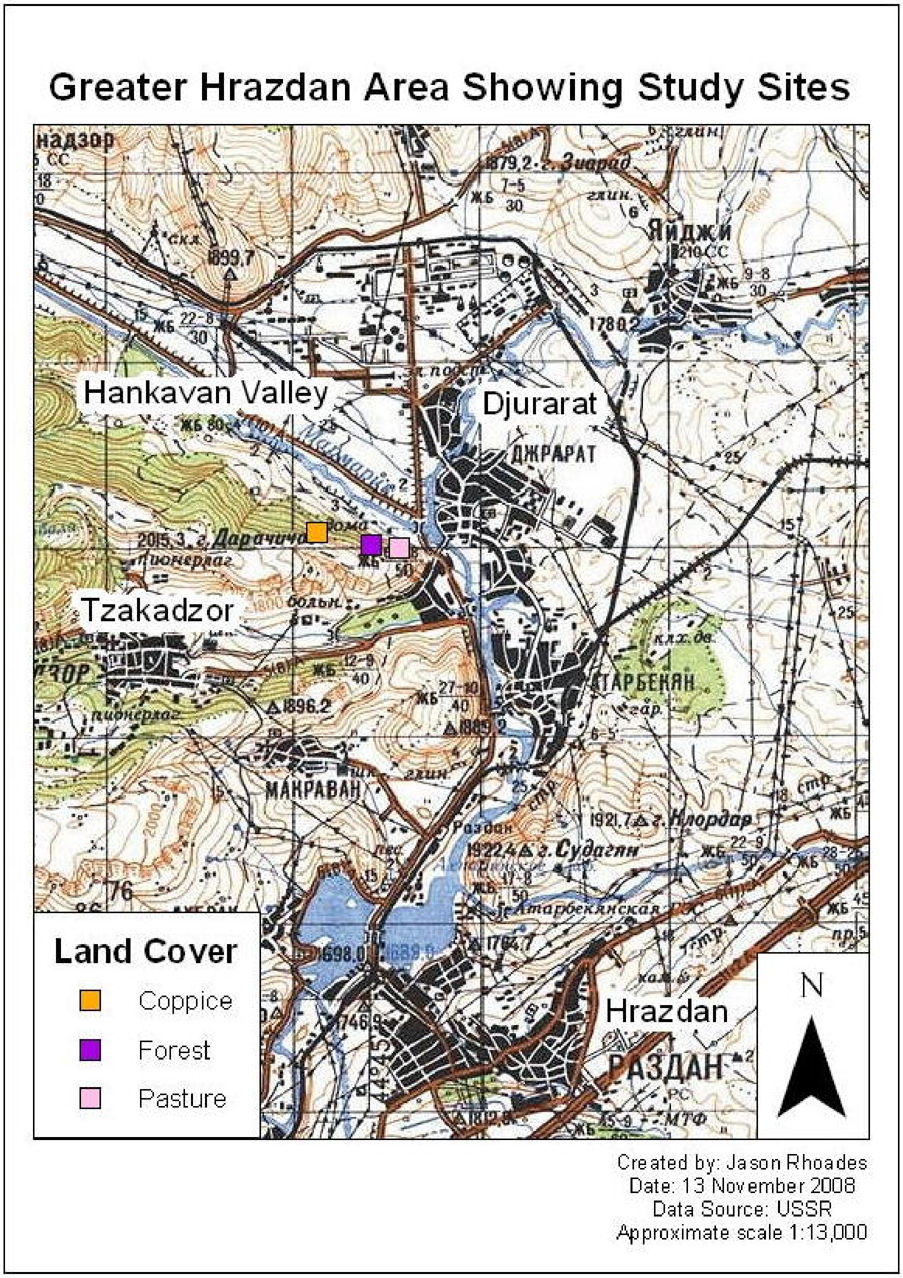

Figure 16. Topographical map with three land cover area study sites. The map prepared by USSR. The map is in the public domain. Documentation can be found in Appendix 1.

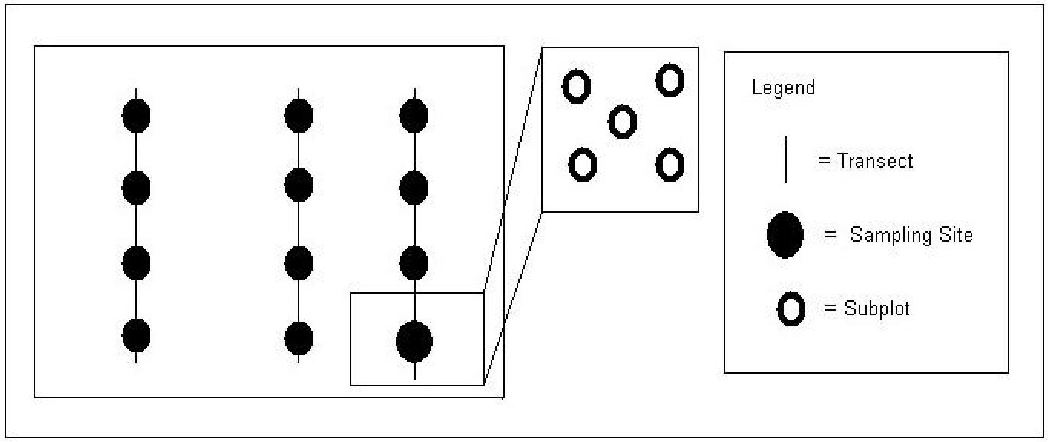

Figure17. Sampling design for one of the three land cover areas. The two other areas had similar designs (figure not to scale).

The soil samples were air dried then sent to the soils laboratories at the State Agricultural Institute (SAI) in the capital city of Yerevan and to the University of Applied Sciences-Weihenstephan in Freising, Germany for analysis. At one sample site within each land cover area that was representative of the land cover area in terms of topography and vegetative cover, a deeper soil pit was dug to further look at soil development and characteristics and to find a key soil horizon common to all three land cover areas. Finally, another transect was run in each land cover area and deep pits were dug at four more sites at 25m intervals in order to provide more observations of soil development and characteristics.

At the SAI laboratory in Yerevan, the soil samples were analyzed for percent soil organic carbon using a modification of the Tyurin method (USSR Science Academy, 1960). Electrical conductivity and total dissolvable salts were determined on an Ultrameter manufactured by the Myron L Company. Determination of pH was done on a

Milwaukee SM 802 pH/EC/TDS meter (Sparks, 1996). Total nitrogen was found using the Ginsburg extraction and Kjeldahl distillation methods (Anon.[a], 1963). Total phosphorus was found using the Ginsburg extraction and color development by an acid ammonium molybdate reagent (Anon.[b], 1963). Total potassium was found using a propane flame spectrophotometer (USSR Science Academy, 1960). Texture was determined by sieving. The carbon to nitrogen ratio was determined from the respective carbon and nitrogen results. Finally the bulk density was recorded by dividing the weight of the samples by the volume of the bulk density sampler ($63.68 cm^3$) (Blake and Hartage, 1986). At the laboratory in Germany, thermogravimetry was used to analyze the soil samples for percent soil organic carbon, percent total nitrogen, and percent clay (Siewert, 2004).

SAS 9.1.3 service pack 4 software was used to test the laboratory results for normality, correlation, ANOVA and Tukey's test for honestly significant difference (Steele and Torrie, 1960) (SAS 9.1.3 service pack 4 is copyright © 2008 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). Results of the statistical analysis are shown in Table 1. No statistically significant differences were found between slope positions or between the interactions of land cover type and slope position in the statistical analysis (results not shown).

Table 1. Laboratory Results. Mean value (± 1 SE) of quantitative soil nutrients and characteristics in the three land cover areas. The same letter for each value indicates no significant difference between land cover areas using Tukey's test for honestly significant difference (α = 0.05). n=36.

	Quantitative Soil Properties					
	Forest		Coppice		Pasture	
%Organic Carbon	8.21 ± 0	a	6.33 ± 0.33	b	5.88 ± 0.45	b
%Organic Carbon - Thermo	6.7 ± 0.31	a	5.4 ± 0.33	b	4.3 ± 0.29	c
pH	6.9 ± 0.03	a	6.8 ± 0.05	a	7.0 ± 0.04	a
Salts	0.3 ± 0.002	a	0.03 ± 0.003	a	0.03 ± 0.003	a
Electrical Conductivity	80.97 ± 4.9	a	78.83 ± 5.8	a	79.63 ± 7.47	a
%Nitrogen	0.46 ± 0.03	a	0.32 ± 0.02	b	0.40 ± 0.04	a, b
%Nitrogen - Thermo	0.58 ± 0.03	a	0.46 ± 0.03	b	0.38 ± 0.02	b
%P2O5	0.19 ± 0.01	a, b	0.16 ± 0.01	a	0.20 ± 0.01	b
%K2O	3.04 ± 0.13	a	2.12 ± 0.18	b	3.16 ± 0.13	a
C:N	10.5 ± 0.47	a	12.1 ± 0.89	a	9.4 ± 0.99	a
Bulk Density (g/cm^3)	0.87 ± 0.02	a	0.93 ± 0.02	b	1.153 ± 0.02	c

Chapter 6: Results and Discussion

The unplanned and unregulated forest cuttings and land cover changes within the study area have had an impact on the soils therein. Erosion rates appear to have increased in both the pasture and the coppice compared to the forest. The increased erosion then acted as an important driver, which affected other soil characteristics and nutrient levels. In addition, the changes in vegetative cover between the three areas and the introduction of grazing animals in the pasture led to different inputs being added to the soils in each of the land cover areas and possibly to differing rates of organic matter decomposition. These changes of input levels and decomposition rates may have further affected soil characteristics and nutrient levels. In the rest of this section, first the evidence for the varying erosion rates will be presented, then the significant variations in soil nutrients and characteristics will be discussed, followed by a general conclusion looking at the impacts of deforestation and land cover change in the study area as a whole.

Erosion

The horizon development, soil structure, and percent coarse fragments in the transects of deep pits in each land cover area indicate that more erosion has taken place in both the pasture and the coppice compared to the forest. The A horizon in the forest had an average depth of 34.5cm. In the coppice the A horizon is only 13.5cm on average (complete descriptions of the deep pit field characteristics are found in Appendix 2) (Figure 18).

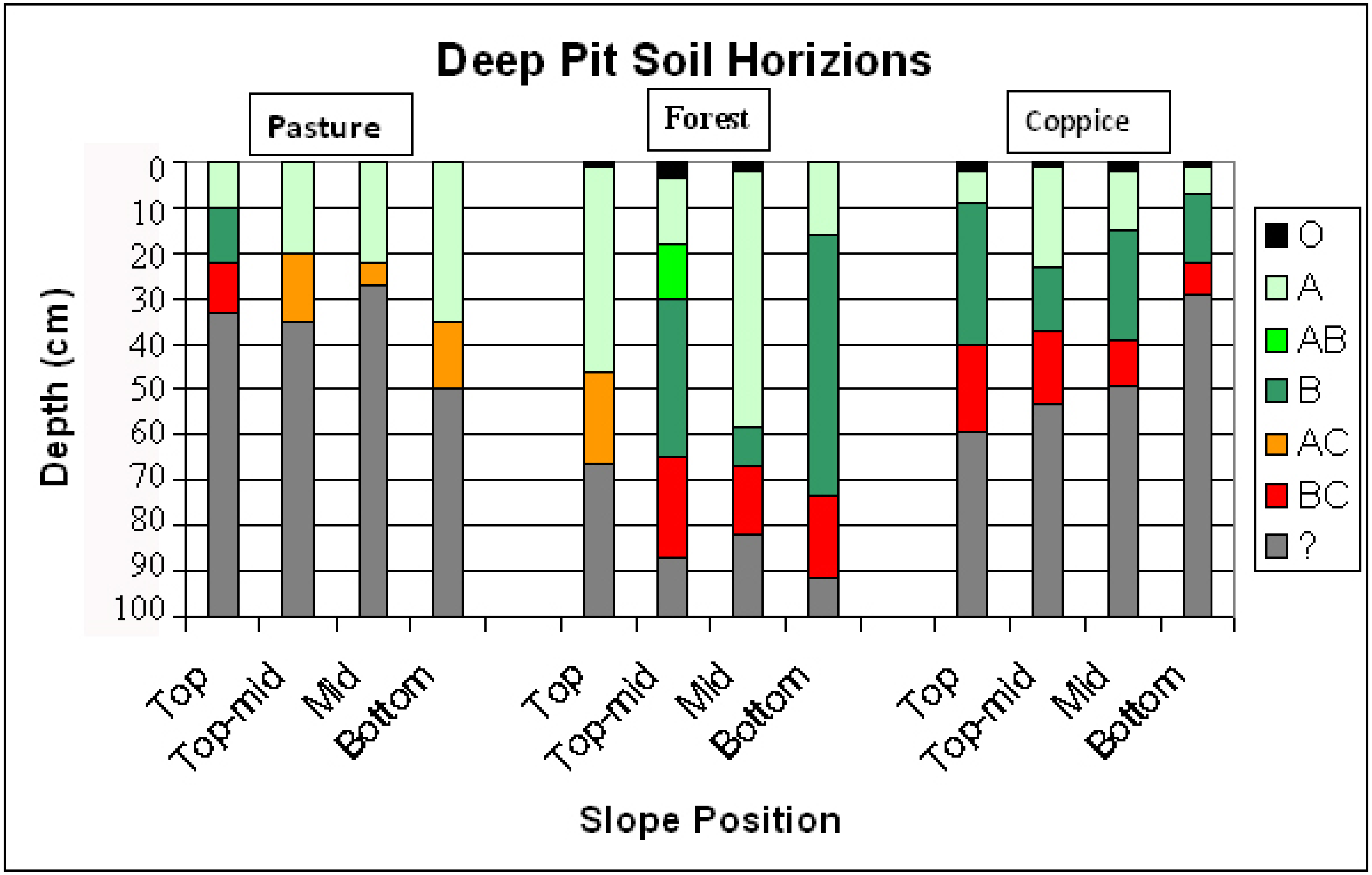

Figure 18. Soil horizons for the soil pits in the deep pit transects. The horizon labeled "?" and colored grey denotes area below maximum depth of pit and so of unknown characteristics.

As slope, aspect, and parent material are the same in the forest and the coppice, increased erosion in the coppice due to the unplanned and unregulated clear cut is the clearest explanation of this difference. Also, in all three land cover areas, the percent of coarse fragments rose sharply, often from 20 or 30% to 55 or 60%. This rise usually coincided with the upper boundary of a transitional C horizon (usually AC in the pasture and usually BC in the forest and coppice) and is marking the transition from primarily soil to the underlying unweathered basalt. In the forest, this coarse fragment-rich transitional C horizon was found at an average depth of 62.75cm. In the coppice it was found at an average depth of 34.5cm (Figure 20). This would indicate that about 20cm or more of soil has been lost due to the one clear cut.

The transitional C horizon indicates that even more erosion has occurred in the pasture. It was found at an average depth of 21.75cm, 41cm shallower than the forest (Figure 19). Unlike the coppice and the forest which generally have an A horizon above a B horizon, three of the four deep transect pits dug in the pasture did not have a B horizon and only contained an A horizon, 21.75cm deep on average, over an AC horizon (Figure 18). If 40cm of soil have been eroded from the pasture compared to the forest, this would mean that the entire A horizon that may have once been present in the pasture soils (34.5cm deep in the forest) has been eroded. The soils now located at the surface would have once been the B horizon when the pasture was under forest cover.

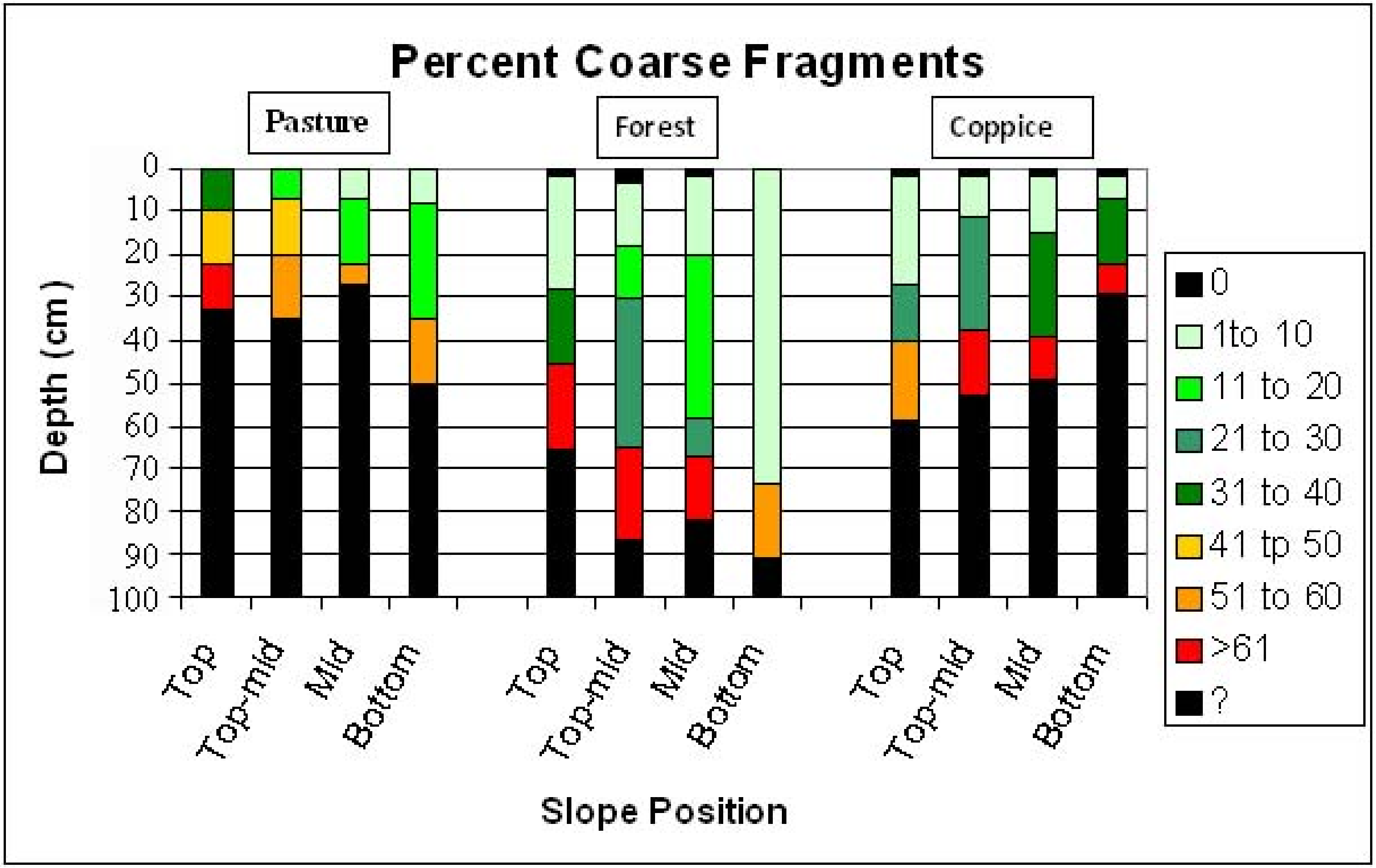

Figure 19. Percentage of coarse fragments for soil pits in the deep pit transects. The horizon labeled "?" and colored black denotes area below maximum depth of pit and so of unknown characteristics.

The A horizon in the pasture, with a characteristic dark brown color (Munsell 10YR 3/3 was recorded most frequently in the pasture A horizon), is due to recent organic matter additions over the past 200 years which can darken the color of a soil in a relatively short amount of time (Soil Survey Staff, 1951; Singer and Munns, 1987; Munsell, 1994; Vidic and Lobnik, 1997; Brady, 2002).

This is supported by the structure of the soils in the forest, pasture, and coppice. Soil structure generally becomes more granular with the addition of organic matter, but it is a complex process and slow to change (Tate, 1987; Brady 2002). Because of this, A horizons often have a more granular structure; lower horizons, including B horizons, are usually more subangular blocky or angular blocky (Singer and Munns, 1987; Vidic and Lobnik, 1997; Brady, 2002; Buol et al., 2003). This is the case in the forest and the coppice, which have a granular structure to an average depth of 13.5cm and 10.5cm respectively before the soil structure changes to subangular blocky (Figure 20). The transition from granular to subangular blocky in the forest and in the coppice generally occurs where the soils transition from an A horizon to a B horizon (Figures 18 and 20). In the pasture only one of the pits had a layer of granular structure (10cm) and the other pits either began as subangular blocky or had a shallow layer (7cm) of granular/subangular blocky soil before becoming subangular blocky (Figure 20). The fact that this structure is generally associated with the B horizon in the forest and coppice but is found in the pasture A horizon supports the idea that the current pasture A horizon was, in fact, once a B horizon that has been uncovered by erosion and has had recent additions of organic matter.

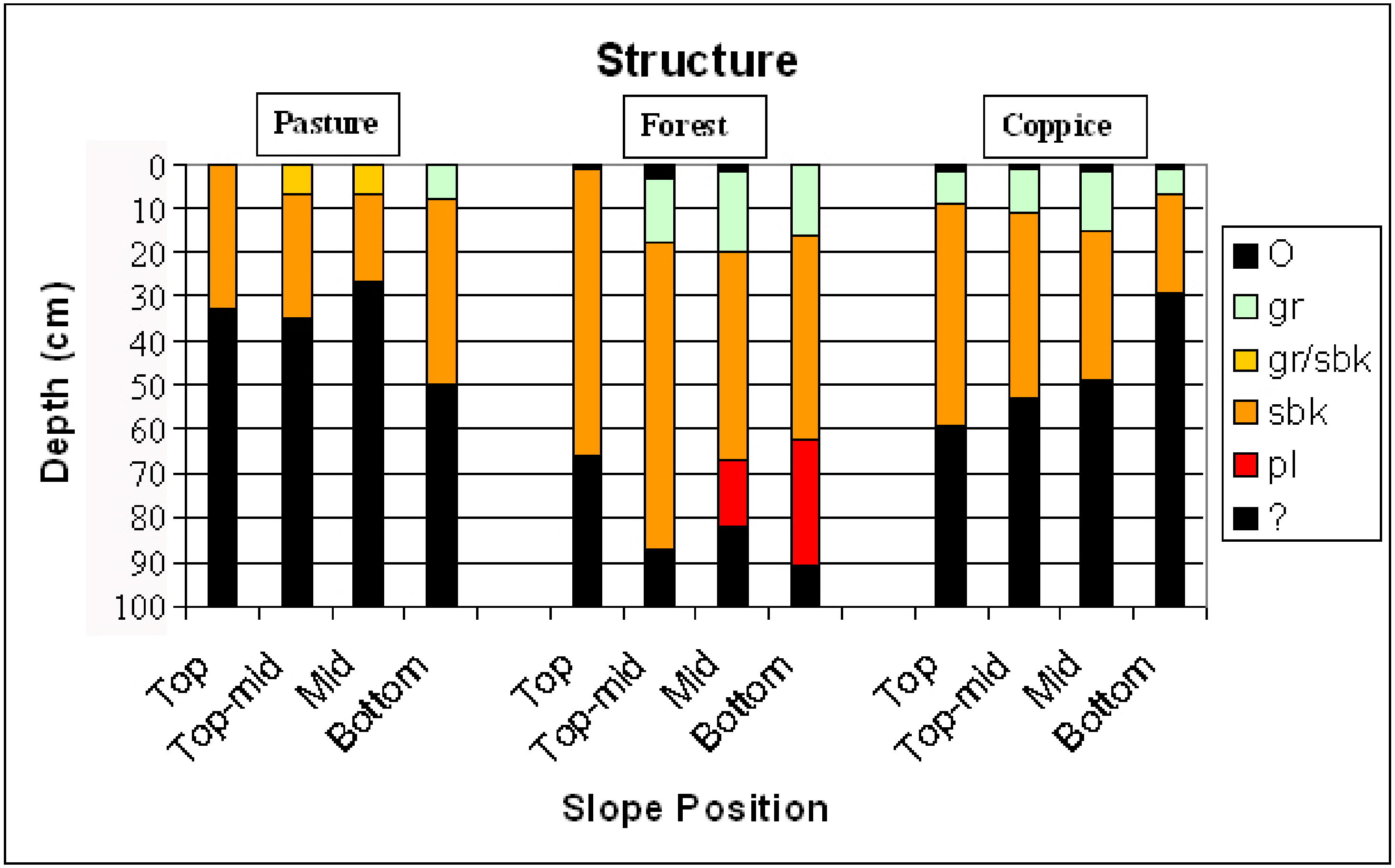

Figure 20. Soil structure for soil pits in the deep pit transects. The horizon labeled "?" and colored black denotes area below maximum depth of pit and so of unknown characteristics.

Other field observations support the argument that erosion has taken place at a higher rate in the pasture and, to a lesser degree, the coppice in comparison to the forest. An O horizon was found in fifteen of the sixteen total pits in the forest. O horizons were only present in five out of sixteen pits in the coppice and were not present in the pasture. Multiple factors may be influencing O horizon development such as varying rates of vegetative residues being added to the soils and varying decomposition rates for organic matter within each land cover area. The inconsistent presence of an O horizon may also be due to erosion and could indicate that greater erosion has taken place in the coppice and the pasture. Higher erosion rates in these areas compared to the forest would remove O horizons that were once present and subsequently prevent their buildup (Dominsky, 1971; Pennock and Kessel, 1997; Abbasi and Rasool, 2005; Khresat et al., 2008).

The relative bulk density of the three land cover areas is another possible indicator of erosion. The differences in the bulk densities of the upper 10cm of soil in each area were statistically significant; highest in the pasture ($1.53 g/cm^3$), lower in the coppice ($0.93 g/cm^3$), and lowest in the forest ($0.87 g/cm^3$) ($P=<0.0001$) (Figure 21). Erosion could have increased the bulk density of the pasture and coppice soils by removing the less dense upper level soils and thereby bringing the denser lower level soils to the surface (Brady, 2002). This is supported by the relatively higher density in the five to ten cm soil compared to the zero to five cm soil found in each of the three land cover areas (Figure 22). It is important to note, however, that compaction due to livestock in the pasture and potentially lower amounts of vegetative residue inputs into the soil leading to lower levels of soil organic matter in both the pasture and the coppice as compared to the forest could also have contributed in creating the differences in the soils' relative bulk densities (Eden et al., 1991; Koutika et al., 1997; Brady, 2002; Abbasi and Rasool, 2005; Abassi et al., 2007; Khresat et al., 2008).

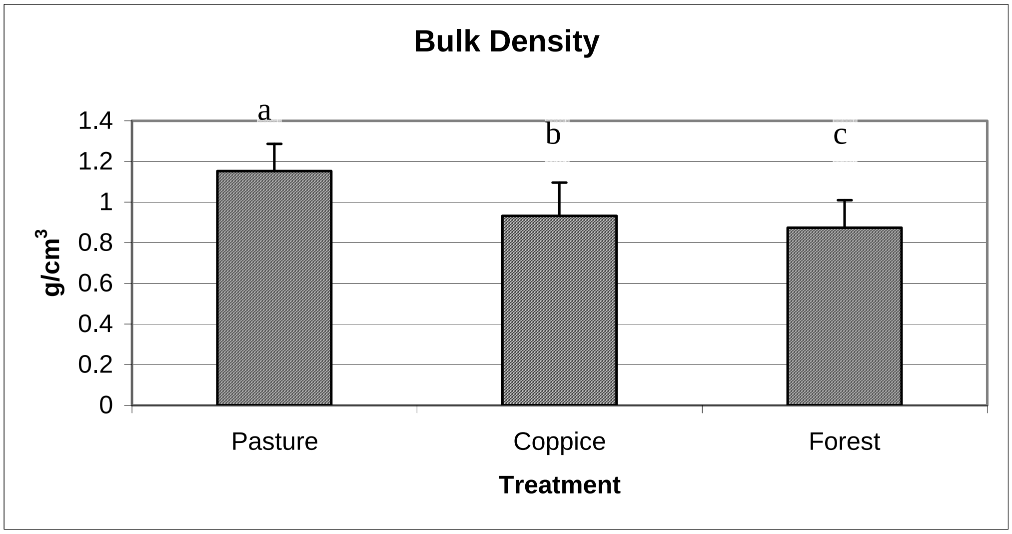

Figure 21. Bulk density of soil samples. Error bars denote one standard deviation. The same letter for the values indicates no significant difference between land cover areas using Tukey's test for honestly significant difference (α = 0.05).

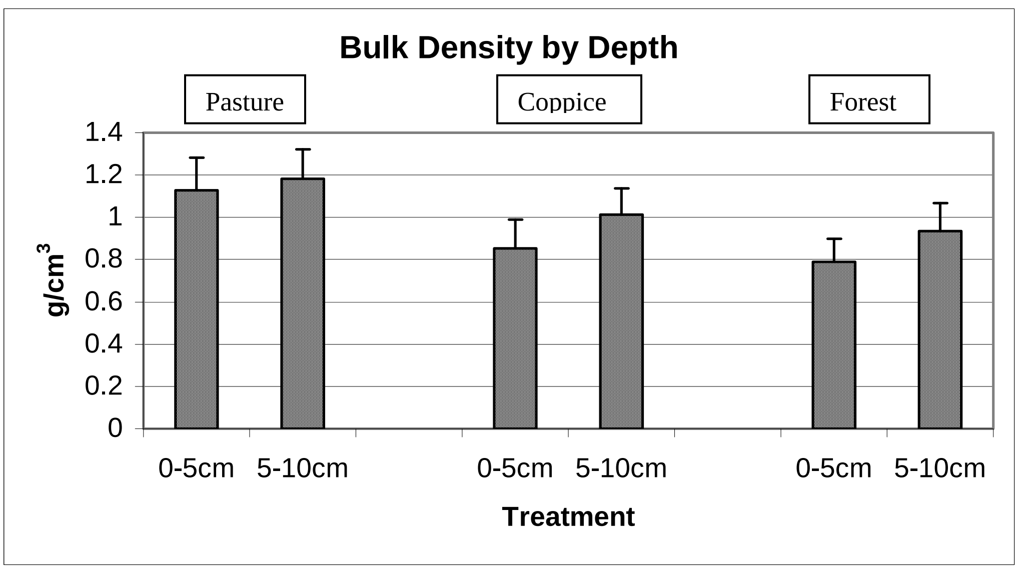

Figure 22. Bulk density by depth of soil samples. Error bars denote one standard deviation.

Although multiple factors affect soil consistency, it can also be used to compare the relative amounts of erosion that may have taken place. Pasture soils tended to be more firm, while forest soils tended to be more friable, with coppice soils falling in between (Table 2). Firm consistency is usually associated with more compacted subsoils while friable consistency is usually associated with surface soils higher in organic matter. (Vidic and Lobnik, 1997; Brady, 2002; Buol et al., 2003). Considering that the three areas are adjacent, from the same parent material, and subject to the same environmental conditions, the clearest explanation of the differences in consistency is that the upper levels of soil have been eroded to a greater extent in pasture and coppice compared to the forest, uncovering the more compacted subsoils that were once located lower in the soil profile.

Table 2. Upper horizon soil consistency in all pits.

	Soil Consistency		
	Very Friable	Friable	Firm
Pasture	0	9	7
Forest	6	10	0
Coppice	0	16	0

Finally, the impacts of recent erosion were visible in parts of the pasture and coppice (Figures 23 and 24). While none of these field observations may be conclusive in and of themselves, taken together they indicate a consistent picture that erosion has occurred as a result of deforestation and land cover change. The relative amount of erosion occurring in each land cover area is an important factor in explaining the other changes that have occurred in the study area due to deforestation and land cover change.

Figure 23. Visual evidence of erosion in pasture. Photo by Jason Rhoades.

Figure 24. Visual evidence of erosion in coppice. Photo by Jason Rhoades.

Other studies have also recorded similar increases in erosion due to land cover change. Sanchez et al. (2002) found that erosion rates had increased from 540kg/ha/yr to 1110kg/ha/yr when forest land was converted to pasture land on steep slopes in the Venezuelan Andes, despite the pasture land being ungrazed. They attributed the increase in erosion across land types in their study to decreasing amounts of organic matter and lack of vegetative cover to intercept rainfall in the deforested areas. In the Hubbard Brook watershed experiments, Bormann et al. (1974) recorded the levels of erosion in terms of particulate matter output after clear cutting a watershed and suppressing regeneration. In five years, the particulate matter output increased exponentially from 16.20kg/ha/yr to 378.80kg/ha/yr while the levels in a similar watershed remained relatively stable at an average of 25.42kg/ha/yr over the same period. Celik (2005) showed only a slight increase in erodibility between pasture and forest land as measured by a USLE-K factor (0.14 and 0.11 respectively). The pasture in Celik's study, however, had higher levels of organic matter than the forest, which would act to reduce erosion and erodibility. Also, Celik's study was conducted on a plateau and so low slope combined with the high levels of organic matter present in the pasture may account for the similar USLE-K values. In agreement with the bulk density levels found in the pasture, forest, and coppice in the current study, many other studies have also found bulk density to be higher in pastures, grasslands, and disturbed sites compared to natural forests, especially in highly degraded or overgrazed pasture lands (Eden et al., 1991; Hajabbasi et al., 1997; Koutika et al., 1997; Abril and Bucher, 2001; Desjardins et al., 2004; Celik, 2005; Abbasi et al., 2007; Zou et al., 2007; Basaran et al., 2008).

Organic Carbon and Organic Matter

The Tyurin method showed the difference in the levels of organic carbon in the forest (8.2%) compared to the coppice (6.3%) and the pasture (5.9%) to be statistically significant (P= <0.0001) (Figure 25). The thermogravimetric results showed all the land cover areas, forest (6.7%), coppice (5.4%), and pasture (4.3%), to have statistically significant differences from one another in organic carbon (P=<0.0001) (Figure 26). Discrepancies between Tyurin and thermogravimetric results are discussed in Appendix 3.

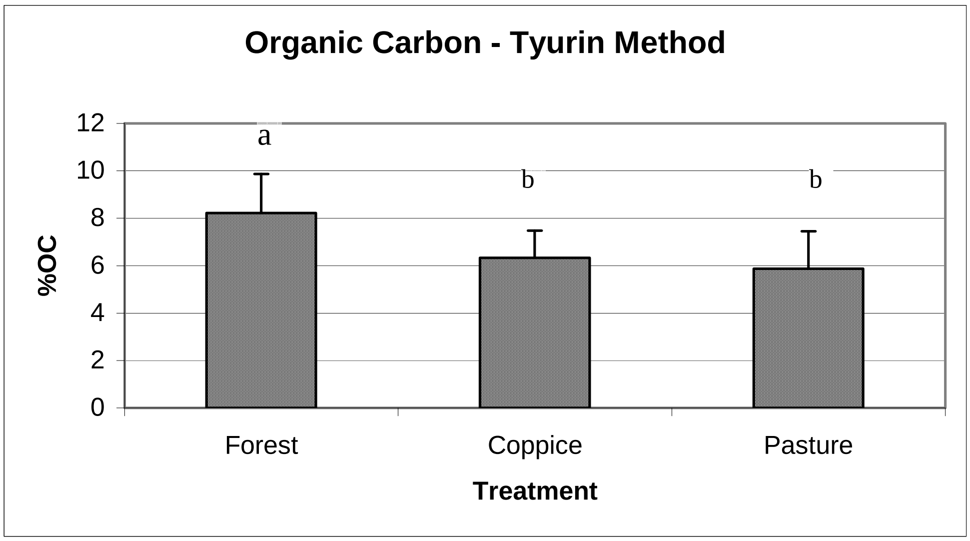

Figure 25. Organic carbon levels for soil samples from the SAI laboratory using the Tyurin method. Error bars denote one standard deviation. The same letter for the values indicates no significant difference between land cover areas using Tukey's test for honestly significant difference (α = 0.05).

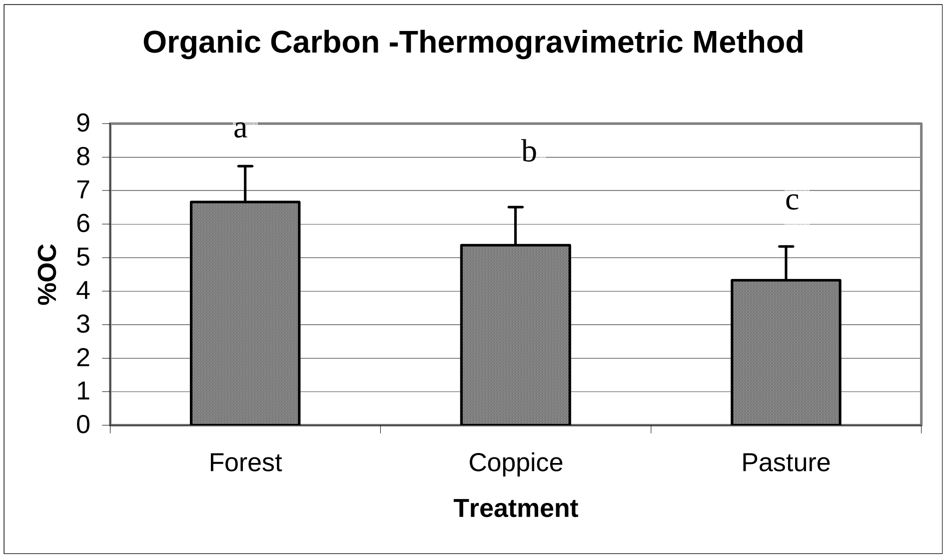

Figure 26. Organic carbon levels for soil samples from the German laboratory determined thermogravimetrically. Error bars denote one standard deviation. The same letter for the values indicates no significant difference between land cover areas using Tukey's test for honestly significant difference (α = 0.05).

The level of organic carbon within the soil is positively correlated with the total organic matter in the soil and various formulas exist from which one can use organic carbon to estimate total organic matter (Buol et al., 2003). Organic carbon and organic matter are added to the soil primarily from decomposing vegetative residues such as leaves, litter, and roots and a decrease in these inputs can lead to a decrease in soil organic carbon and matter (Harvey et al., 1980; Anderson and Coleman, 1985; Lugo et al., 1986; Bernoux et al., 1998). Also, organic matter and organic carbon often accumulate at the top of the soil profile and therefore their abundance in a soil can be reduced by erosion (Dominski, 1971; Brady, 2002; Murty, et al., 2002; Abbasi and Rasool, 2005; Zheng et al., 2005).

The higher levels of organic carbon in the forest compared to the coppice could be attributed to these factors. First, the unplanned and unregulated clear cutting of the coppice and the essential removal of all tree biomass for use as fuelwood removed organic material high in nutrients (Boyle et al., 1973; Harvey et al., 1980; Mroz et al., 1985; Pennock and Kessel, 1997; Schwendenmann and Pendall 2006; Yimer et al., 2007; Khresat et al., 2008). Therefore, following the cut, the coppice soils would have had fewer inputs of vegetative residues than the forest soils. Higher erosion rates after the removal of the overstory in the coppice could also be removing decomposable vegetative material as well as the upper levels of soil where organic matter would accumulate. This is supported by the proportionally lower abundance of an O horizon in the coppice (five out of sixteen pits) as compared to the forest (fifteen out of sixteen pits). The removal of the overstory vegetation when the coppice was cut could also have increased the solar radiation reaching the soil surface and raised daytime temperatures. This would decrease organic matter by increasing organic matter mineralization rates in the soil (Dominsky, 1971; Anderson and Coleman 1985; Pennock and Kessel, 1997; Abbasi and Rasool, 2005; Schwendenmann and Pendall 2006; Zou et al., 2007).

Grasslands and pastures often have levels of organic carbon and organic matter comparable to forest ecosystems due to the high amounts of vegetative biomass usually found in them (Lugo et al., 1986; Koutika et al., 1997; Saviozzi et al., 2001; Murty, et al., 2002; Conant et al., 2004; Desjardins et al., 2004; Schwendenmann and Pendall 2006;). Overgrazing, however, can lead to significant losses in organic matter and organic carbon by impacting above and below ground biomass, plant litter, and soil respiration and temperature (Parton et al., 1987; Abril and Bucher, 2001; Murty, et al., 2002; Zou et al., 2007). The comparatively low levels of organic carbon in the pasture illustrate the overgrazed and degraded nature of the pasture. Reduced above and below ground biomass, due to grazing, would also leave the steep (28%) pasture soils more exposed and prone to erosion which would remove surface soil where organic matter would be accumulating (Eden et al., 1991) (Figures 27 and 28).

Figure 27. Impact of grazing on herbaceous cover in pasture. Photo by Jason Rhoades.

Figure 28. Low vegetative biomass in pasture. Photo by Jason Rhoades.

With similar results to the coppice in relation to the forest, in the Hubbard Brook watershed clear cut experiment, Borrman et al. (1974) saw organic matter decrease by 41% in the three years following the cut. Zheng et al. (2005) found erosion to result in a loss of 69% of organic matter seven years after deforestation. Hajabbasi et al. (1997) also found forests to have higher levels of organic matter (2.50%) than deforested sites under cultivation (0.97%).

In contradiction to the results in the pasture compared to the forest, many studies have shown native or installed grasslands and pastures to have comparable or even higher levels of organic carbon or organic matter than native forests (Koutika et al., 1997; Savozzi et al., 2001; Conant et al., 2004; Desjarins et al., 2004; Celik, 2005). Other studies, with conditions similar to the pasture in this study, often involving a steep slope or overgrazing, showed decreases in organic carbon or organic matter of 26% or more (Glaser et al., 2000; Abril and Bucher, 2001; Sanchez et al., 2002; Nael et al., 2004; Abassi et al., 2007; Zou et al., 2007). In Mongolia, Zou et al. (2007) specifically found highly degraded pastures to have less organic carbon than protected pastures (1.69kg/m^2 and 9.23kg/m^2 respectively).

Phosphorus

The difference in total phosphorus levels between the pasture (0.20%) and the coppice (0.16%) was statistically significant (P=0.0271). Phosphorus values in the forest (0.19%) were in between and no statistically significant differences were reported between the forest and the pasture or coppice (Figure 29). Phosphorus is primarily introduced to a soil via organic matter (Singer and Munns, 1987; Abassi et al., 2007; Brady, 2002). As would be expected, the forest, which had higher levels of organic matter than the coppice, also had higher levels of phosphorus than the coppice.

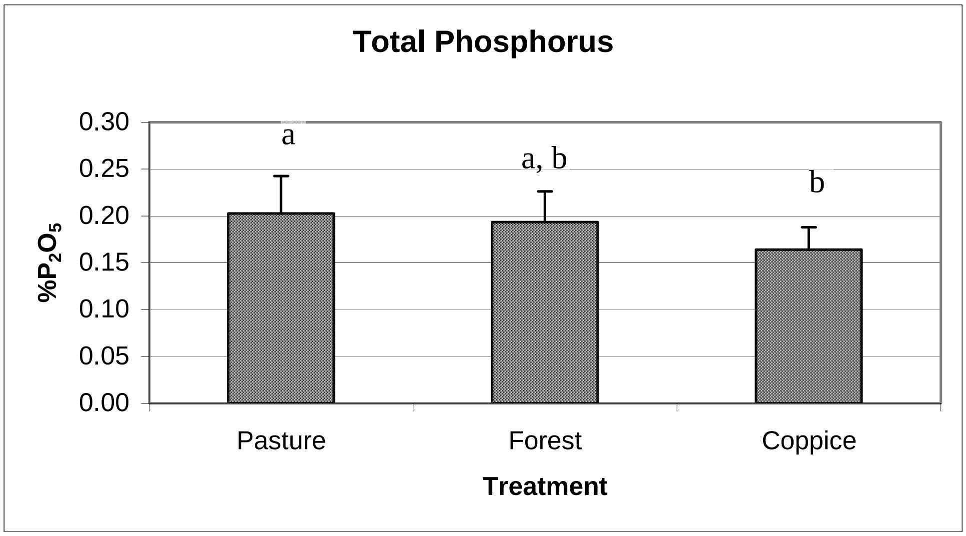

Figure 29. Phosphorus levels for soil samples. Error bars denote one standard deviation. The same letter for the values indicates no significant difference between land cover areas using Tukey's test for honestly significant difference ($\alpha = 0.05$).

The pasture, in contrast to the low levels of organic matter found there, however, had the highest levels of phosphorus. This may be explained by the high concentrations of phosphorus being added to the pasture soils in the form of animal deposition (Wolton, 1955; Watkin, 1957 Saunders, 1984; Turrion et al., 2000). Animal deposition generally has proportionally higher levels of phosphorus compared to decaying plant material (Goland, 1993; Allison et al., 1998; Xu and Hirata, 2005; Garg et al., 2006). This relatively phosphorus rich input could offset the amount being lost to erosion and make up for the lack of phosphorous being added to the system from vegetative residues.

Different studies have recorded various changes in phosphorus levels due to deforestation and land cover change. Similar to the relative values of the forest and the coppice, Zheng et al. (2005) found deforestation and subsequent erosion to result in a 86.6% loss of phosphorus. In contrast, Boyle et al. (1973) reported no long term loss of phosphorus due to whole tree clear cutting in Wisconsin but did note that overall nutrient losses may have been greater if the cut was on a steeper slope or if the regeneration following the cut was suppressed. Nearby, in the Upper Peninsula of Michigan, Mroz et al. (1985) found no decrease in extractable phosphorus one and a half years after a whole tree clear cut. Again, this study was conducted on a flat area with only one to two percent slopes and more phosphorus may have been lost if the slopes in this study were as steep as in the coppice (28%). In contrast to the similar phosphorus levels found in the pasture and the forest in this study, in Rawalakot Azad Jammu and Kashmir, Abbasi et al. (2007) found available phosphorus to decrease from 10.6mg/kg to 5.0mg/kg between natural forest and grassland. With opposite results, Hajabbasi et al. (1997) observed an increase from 35mg/kg under natural forests to 67mg/kg under completely deforested land currently being cultivated. With similar results to this study, Turrion et al. (2000) found conversion of forest to pasture in the mountains of Khyrgyzia to result in higher total phosphorus levels in the installed pasture (1566mg/kg) than the native forest (1093mg/kg). They also proposed that the higher levels of phosphorus in the pasture might have been due to animal deposition.

Potassium

The amount of total potassium in the coppice (2.1%) compared to the pasture (3.1%) and the forest (3.0%) was less by a statistically significant amount ($P= <0.0001$)

(Figure 30). Unlike phosphorus, which usually enters a soil through organic matter, potassium is most often found in the soil in inorganic forms, usually resulting from the mineral weathering of the rocks and parent material in the soil (Brady, 2002). Because it is often a mobile ion in soils, potassium losses to leaching can be significant. (Mroz et al., 1985; Brady, 2002; Alfaro et al.[a], 2004; Alfaro et al.[b], 2004;). Although the potassium levels found in the three land cover areas, particularly the high level in the pasture, are difficult to explain, these two factors could be partially responsible.

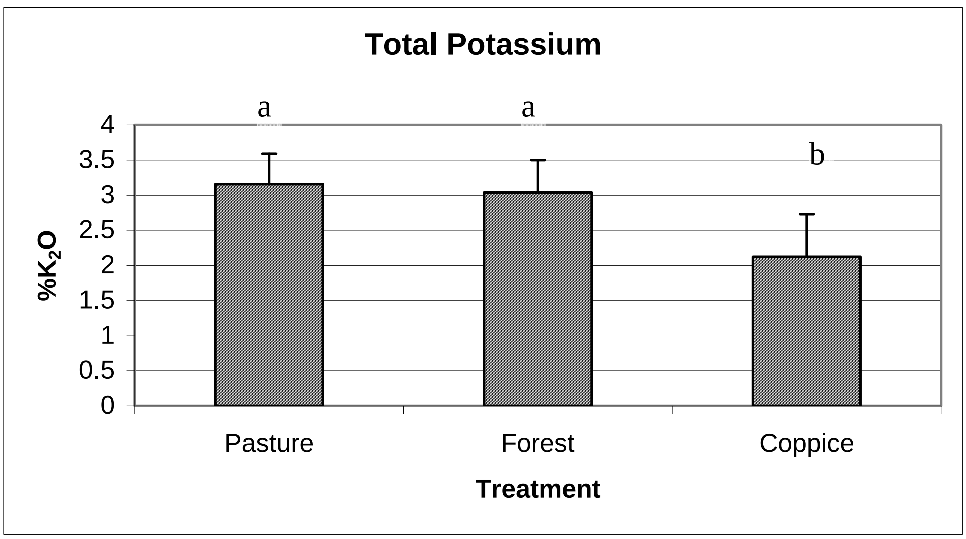

Figure 30. Potassium levels for soil samples. Error bars denote one standard deviation. The same letter for the values indicates no significant difference between land cover areas using Tukey's test for honestly significant difference ($\alpha = 0.05$).

The unplanned and unregulated clear cutting of the forest, which resulted in the coppice, could have increased both lateral and vertical movement of water and resulted in leaching of potassium from the upper levels of the soil (Pennock and Kessel, 1997). The hydrological processes in the pasture may also be similar to those in the coppice following the clear cut. Over the past 200 years, however, the erosion in the pasture appears to have been so extreme that the soil surface of the pasture is closer to the weathering, potassium-rich parent material than the forest or coppice soils. The soil samples were taken to a depth of 24cm. Within the pasture, the depth at which coarse fragments reached a minimum of 50% was found within ten centimeters of the soil surface (Figure 19). Therefore, many of the pasture soil samples analyzed at the SAI laboratory were partially collected from the area of the soil profile having a high percentage of coarse fragments. This was not true of the soil samples in the forest or the coppice. The weathering of the rocks and resultant minerals, such as potassium, in this layer would be an input into all the land cover area soils. Due to the relative depth of this layer in the three land cover areas, however, potassium resulting from this weathering could possibly be more strongly recorded in the pasture samples. Animal deposition in the pasture may also be contributing to the potassium levels in the pasture (Wolton, 1955; Watkin, 1957; Richards and Wolton, 1976; Saunders, 1984; Sakadevan et al., 1993; Alfaro et al. [b], 2004).

Other studies report dramatic decreases in potassium following deforestation such as occurred in the unplanned and unregulated clear cut that resulted in the coppice in this study. In their whole tree clear cut study, Mroz et al. (1985) found exchangeable potassium to decrease on three sites, from 1483kg/ha to 508kg/ha, 1230kg/ha to 347kg/ha, and 1396kg/ha to 282kg/ha respectively, a year and a half after the cut. Bormann et al. (1968) recorded a seven-fold rise in exchangeable potassium levels found in runoff in the Hubbard Brook watershed study following a clear cut and regeneration suppression. In their deforestation study in Iran, Hajabbasi et al. (1997) found potassium levels to be 0.25 meq/L in the natural forest and only 0.15 meq/L in deforested areas under cultivation. As with phosphorus, Boyle et al. (1973) saw no decrease in long term potassium levels following the whole tree clear cut, but speculated that steeper slopes or regeneration suppression could result in significant nutrient losses. Eden et al. (1991) recorded similar results to this study in regard to the conversion of forest to pasture. In their study, the conversion of evergreen forest in Roraima, Brazil only resulted in a slight decrease in exchangeable potassium, from 0.11meq/100g to 0.09meq/100g. In contrast, Abbasi et al. (2007) observed lower values in available potassium, from 69.9mg/kg to 44.4mg/kg, when comparing natural forest and grassland.

Nitrogen

According to results using the Ginsburg extraction and Kjeldahl distillation methods, the difference between total nitrogen levels in the forest (0.46%) and the coppice (0.31%) was statistically significant ($P=0.0176$). Pasture levels (0.40%) were in between and no statistically significant differences were reported (Figure 31). Thermogravimetric analysis showed the difference in total nitrogen levels in the forest (0.58%) to be statistically significant compared to both the coppice (0.46%) and the pasture (0.38%) ($P=<0.0001$) (differences between Ginsburg extraction/Kjeldahl distillation and thermogravimetric results are discussed in Appendix 3) (Figure 32). Nitrogen can enter the soil through organic matter, precipitation, and also through biological nitrogen fixation. Nitrogen leaves the soil through leaching, volatilization, and biological uptake (Dominski, 1971; Brady, 2002; Wachendorf, 2008). The higher levels of total nitrogen in the forest compared to the coppice and the pasture can be explained by the higher amounts of organic matter in the forest soils.

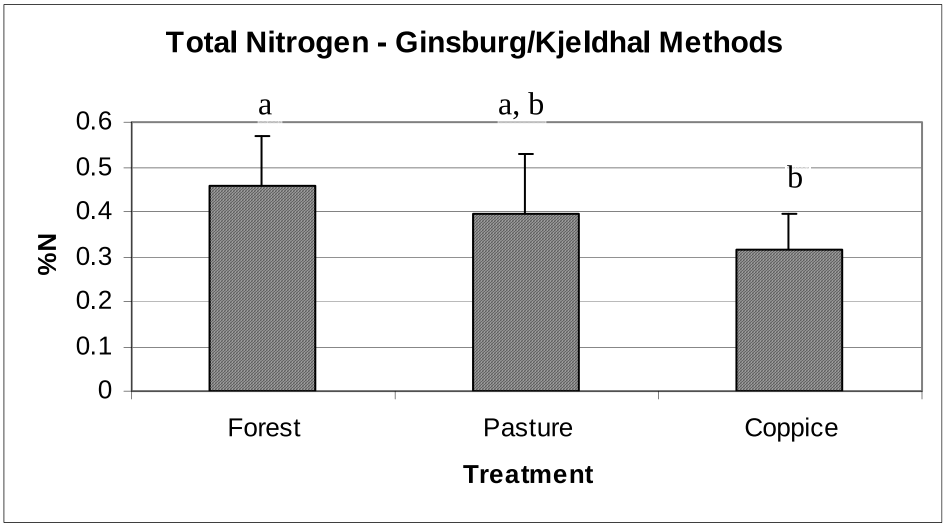

Figure 31. Nitrogen levels for soil samples from the SAI laboratory using the Ginsburg extraction and Kjeldahl distillation methods. Error bars denote one standard deviation. The same letter for the values indicates no significant difference between land cover areas using Tukey's test for honestly significant difference (α = 0.05).

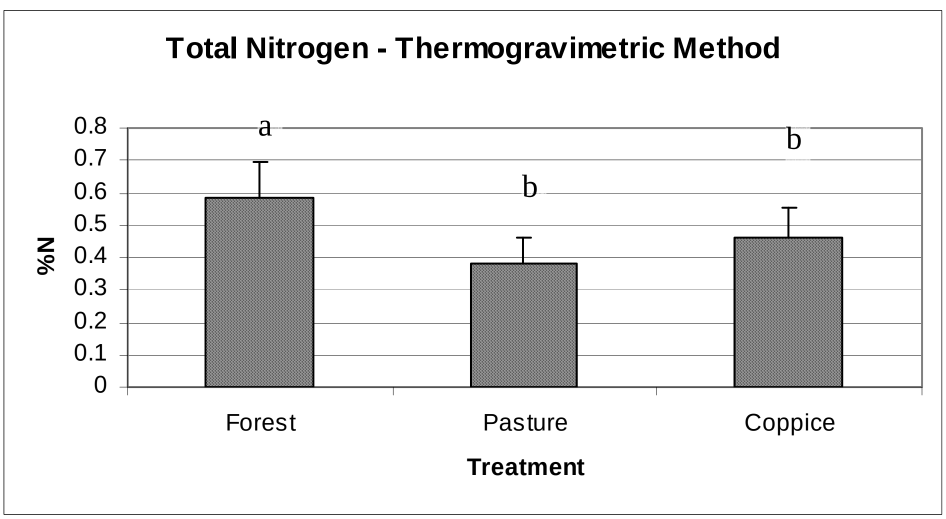

Figure 32. Nitrogen levels for soil samples from the German laboratory determined thermogravimetrically. Error bars denote one standard deviation. The same letter for the values indicates no significant difference between land cover areas using Tukey's test for honestly significant difference (α = 0.05).

In addition, removing the overstory in the coppice and the pasture could have caused increased organic matter decomposition and nitrogen transformation rates resulting in more nitrogen being leached out of the soil (Dominski, 1971; Harvey et al., 1980; Mroz et al., 1985; Pennock and Kessel, 1997; Khresat et al., 2008). Despite possible nitrogen additions from the higher percentage of nitrogen fixing plants in the coppice (6.1% ground cover) compared to the forest (1.7% ground cover), these factors could have combined to result in less nitrogen in the coppice than the forest. Comparatively low total nitrogen levels in the pasture, due to erosion, overgrazing, increased decomposition rates, and leaching, however, may also be partially compensated for by nitrogen fixing plants (5.9% ground cover) and by nitrogen inputs in urine and dung deposition by grazing animals on the pasture (Wolton, 1955; Watkin, 1957; Richards and Wolton, 1976; Saunders, 1984; Sakadevan et al., 1993 De Klein and Van Logtestijn, 1994; Flessa et al., 1996; Somda et al., 1997; Ma et al., 2007; Wachendorf, 2008). The additional inputs of nitrogen from animal deposition in the pasture could explain the proportionally higher nitrogen to organic carbon ratio in the pasture compared to the coppice.

Similar to the forest and coppice nitrogen levels in this study, Mroz et al. (1985) found total nitrogen to decrease following whole tree clear cuts on three sites from 5052kg/ha to 3797kg/ha, 4855kg/ha to 3992kg/ha, and from 4716kg/ha to 4232kg/ha. Likewise, in the Hubbard Brook watershed clear cut, Bormann et al. (1968) recorded a higher net loss of 57kg/ha compared to a similar undisturbed watershed. In another study where erosion was an important driver of site characteristics, Zheng et al. (2005) reported that erosion following deforestation resulted in a 46.7% decrease in total nitrogen. In a study with contrasting results, Boyle et al. (1973) found no long term losses in N but speculated that overall nutrient losses could potentially be greater on a steep slope, such as was found in this study, or if the regeneration was suppressed, as was the case in the pasture.

Similar to the forest and pasture results, Abbasi et al. (2007) recorded total nitrogen levels in grasslands to be nearly half those in forest lands (1.54g/kg and 2.83g/kg respectively). Based on a study in Ethiopia, Yimmer et al. (2007) also found grazed grasslands to have lower total nitrogen levels than native forests (0.66% and 0.72% respectively). Many other studies have found the opposite result. Lugo et al. (1986), Koutika et al. (1997), Glaser et al. (2000), and Savozzi et al. (2001) all reported grasslands and pastures to have higher levels of nitrogen than forestland. The disparity in these findings with regards to the results found in this study are probably due in part to the low levels of organic matter in the pasture and point to its overgrazed and degraded nature.

Regeneration and Species Composition

In addition to changes in soil nutrients and characteristics, the unplanned and unregulated clear cut in the coppice has also affected the species composition of seedlings and saplings. The regeneration, in terms of saplings and seedlings, in the forest is 48% oak, 31% hornbeam, with maple and other species taking up 21%. The clear cut in the coppice has increased the numbers of hornbeam seedlings and saplings in the coppice compared to the forest (from 256 to 1723 seedlings and 184 to 1038 saplings) and now the regeneration in the coppice is 80% hornbeam (Figure 33). This means, as the coppice eventually grows into a mature forest, it will have a different species composition that it did before the cut. This could have negative effects on wildlife as some species may be better adapted to the original oak/hornbeam forest species composition and have a more difficult time in a predominately hornbeam forest. This could be especially true as the mast of oak trees is an important food source for many wildlife species (Van Dersal, 1940).

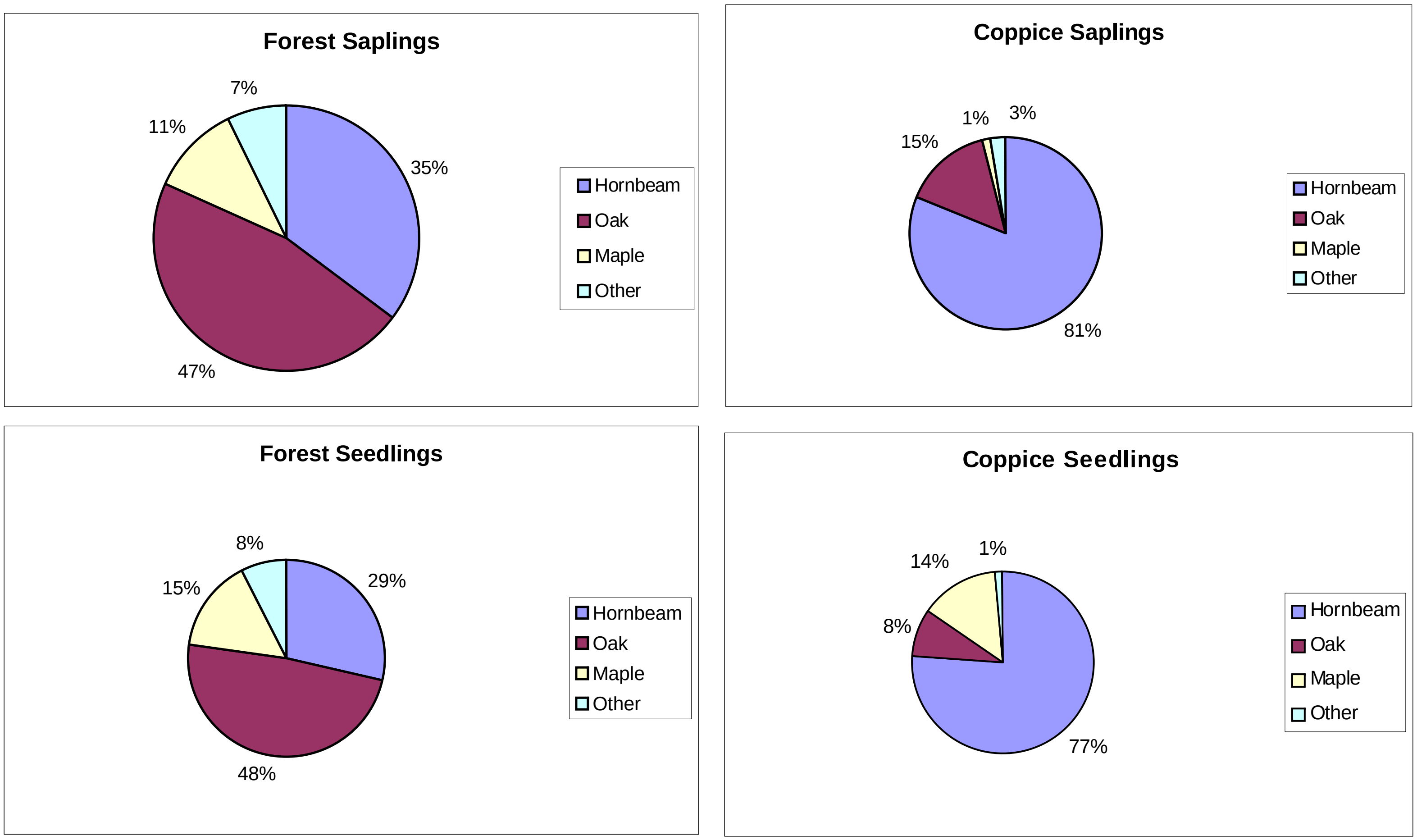

Figure 33. Forest and coppice regeneration for both saplings and seedlings. (n=36)

Chapter 7: Conclusion

The clearing of the far eastern edge of the forest, the conversion of that area of land into pasture, and the subsequent unregulated grazing of cows, sheep, and goats have altered the erosion rate, nutrient levels and soil characteristics in comparison with the adjacent native oak/hornbeam forest. With the forest cover removed and with the growth of herbaceous plants in the pasture limited by unregulated grazing, it can be estimated that 40cm of soil may have been lost due to erosion in the pasture compared to the forest. While grazing animal deposition may have added some inputs to the pasture, erosion and potentially low levels of vegetative residue due to the limited vegetative cover have in turn led to reduced levels of organic carbon and organic matter. The reduced levels of organic carbon and organic matter will only lead to further erosion and erodibility of the soil and reduce the nutrient and water holding capacities of the soil (Anderson and Coleman, 1985; Brady, 2002; Abassi and Rasool, 2005; Abassi et al., 2007). While this study was limited to only one hillside and therefore conclusions may not be extended to the conversion of forest to pasture in other areas, it is clear that the conversion of this forest to pasture and the continued unregulated grazing within the study area is an unsustainable practice.

The soils in the area adjacent to the forest on the western side, where the forest was nearly completely harvested without planning or regulation, allowed to regenerate, and thereby turned into a coppice forest, have been affected in a manner similar to that of the pasture but to a lesser degree. Due to the more recent cutting of the coppice compared to the pasture and the natural regeneration within the coppice area, the estimated erosion that has occurred falls between that of the forest and the pasture. Similarly, with the intermediate levels of erosion, and intermediate amounts of vegetative residue inputs to contribute to the soil in relation to the forest and pasture, the organic carbon level in the coppice falls between the levels of the forest and the pasture. With lower levels of organic carbon and organic matter and a higher erosion rate than the forest, the coppice also had significantly less nitrogen, phosphorus, and potassium than the forest. Again, while this study is limited to just one hillside, and therefore the potential impacts of cutting in other areas are unknown, it is clear that just the one unplanned and unregulated clear cutting immediately followed by natural regeneration had negative impacts on the underlying soils within this study area.

While this study was limited to one hillside and so does not have replicates, the findings are consistent with other studies on deforestation and land cover change from a variety of locations around the world (Table 3). Therefore, it is reasonable to expect that the impacts found within this study, and the other studies mentioned, would also be occuring in other locations within Armenia where deforestation and land cover change have occurred. Until more studies are conducted, it would be prudent to assume that deforestation and land cover change may be having significant and long term impacts on soils throughout Armenia.

Table 3. Comparison of impacts of deforestation and land cover change between this study and similar studies. Arrows indicate trends in the property of varying degrees. ▲ indicates an increase in the property due to land cover change. ▼ indicates a decrease in the property due to land cover change. O indicates no trend. - indicates that no data was recorded for this property in the study. Studies have been included in the table which measure the impacts upon multiple properties due to land cover change.

Study	Location	Erosion	OM/OC	P	K	N	Bulk Density
Hrazdan Study	Hrazdan, Armenia	▲	▼	O	O	▼	▲
Mroz et al., 1985	Michigan, USA	-	-	O	▼	▼	-
Sanchez et al., 2002	Andes Mountains, Venezuela	▲	▼	-	-	-	-
Bormann et al., 1968, 1974	New Hampshire, USA	▲	▼	-	▼	▼	▲
Celik, 2005	Taurus Mountains, Turkey	▲	▲	-	-	-	▲
Hajabbasi et al., 1997	Lordegan, Iran	-	▼	▲	▼	-	▲
Koutika et al., 1997	Eastern Amazon, Brazil	-	▲	-	-	▲	▲
Abbasi et al., 2007	Rawalakot Azad Jammu and Kashmir, Pakistan	-	▼	▼	▼	▼	▲
Zheng et al., 2005	Loess Plateau, China	-	▼	▼	-	▼	-
Boyle et al., 1973	Wisconsin, USA	-	-	O	O	O	-

Further studies need to be conducted to investigate the impacts grazing has on native mountain pastures and other forest areas that have been converted into pastures within Armenia, how the impacts of grazing are affected by slope and soil type, and to compare how differing levels of grazing intensity may affect pasture vegetation and soils. Additional studies should focus on looking at the impacts that different types of forest cuts (i.e. planned and regulated clear-cuts, shelterwood cuts, and selective harvesting) involving different rotations and basal areas have on soils, stand dynamics and vegetative cover. These studies should also investigate the role various soil types, slopes and climates may play in the impacts those cuts may have on soils, stand dynamics, and general vegetative cover throughout Armenia.

Until further research is conducted within Armenia and the impacts of various logging methods are known in regards to various soils, slopes, and climates, and an accurate forest inventory is conducted from which informed management decisions can be made, those who control the fate of Armenia's forests should proceed with great caution to avoid causing irreversible damage to this fragile and precious resource.

Literature Cited

Abbasi, M.K.; M. Zafar, and S.R. Khan, 2007. Influence of different land-cover types on the changes of selected soil properties in the mountain region of Rawalakot Azad Jammu and Kashmir. *Nutrient Cycling in Agroecosystems*, 78(1):97-110.

Abbasi, M.K., and G. Rasool, 2005. Effects of different land-use types on soil quality in the hilly area of Rawalakot Azad Jammu and Kashmir. *Acta Agriculturae Scandinavica*, 55(3):221-228.

Abril, A. and E.H. Bucher, 2001. Overgrazing and soil carbon dynamics in the western Chaco of Argentina. *Applied Soil Ecology*, 16:243-249.

Alfaro[a], M.A., P.J. Gregory, and S.C. Jarvis, 2004. Dynamics of potassium leaching on a hillslope grassland soil. *Journal of Environmental Quality*, 33:192-200.

Alfaro[b], M.A., S.C. Jarvis, and P. J. Gregory, 2004. Factors affecting potassium leaching in different soils. *Soil Use and Management*, 20(2):182-189.

Allison, R.A., F.H.S. Chiew, and T.A. McMahon, 1998. Nutrient contribution of leaf litter in urban stormwater. *Journal of Environmental Management*, 54:269-272.

Anderson, D. W. and D.C. Coleman, 1985. The dynamics of organic matter in grassland soils. *Journal of Soil and Water Conservation*, 40(2):211-216.

Anon.[a], 1963. Soil Science, Journal No.5, Moscow (in Russian). (grey literature, Appendix 4).

Anon.[b], 1963. Pochvovedenie, Journal No.5, Moscow (in Russian). (grey literature, Appendix 4).

Avery, T.E. and H.E. Burkhart. Forest Measurements Third Edition. McGraw-Hill Publishing, New York, 1983.

Basaran, M., G. Erpul, A. E. Tercan, M. R. Canga, 2008. The effects of land use changes on some soil properties in Indagi Mountain Pass – Cankiri Turkey. *Environmental Monitoring and Assessment*, 136:101-119, 82:43-58.

Bernoux, M., C.C. Cerri, C.N., Jener F.L. de Moraes, 1998. The use of stable carbon isotopes for estimating soil organic matter turnover rates. *Geoderma*, 82(1-3):43-58.

Blake, G. R. and K. H. Hartge. Methods of Soil Snalysis. Part 1. Physical and Mineralogical Methods, Second Edition (A Klute editor). American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Wisconsin, 1986.

Blanco, H. and R. Lal. Principles of Soil Conservation and Management. Springer Science and Business Media B.V., New York, 2008.

Bormann, F. H., G. E. Likens, D. W. Fisher, R. S. Peirce, 1968. Loss accelerated by Clear-Cutting of a Forest Ecosystem. *Science*, 159:882-884.

Bormann, F. H., G. E. Likens, T. G. Siccama, R. S. Pierce, J. S. Eaton, 1974. The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. *Ecological Monographs*, 44 (3):255-277.

Boudjikanian, D.P. Armenia independence and deforestation. 2006. On line: http://www.american.edu/ted/ice/armenia-forest.htm. Site accessed February, 2007.

Bournoutian,G.A. A Concise History of the Armenian People (From Ancient Times to the Present), Fourth Edition. Mazda Publishers Inc., Costa Mesa, California, 2003.

Boyle, J.R., J.J. Phillips, and A.R. Ek, 1973. "Whole tree" harvesting: nutrient budget evaluation. *Journal of Forestry*, 71(12):760-762.

Brady, N.C. and R.R. Weil. The Nature and Properties of Soil, Thirteenth Edition. Prentice Hall, New Jersey. 2002.

Buol, S.W., R.J. Southhard, R.C. Graham, P.A. McDaniel. Soil Genesis and Classification, Fifth Edition. Iowa State Press, Ames, Iowa, 2003.

Cebecauer, T., and J. Hofierka, 2008. The consequences of land-cover changes on soil erosion distribution in Slovakia. *Geomorphology*, 98:187-198.

Celik, I. 2005. Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. *Soil & Tillage Research*, 83:270-277.

CEPF (Critical Ecosystem Partnership Fund). *Caucasus Biodiversity Hotspot.* Ecosystem Profile, 2003. On line: http://www.countdown2010.net/caucasus/Caucasus%20Ecosystem%20Profile.pdf. Site accessed November, 2008.

CIA (Central Intelligence Agency), U.S., 2008. The World Factbook-Armenia. On line: https://www.cia.gov/cia/publications/factbook/geos/am/html. Site accessed June, 2008.

Conant, R.T., J. Six, and K. Paustian, 2004. Land use effects on soil carbon fractions in the southeastern United States. II. Changes in soil carbon fractions along a forest to pasture chronosequence. *Biology and Fertility of Soils*, 40:194-200.

De Klein, C.A.M. and R.S.P. Van Logtestijn, 1994. Denitrification and N2 emission from urine-affected grassland soil. *Soil and Plant*, 163:235-242.

Desjardins, T., E. Barros, M. Sarrazin, C. Girardin, A. Mariotti, 2004. Effects of forest conversion to pasture on soil carbon content and dynamics in Brazilian Amazonia. *Agriculture Ecosystems and Environment*, 103:365-373.

Dominski, A.S., 1971. Nitrogen transformations in a northern-hardwood podzol on cutover and forested sites. Ph.D. Thesis. Yale University, New Haven.

Eden, M.J., P.A. Furley, D.F.M. McGregor, W. Milliken, and J.A. Ratter, 1991. Effect of forest clearance and burning on soil properties in northern Roraima, Brazil. *Forest Ecology and Management*, 38:283-290.

Edilyan, R. A. and G.P.Petrosyan. The Soils of Armenian SSR. Yerevan. (in Russian) 1976.

Flessa, H., P. Dorsch, F. Beese, H. Konig, and A. F. Bouwman, 1996. Influence of cattle wastes on nitrous oxide and methane fluxes in pasture land. *Journal of Environmental Quality*, 25:1366-1370.

Fretter, C.W. Applied Hydrology, Fourth Edition. Prentice Hall, New Jersey, 1994.

Fu, B., S. Liu, Y. Lu, L. Chen, K. Ma, and G. Liu, 2003. Comparing the soil quality changes of different land uses determined by two quantitative methods. *Journal of Environmental Sciences*, 15(2):167-172.

Garg, V.K., Y.K. Yadav, A. Sheoran, S. Chand, P. Kaushik, 2006. Livestock excreta management through vermicomposting using an epigeic earthworm *Eisenia foetida*. *Environmentalist*, 26:269-276.

Glaser, B., M. Turrion, D. Solomon, A. Ni, W. Zech, 2000. Soil organic matter quantity and quality in mountain soils of the Alay Range, Kyrgizia, affected by land use change. *Biology and Fertility of Soils*, 31:407-413.

Goland, C., 1993. Cultivating diversity: field scattering as agricultural risk management in Cuyo Cuyo, department of Puno, Peru. Denison University. On line: http://www.anthro.ucdavis.edu/winterweb/html/research/andean/golandCD/title.htm. Site accessed November, 2008.

Hajabbasi, M.A., A. Jalalian and H.R. Karimzadeh, 1997. Deforestation effects on soil physical and chemical properties, Lordegan, Iran. *Plant and Soil*, 190:301-308.

Harvey, A.E., M.J. Larsen and M.F. Jurgensen, 1980. Biological implications of increasing harvest intensity on the maintenance and productivity of forest soils. In: USDA Forest Service General Technical Report INT-90. Environmental consequences of timber harvesting in Rocky Mountain coniferous forests. pp. 211-220. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hunter, M.L. Jr.. Wildlife, Forests, and Forestry: Principles of Managing Forests for Biological Diversity. Regents/Prentice Hall, Englewood Cliffs, NJ, 1990.

Hurlbert, S.H., 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs*, 54(2):187-211.

Khresat, S., J. Al-Bakri, and R. Al-Tahhan, 2008. Impacts of land use/cover change on soil properties in the Mediterranean region of northwestern Jordan. *Land Degradation and Development*, 19(4):397-407.

Kouita, L.-S., F. Bartoli, F. Andreux, C.C. Cerri, G. Burtin, T. Chone, R. Philippy, 1997. Organic matter dynamics and aggregation in soils under rain forest and pastures of increasing age in the eastern Amazon Basin. *Geoderma*, 76:87-112.

Likens, G.E., F. H. Bormann, N.M. Johnson, D.W. Fisher, R.S. Pierce, 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecological Monograph*, 40 (1):23-47.

Lugo, A.E., M.J. Sanchez, and S. Brown, 1986. Land use and organic carbon content of some subtropical soils. *Plant and Soil*, 96: 185-196.

Ma, X., S. Wang, G. Jiang, S. Haneklaus, E. Schnug, and P. Nyren, 2007. Short-term effect of targeted placements of sheep excrement on grassland in inner Mongolia on soil and plant parameters. *Communications in Soil Science and Plant Analysis*, 38:1589-1604.

Marks, P.L., and F.H. Bormann, 1972. Revegetation following forest cutting: mechanisms for return to steady-state nutrient cycling. *Science*, 176(4037):914-915.

MNP (Ministry of Nature Protection of the Republic of Armenia). National report on the biodiversity of Armenia. 2002. On line: http://www.nature-ic.am/biodiv/index%20eng.html. Site accessed February, 2007.

MNP (Ministry of Nature Protection of the Republic of Armenia). National report. State of the environment of the Republic of Armenia in 2002. Yerevan, 2003.

Moreno-Sanchez, R. and H.Y. Sayadyan, 2005. Evolution of the forest cover in Armenia. *The International Forestry Review*, 7 (2):113-127.

Mroz, G.D., M.F. Jurgensen, and D.J. Frederick, 1985. Soil nutrient changes following whole tree harvesting on three northern hardwood sites. *Soil Science Society of America Journal*, 49:1552-1557.

Munsell Soil Color Charts, 1994 Revised Edition. GretagMacBeth, New York, 1994.

Murty, D., M.U.F. Kirschbaum, R.E. McMurtrie, and H. McGilvary. Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. *Global Change Biology*, 8:105-123.

Nael, M., H. Khademi, M. A. Hajabbasi, 2004. Response of soil quality indicators and their spatial variability to land degradation in central Iran. *Applied Soil Ecology*, 27:221-232.

Oksanen, L., 2004. The devil lies in details: reply to Stuart Hurlbert. *Oikos*, 104(3):598-605.

Oksanen, L., 2001. Logic of experiments in ecology: is pseudoreplication a pseudoissue? *Oikos*, 94(1):27-38.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima, 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal*, 51:1173-1179.

Pennock, D. J, and C. van Kessel, 1997. Clear-cut forest harvest impacts on soil quality indicators in the mixedwood forest of Saskatchewan, Canada. *Geoderma*, 75:13-32.

Richards, I.R., and K.M. Wolton, 1976. The spatial distribution of excreta under intensive cattle grazing. *Journal of the British Grassland Society*, 31(2):89-92.

Sakadevan, K., A.D. Mackay, and M.J. Hedley, 1993. Influence of sheep excreta on pasture uptake and leaching losses of sulfur, nitrogen and potassium from grazed pastures. *Australian Journal of Soil Research*, 31(2):151-162.

Sanchez, L.A., M. Ataroff, and R. Lopez, 2002. Soil erosion under different vegetation covers in the Venezuelan Andes. *The Environmentalist*, 22 (2):161-172.

Saunders, W.M.H., 1984. Mineral composition of soil and pasture from areas of grazed paddocks, affected and unaffected by dung and urine. *New Zealand Journal of Agricultural Research*, 27(3):405-412.

Saviozzi, A., R. Levi-Minzi, R. Cardelli, and R. Riffaldi, 2001. A comparison of soil quality in adjacent cultivated, forest and native grassland soils. *Plant and Soil*, 233:251-259.

Sayadyan, H.Y. and R. Moreno-Sanchez, 2006. Forest policies, management, and conservation in Soviet (1920-1991) and post-Soviet (1991-2005) Armenia. *Environmental Conservation*, 33 (1):60-72.

Schwendenmann, L., and E. Pendall, 2006. Effects of forest conversion into grassland on soil aggregate structure and carbon storage in Panama: evidence from soil carbon fractionation and stable isotopes. *Plant Soil*, 288:217-232.

Siewert, C., 2004. Rapid Screening of Soil Properties using Thermogravimetry. *Soil Science Society of America Journal*, 68:1656-1661.

Singer, M.J. and D.N. Munns. Soils an introduction. Macmillan Publishing Company, New York, 1987.

Soil Survey Staff. Soil Survey Manual. United States Department of Agriculture, Washington D.C., 1951.

Somda, Z.C., J.M. Powell, and A. Bationo, 1997. Soil pH and nitrogen changes following cattle and sheep urine deposition. *Communications in Soil Science and Plant Analysis*, 28(15-16):1253-1268.

Sparks, D.L., editor. Methods of Soil Analysis, Part 3-Chemical Methods. Soil Society of America, Inc. Madison, Wisconsin, 1996.

Steele, R.G.D. and J.H. Torrie. Principles and Procedures of Statistics. McGraw Hill Publishing, New York, 1960.

Tate, R.L. III. Soil Organic Matter: Biological and Ecological Effects. John Wiley and Sons, New York, 1987.

Turrion, M.B., B. Glaser, D. Solomon, A. Ni, W. Zech, 2000. Effects of deforestation on phosphorus pools in mountain soils of the Alay Range, Khyrgyzia. *Biology and Fertility of Soils*, 31:134-142.

UNECE, Illegal logging and trade of illegally-derived forest products in Armenia. On line: www.unece.org/timber/docs/sem/2004-1/full_reports/Armenia.pdf. Site accessed February, 2007.

UNEP/Grid-Adrenal. State of the environment in Armenia. 2000. On line: http://enrin.grida.no/htmls/armenia/. Site accessed February, 2007.

USSR Science Academy, editor. Soil Agrochemical Research Methods. USSR Science Academy Publishing, Moscow, 1960 (in Russian). (grey literature, Appendix 4).

Van Dersal, W.R., 1940. Utilization of oaks by birds and mammals. *The Journal of Wildlife Management*, 4(4):404-428.

Vidic, N.J., and F. Lobnik, 1997. Rates of soil development of the chronosequence in the Ljubljana Basin, Slovenia. *Geoderma*, 76:35-64.

Wachendorf, C., C. Lampe, F. Taube, and K. Dittert, 2008. Nitrous oxide emissions and dynamics of soil nitrogen under ^{15}N-labled cow urine and dung patches on a sandy grassland soil. *Journal of Plant Nutrition and Soil Science*. 171:171-180.

Watkin, B.R., 1957. The effect of dung and urine and its interactions with applied nitrogen, phosphorus and potassium on the chemical composition of pasture. *Journal of the British Grassland Society*, 12(4):264-277.

Wolton, K.M., 1955. The effect of sheep excreta and fertilizer treatments on the nutrient status of pasture soil. *Journal of the British Grassland Society*, 10(3):240-253.

Wu, J. and R. Hobbs, 2002. Key issues and research priorities in landscape ecology: An idiosyncratic synthesis. *Landscape Ecology*, 17:355-365.

Xiubin, H., L. Zhanbin, H. Mingde, T. Keli, and Z. Fengli, 2003. Down-scale analysis for water scarcity in response to soil-water conservation on Loess Plateau of China. *Agriculture, Ecosystems and Environment*, 94:335-361.

Xu, X., and E. Hirata, 2005. Decomposition patterns of leaf litter of seven common canopy species in a subtropical forest: N and P dynamics. *Plant and Soil*, 273:279-289.

Yimer, F., S. Ledin, A. Abdelkair, 2007. Changes in soil carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, south-eastern highlands of Ethiopia. *Forest Ecology and Management*, 242:337-342.

Zheng, F., X. He, X. Gao, C. Zhang, K. Tang, 2005. Effects of erosion patterns on nutrient loss following deforestation on the Loess Plateau of China. *Agriculture Ecosystems and Environment*, 108:85-97.

Zou, C., K. Wang, T. Wang, and W. Xu, 2007. Overgrazing and soil dynamics in eastern Inner Mongolia of China. *Ecological Research*, 22:135-142.

Appendix 1. Copyright permission.

Copyright permission for Figure 1, source: Acopian Center for the Environment, American University of Armenia:

From: Karen Aghababyan <karen@aua.am>
To: jason rhoades <jasonleonrhoades@yahoo.com>
Cc: Jennifer Lyman <jenclyman@gmail.com>; Tom G. Lyman <tomglyman@gmail.com>; Levan Janoian <janoian@aua.am>
Sent: Monday, November 3, 2008 1:35:54 AM
Subject: Re: map copywrite permission

Hi Jason,

The name of our center was changed. It is now Acopian Center for the Environment.

Any map which you have got from internet is fine to use just with the sign: "The map prepared by Acopian Center for the Environment, American University of Armenia. Date of preparation, if known"

If you have got the map from our office (which means that the map is not published yet in internet or separately or within article), we would appreciate the acknowledgement with the name of person, who have prepared it.

Kind wishes,
Karen

Documentation for Figures 3 and 16, source USSR:

http://ccablog.blogspot.com/2005/11/soviet-topographic-maps.html

Soviet topographic maps

Published Sunday, November 20, 2005 by CCAer | E-mail this post

---

For the 50 years prior to the collapse of the Soviet Union in the early 1990s, the Soviet military sought to map every corner of the globe. The result was an extensive collection of standardized maps at various scales. John Davies has written a 28 page, 2 part paper on the topic for *Sheetlines*, the publication of the Charles Close Society, an organization that studies the U. K.'s Ordinance Survey maps. In his paper he indicates that the Soviets mapped the entire world at 1:1,000,000, 1:500,000 and 1:200,000, most of Asia, Europe, north Africa and North America at 1:100,000, the Soviet Union, Europe and parts of Asia at 1:50,000, the Soviet Union and eastern Europe at 1:25,000 and about a quarter of the Soviet Union at 1:10,000. "In addition," writes Davies, "plans at 1:25,000 and 1:10,000 were produced of thousands of towns and cities around the world." In some areas, the Soviet maps are still among the best available.

What is just as amazing as the number of maps churned out by the Soviet military is the fact that none of these maps are copyrighted since the Soviet Union was not a signatory to the Berne Convention on copyright. The U. K. 's Ordinance Survey believes that the Russian topographic maps of the U. K. are simply copies of OS maps of the time; however, Davies compares the two side by side and raises questions about the OS' position.

A 1958 map symbol guide is available online in pdf.

Update: For an update, see the blog post for 30 November 2005.

Some of these maps are freely available on the Internet. The two best sources are the University of California, Santa Cruz and the University of California, Berkeley. Together they have an extensive collection of mostly 1:100,000 and 1:200,000 maps for Asia and parts of Europe and Africa. The Perry-Castañeda Library has links to various bits and pieces of Russian topographic maps (search by country).

Paper versions of Russian topographic maps for other parts of the world can still be purchased from a variety of sources (for example Omnimap, Eastview Cartographic, Fourone)

Appendix 2. Field Observations for Deep Pit Transect Pits.

11-May-08	230 PM	Partly Cloudy

Pit	Horizon	Depth	Color (moist)	Texture	C.F. %	Structure	consistence	roots	Horizon Boundary	Other notes	Diagnostic Subsurface horizons	
Forest - bottom			slope 26%									
	A	16	2.5/1	20	5	Gr-2	vfr	m-f	Ab	Ustic	<60% BS	Typic Dystrustept
		28	7.5 YR 4/3	28	10	sbk-2	fr	m-m	Cl		>60% BS	Udic Haplustept
	Bw1	37	7.5YR 4/3		15	sbk-2	fr	m-m	Gr			
	Bw2	62	7.5YR 3/1	31	15	sbk-2	fr	m-m	Cl			
	Bw3	73	7.5YR 3/1		15	Pl-1	fr	m-f	Cl			
	BC	91+	10YR 4/4	30	60	Pl-1	fr	f-f	n/a			
Forest - mid			slope 27%									
	Oi	1										
	Oe	2	N 2/							Ustic		Pachic Haplustoll
	A1	20	2.5/1		5	Gr-3	vfr	m-f	Cl			
	A2	58	7.5YR 3/1		15	sbk-2	fr	m-m	Cl			
	Bw2	67	10YR 4/4		25	sbk-1	fr	m-c	Gr			
	BC	82+	10YR 4/4		65	sbk-1/pl-1	fr	f-f	n/a			

Pit	Horizon	Depth	Color (moist)	Texture	C.F. %	Structure	consistence	roots	Horizon Boundary	Other notes	Diagnostic Subsurface horizons	
Forest – top-mid			slope 32%									
	Oi	1	N 2/									
	Oe	3	N 2/							Ustic		
	A	18	N 2.5/1	20	5	Gr-3	vfr	m-f				Entic Haplustoll
	AB	30	10YR 3/2	24	15	sbk-2	fr	m-m				
	Bw1	65	10YR 4/4	33	25	sbk-2	fr	m-m				
	BC	87+	7.5YR 4/4	37	65	sbk-1	fr	f-f				
13-Jul-08	12:15	Parly Cloudy		mid 80's								
Forest - top			Slope 29%									
	Oi	1		Clay %								
	A1	11	7.5YR 3/3	26	5	sbk-2		m-f		Ustic		Pachic Haplustoll
	A2	28	10YR 3/2	32	5	sbk-2		c-m				
	A3	46	10YR 3/2	31	30	sbk-2		c-m		root mat		
	AC	66+	10YR 4/2	33	65	sbk-1		f-f				
Pasture - top												
	A	10	10YR 3/2	27	35	sbk-1	fr	m-f		Ustic	if frigid	Udic Ustorthent
	Bw	22	7.5YR 4/3	29	50	sbk-2	fr	c-f				
	BC	33	7.5YR 4/3	34	65	sbk-1	fi	f-f			if frigid	Typic Ustorthent

Pit	Horizon	Depth	color (moist)	Texture	C.F. %	Structure	consistence	roots	Horizon Boundary	Other notes	Diagnostic Subsurface horizons	
Pasture - top-mid											if mesic	Typic Ustorthent
	A1	7	10YR 3/3	26	15	gr-1/sbk-1	fr	c-f				
	A2	20	10YR 3/3	34	45	sbk-1	fi	f-m		Ustic		Entic Haplustoll
	AC	35+	10YR 3/3	33	60	sbk-1	fi	f-m				
Pasture – mid												
	A1	7	10YR 3/2	28	10	gr-1/sbk-1	fr	m-f		Ustic		Entic Haplustoll
	A2	22	10YR 3/2	31	15	sbk-1	fr	f-c				
	AC	27+	10YR 3/3	32	55	sbk-1/m-0	fi	f-f				
Pasture - bottom												
	A1	8	7.5YR 3/2	30	10	gr-2	fr	c-f		bench/rounded c.f.'s		
	A2	35	7.5YR 3/3	32	15	sbk-2	fr	c-f		Ustic		Entic Haplustoll
	AC	50+	7.5YR 3/3	34	55	sbk-1	fr	c-f/m				
Coppice – top												
	Oi	1										
	Oe	2										
	A	9	10YR 2/1	25	5	gr-2	fr	m-f		Ustic	<60% BS	Dystrusept
	Bw1	27	7.5YR 4/2	28	10	sbk-2	fr	c-f			>60% BS	Haplustept
	Bw2	40	7.5YR 3/2	31	25	sbk-2	fr	c-m				
	BC	59+	7.5YR 3/2	31	60	sbk-1	fr	f-f				

Pit	Horizon	Depth	color (moist)	Texture	C.F. %	Structure	consistence	roots	Horizon Boundary	Other notes	Diagnostic Subsurface horizons	
Coppice – top-mid												
	Oi	1										
	A1	11	10YR 2/2	26	10	gr-2	fr	m-f				
	A2	23	10YR 3/2	33	30	sbk-2	fr	c-f/m		Ustic		Entic Haplustoll
	Bw	37	7.5YR 3/2	35	30	sbk-2	fr	c-m				
	AC	53+	7.5YR 4/2	33	65	sbk-1	fr	f-f				
Coppice – mid												
	Oi	1										
	Oe	2										
	A	15	10YR 3/2	28	5	gr-2	fr	m-f		Ustic		Entic Haplustoll
	Bw	39	7.5YR 4/2	30	35	sbk-2	fr	c-f				
	BC	49+	7.5YR 4/2	32	65	sbk-1	fr	f-f				
Coppice – bottom												
	Oi	1	N 2/									
	A	7	10YR 2/1	27	5	gr-3	fr	m-f		Ustic		Entic Haplustoll
	Bw	22	10YR 4/2	28	35	sbk-2	fr	c-f				
	BC	29+	10YR 4/2	29	65	sbk-2	fr	f-f				

Appendix 3. Differences between State Agricultural Institute soil laboratory and the thermogravimetric results.

The Tyurin method, which was employed by the SAI laboratory, employs wet chemical oxidation of organic matter to measure organic carbon in the soil (Appendix 4). In contrast, thermogravimetry calculates organic carbon indirectly by measuring the weight loss of the soil sample as it is heated with a controlled increase in temperature over time. Because these methods are measuring organic carbon in different ways, discrepancies in results are possible. The levels of organic carbon found by each method, however, are similar enough and following the same trends between land cover areas as to be mutually supportive.

The SAI laboratory measured total nitrogen by digestion, extraction, and titration (Appendix 4). Again, thermogravimetry calculates total nitrogen indirectly by measuring the weight loss of the soil sample as it is heated with a controlled increase in temperature over time. Discrepancies are possible due to the different ways that total nitrogen is being measured by each method. As with organic carbon, the results of the two methods are close enough to lend credence to the respective findings. It is interesting to note that total nitrogen according to the SAI laboratory was somewhat higher in the pasture than the coppice, while thermogravimetry showed the opposite. Without more knowledge about the total nitrogen present in the soil samples, it is difficult to speculate about the cause of the divergent values. The variation was slight, however, and neither method showed a statistically significant difference between the two land cover areas.

Appendix 4. State Agricultural Institute Soil Laboratory Analysis Procedures.

Organic Carbon

The Tyurin method is used to analyze organic carbon content in soils at the State Agricultural Institute laboratory in Yerevan, Armenia. The method was originally described in the USSR Science Academy book Soil Agrochemical Research Methods (1960) which is available at the State Agricultural Institute's soils laboratory. Soil samples are air dried and then 0.1-0.2 grams of soil is ground with mortar and pestle to less than 0.25mm. The soil is then combined with 10ml of $K_2Cr_2O_7$ and concentrated H_2SO_4 and boiled for five minutes. The solution is then cooled and titrated to end point with Mohr's Salt – $FeSO_4(NH_4)2SO_4$.

Total Nitrogen

The State Agricultural Institute laboratory in Yerevan, Armenia, analyzes total nitrogen using the Ginsburg extraction and Kjeldahl distillation method. The method was originally described in *Soil Science*, Journal number 5 (1963), which is available at the State Agricultural Institute's soils laboratory. Soil samples are air dried and then 0.5g of soil is digested with a 20ml mixture of H_2SO_4 and $HClO_4$ and then boiled for about 30 minutes until clear. NaOH (40%) is then added to the mixture and distilled. The distillate is then titrated with H_2SO_4 and $HClO_4$.

Total Phosphorus

Total phosphorus is determined at the State Agricultural Institute laboratory in Yerevan, Armenia, using Ginsburg extraction and color development by an acid ammonium molybdate reagent. The method was originally described in the

Pochvovedenie, Journal number 5 (1963), which is available at the State Agricultural Institute soils laboratory. Soil samples are air dried and then 0.5g of soil is digested with a 20ml mixture of H_2SO_4 and $HClO_4$ and then boiled for about 30 minutes until clear. The extraction is then mixed with ammonium molybdate color developing solution and absorbance is measured on a spectrophotometer. The absorbance values were compared to the standard curve.

Total Potassium

To determine total potassium at the State Agricultural Institute soil laboratory, a 250ml digestion was prepared from 0.5g of soil, concentrated HF and distilled water. Total potassium is then determined on a propane flame spectrophotometer with a filter for potassium. The results were compared to a calibration curve. This method is described in the USSR Science Academy book, Soil Agrochemical Research Methods (1960), which is available at the State Agricultural Institute's soil laboratory.