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Experiments to Measure the Effects of Timber Harvesting Equipment on Surface Lithic Scatters

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EXPERIMENTS TO MEASURE THE EFFECTS OF TIMBER HARVESTING EQUIPMENT ON SURFACE LITHIC SCATTERS

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by

Douglas James Baughman

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ABSTRACT

EXPERIMENTS TO MEASURE THE EFFECTS OF TIMBER HARVESTING EQUIPMENT ON SURFACE LITHIC SCATTERS

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The importance of cultural resource preservation cannot be overstated; however local economies are at least as important. Due to conservative archaeological site protection practices in Region 5 of the United States Forest Service, the economy of Northeastern California is being adversely affected. In an attempt to help the Forest Service make more informed management decisions and improve the Northeastern California economy, I undertook experiments on the effects of timber harvesting on lithic scatters on Modoc National Forest. The experiments involved placement of 225 glass tiles (proxy lithics) in each of three plots subject to vehicle traffic and log dragging by steel-tracked and rubber-wheeled equipment. After the harvest, there was almost no tile breakage (0.15%), and scratch damage was slight (2/3 of tiles had <20% scratch coverage). Artifact movement was greater in plots closer to log landings. Steel-tracks caused more damage than rubber wheels, but movement was greater with rubber-wheeled vehicles.

ACKNOWLEDGEMENTS

Research on the effects of modern disturbance on lithic scatters has been carried out by numerous people over the years, and I thank each and every one for their individual contribution that culminated in this thesis. I also thank those who will undertake research on the subject in the future. The ever-evolving nature of modern technology necessitates the need for continuing experiments with newer and more powerful pieces of timber harvesting equipment. Archaeologists may deal with the past but we surely need to be concerned about site protection in the future!

Dr. Patrick Lubinski, my committee chair, deserves special recognition for his support, patience and guidance throughout this project. I also would like to thank the remaining committee members, Dr. Steve Hackenberger (co-chair) and Gerald (Gerry) Gates, M.A., for their encouragement throughout my graduate school career. Gerry Gates first brought the need for a solid experiment to analyze the effects of timber harvesting equipment on lithic scatters to my attention as a thesis project and continues to be an important figure in Northern California archaeology and a champion of lithic scatters everywhere. Joseph Gallagher, formerly of the US Forest Service and currently owner of Historic Preservation Resources, was incredibly generous with his time and was very helpful in answering questions about his past experiment and recommendations for my thesis and experiment. The entire staff at the Central Washington University Brooks Library were extremely helpful while I was doing my research and literature review. I owe a great deal of gratitude to Meghan Kerley and Jeanette Boggess for assisting me with my experiment.

My parents, John and Barbara Moore, provided me much-needed love and support throughout my time as a graduate student, as well as accomplishing the tedious tasks of individually numbering and gluing a washer on the back of 900 glass tiles. My wife, Jenifer, was and is a constant source of motivation, encouragement and love. My friends and bosses Cristina Weinberg and Dan Elliott were very understanding with the hours I needed to take off of work to finish my thesis. And to everyone else in my life that supported, mentored, and/or generally put up with my whining, complaining, stressing out, in good times and bad, thank you so very much! I could not have done it without all your help!

This thesis is dedicated to the memory of my Grandfather Douglas Acel Passey, who gave me nothing but love, affection and encouragement every day of my life. His wisdom and advice have guided me in everything that I do. I miss you and hope you are proud of me.

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CHAPTER I

INTRODUCTION

In the early summer of 2005, a timber company, without consulting the Modoc National Forest, bulldozed a one-mile stretch of the historic Applegate Emigrant Trail in Northeastern California (part of which is now Forest Service Road 46N19), increasing the trail's width and damaging an adjacent prehistoric archaeological site. The timber company's reason for bulldozing was simple: its logging trucks could not navigate the narrow corridor. The road was damaged in two segments that have been in continuous use since 1846, one as a Forest Service system road (46N19) and the other as a user-created non-system road, probably used for wood cutting. As I surveyed the damage to what was once a fairly intact archaeological site, the realization of just how destructive a man and his machine could be filled me with sorrow – we can never replace what was lost here – and frustration: here was hard evidence of what happens when timber companies and the Forest Service do not adequately communicate with one another. This resulted in a contract breach by the logger. I realized we needed better research – solid data that would help both sides accomplish their important work.

Federal law as it exists today requires that any project undertaken on federally-owned land that "significantly affects the quality of the human environment," must have an assessment to uncover the possibility of negative impacts completed before beginning operations (United States Congress 1969). Included in the assessment are cultural as well as natural resources. Laws such as Section 106 of the National Historic Preservation Act

(NHPA) preclude any undertaking on public land before such things as archaeological sites are taken into account (United States Congress 1966). Even if a timber company follows the rules and has these assessments completed, it may not be able to undertake its desired timber cut due to the conservative archaeological site protection policies on Region Five of the United States Forest Service (USFS).

Region Five (Pacific Southwest Region) includes national forest lands in California and Hawaii and manages over 20 million acres of land (USFS 2013). The current tendency on Region Five follows a “flag-and-avoid” approach to archaeological site protection (USFS Region Five 2001). While completing the assessment for a particular project, if any site that could be eligible for the National Register of Historic Places (which current historic preservation law deems to be all unevaluated sites) is found, Forest Service archaeologists flag the boundaries of the site, plus a 5-10 m buffer to warn timber crews to “keep out.” Within the boundaries of this flagged area very few activities are allowed, which has the effect of making small islands of extant timber on the forest.

It has been observed by law enforcement officers, as well as Forest Service archaeologists, that these small islands of timber attract illegal artifact hunters. Most knowledgeable looters know what color of flagging tape different National Forests use to mark boundaries of archaeological sites and soon realize that these small islands of trees usually indicate exact archaeological site boundaries. In addition to looters, the shade these timber islands offers are favorite gathering places for wildlife and livestock. The trampling caused by these animals is cumulative and could be considered an inadvertent effect on the integrity of the archaeological site.

The current tendency to “flag-and-avoid” exacerbates the feeling of ill will between timber companies and the Forest Service; large amounts of timber become off-limits to harvesting. The brunt of the timber industry’s negativity is directed toward Forest Service archaeologists, who are seen as a threat to the Northern California economy. The forest products industry represents close to 13% of personal income; about 16% of total Northern California jobs are in the forest products industry (Laaksonen-Craig and McKillop 2003 p. 10).

Given the importance of timber harvest to the area and the current tendency to “flag-and-avoid”, one could wonder about the nature of timber harvest impacts to archaeological sites and whether the overwhelming use of the “flag-and-avoid” practice is justified. While there very likely are some significant impacts of timber harvesting on archaeological sites that require careful planning and policies (Greulich 1999), little is known about the nature of these impacts to lithic scatter sites. There is a data gap when it comes to understanding the effects of different types of timber harvesting and removal equipment on various site types throughout the year. Although some studies have been accomplished (DeBloois 1974; Foster-Curley 1998; Gallagher 1978; McBride and Mercer 2012; Minnesota Forest Resources Council 1998), none specifically addresses the effects of timber harvesting equipment on movement and damage to artifacts in surface lithic scatters.

To address this data gap, I completed an experiment on the Modoc National Forest that involved placement of glass tiles to mimic four surface lithic scatters prior to a timber cut, and then monitored how these study plots were affected by the harvest. I studied the three-dimensional movement of my tiles in the soil, and the amount of damage caused to the tiles at three experimental plots within the timber cut, and also for a control plot placed outside of the timber cut. Since I recorded the equipment used on the harvest, the location of the plots relative to the log landing, and the slope and soil type of each plot, I hoped to address the role of these variables in the resulting impacts.

The purpose of this thesis is to help cultural resource managers make more informed decisions when deciding what kind of activities will be allowed within the boundaries of prehistoric lithic scatters. Through my experiment, I attempt to give cultural resources managers a better idea of what can be expected during a timber sale in a similar environment. The degree of risk that the Forest Archaeologist and/or the District Ranger is willing to take will ultimately determine what timber harvesting techniques are allowed but hopefully this thesis will be used as a tool to help lessen that risk.

More specifically, it is hoped that the experimental data will be used to increase the use of "flag-and-treat" resource protection measures in place where "flag-and-avoid" protection measures would have formerly been used. The "flag-and-treat" measures are currently allowed under special circumstances, such as when using the Regional Programmatic Agreement for treatment of dangerous trees within archaeological site boundaries and in the Hazardous Fuels Protocols (Forest Service 2001). This tool gives us the ability to "treat" within the flagged archaeological site boundaries using prescribed logging methods designed to avoid or minimize surface disturbances. Examples of flag and treat methods are directional felling of timber away from the site, and using hand tools to thin brush or small trees within site boundaries. Also, occasionally we allow felling of trees if the operators can achieve full suspension to remove them; otherwise they have to fell each tree and leave it in place.

By finding non-destructive timber harvesting and removal techniques, and making the results available to other interested parties, this study will help to mitigate damage to valuable cultural materials, while also opening up many more acres of the Pacific Southwest Region of the USDA Forest Service to timber harvesting by avoiding the dreaded "flag and avoid" policy. A delicate balance of natural resource gathering and cultural resource protection can be achieved with a thorough and proper study.

Organization of This Thesis

This thesis begins with a review of the literature for the study area (Chapter II), followed by a review of pertinent literature on prior studies of archaeological impacts from timber harvest (Chapter III). In Chapter IV, I discuss the methods I used while conducting this study. Chapter V highlights the results of the study with some unexpected findings. Finally, Chapter VI summarizes the entire project, compares each of the study units, and recommends areas of further study.

CHAPTER II

STUDY AREA BACKGROUND

The study area is the Modoc National Forest. This is located in Modoc, Lassen and Siskiyou Counties, in northeastern California (Figure 1). The Modoc National Forest is located at the borders of several geographic units. Environmentally, it is located at the border of the Great Basin, the Medicine Lake Highlands (part of the Cascade Range), and the Modoc Plateau. In terms of anthropological units, it is at the boundary of the Plateau, Great Basin, and California culture areas.

Figure 1. Location of the study area, modified from City Maps (2005).

Environmental History

Northeastern California is home to a rich diversity of faunal and floral species. The dense coniferous forests and expansive sage covered grasslands attracted early loggers and ranchers alike. The plethora of big game species in the region has attracted hunters for thousands of years and this area continues to be popular with sportsmen today.

The largest percentages of trees on Modoc National Forest are western juniper (*Juniperus occidentalis*), Jeffrey and ponderosa pine (*Pinus jeffreyi* and *ponderosa*), red and white fir (*Abies magnifica* and *concolor*), incense cedar (*Libocedrus decurrans*), and quaking aspen (*Populus tremuloides*) (Modoc National Forest 2007c). Several other species of trees, in smaller numbers, also exist within the boundaries of the Modoc. Due to the large percentage of coniferous trees on the Modoc (especially pine) a layer of needle-rich duff covers much of the ground. I have seen this layer as thick as half a meter but usually it is 0-30 cm.

Several waterways exist on Modoc National Forest. Medicine Lake, Clear Lake, Blue Lake (Figure 2), Goose Lake, Big Sage Reservoir, Pit River, and many other water sources are home to a vast number of species of plants and animals. These waterways are also used for local irrigation and as watering holes for large herds of free ranging cattle. Waterways were an important resource for indigenous cultures and many archaeological sites are located near them.

Figure 2. Blue Lake, California (Robertson 2007).

The geology of the Modoc National Forest is also worth mentioning, specifically the geological history that provided the lithic materials used to make chipped stone tools found in the forest. Based on my finds of artifacts in the forest, the three main lithic materials used by the indigenous population of the area were obsidian, chert, and basalt. It is important when discussing the geological history of the Modoc to discuss how these important lithic sources formed. Obsidian is formed by the rapid cooling of a mixture of molten silica (SiO_2) and small quantities of one or more other elements. Basalt forms when hot basaltic magma rises through tens of kilometers of continental crust, incorporating many of the materials in its path. Chert develops as silica-rich chemicals precipitate in water. Over long periods of time these silica-rich deposits form layered beds of chert (Chernicoff 1999).

Eight hundred million years ago the old continental margin (west coast of North America) stretched from southeastern British Columbia, across northeastern Washington, and then south along a line near the western border of Idaho (Alt and Hyndman 1995). There is a piece missing from Idaho to the Sierra Nevada in California. It seems plausible then to assume that at least a portion of Modoc County in northeastern California was a coastal plain and possibly beneath shallow coastal waters.

One hundred million years ago a sliding transform plate boundary caused the Klamath block (which later rose to become the Klamath Mountains) to move westward, leaving behind the northern edge of the Sierra Nevada and opening up a miniature ocean about 60 miles wide to the east of the Klamath block and north of the Sierra Nevada (Alt and Hyndman 1995). This miniature ocean existed for over 50 million years and was yet another source of silica-rich marine deposits that fueled later chert and obsidian formations on the Modoc Plateau. 17 million years ago, during the middle Miocene, there is evidence that a large asteroid or comet struck southeastern Oregon causing a "Lava Lake Volcano" to form in northeastern California, the northwestern corner of Nevada, across much of Oregon, most of eastern Washington, and the western edge of Idaho. Over a period of less than two million years, flood basalt lava flows and rhyolite ash spread across much of the western United States (Alt and Hyndman 1995).

The availability of obsidian quarries attracted prehistoric peoples here. This area of north-eastern California has been shaped over countless millennia by volcanic activity. One can walk around anywhere on the Forest (especially Devil's Garden) and notice the massive amount of basalt strewn far and wide. A joke that locals tell is that "the only thing the devil grew on Devil's Garden were damn rocks!!" I can't help but imagine that Native Americans of the past must have either had tough feet or very good shoes. The forest is covered in light brown to reddish-brown sandy loam that is fairly acidic and affords preservation of only the toughest materials such as stone. It is due to this situation that the majority of archaeological material that exists on the Modoc National Forest is in the form of obsidian waste flakes.

There are rich abundances of obsidian quarries scattered throughout Modoc National Forest. Obsidian was one of the best tool making materials available to ancient peoples. There are at least four major varieties of obsidian originating on the Modoc. Through on-the-job training I have learned these types and where they originate: Gray Translucent is high quality obsidian from Glass Mountain in the Medicine Lake Highlands (Dillian 2002), Black Translucent originates in the north Warner Mountains and is also of extremely high quality, Mahogany is a slightly lower grade obsidian (as compared to Black and Gray Translucent) but is still highly knappable and looks nice, coming from the central Warner Mountains (Gates 2007), and Blue Mountain obsidian comes from Blue Mountain on the Doublehead Ranger District. Blue Mountain obsidian is a low to mid-quality peppery obsidian that looks black but when candled (held up to the light) is actually green translucent (Van De Hoek 1990).

The climate on the Modoc National Forest varies greatly with altitude, typically the higher the elevation the greater the annual snowfall. With altitudes ranging from 4,000 to over 8,000 feet the Modoc has a wide range of year-round temperatures. These elevation changes are also a factor in different plant and animal species' habitats; moving from one elevation to the next, gradual changes in the fauna and flora take place due to species specific adaptations to the environment.

Archaeological Background for the Modoc Plateau

Archaeological evidence of early human occupation in northeastern California dates back to least 11,450 ± 340 BP (Beaton 1991). Since that time, many thousands of years ago, this area has seen many diverse cultures and traditions. The first tradition in the region is Paleo-Indian, but there is relatively little evidence of this in the Forest (Elliott 2001). Early use of the Forest by Paleo-Indian people appears to have been sporadic and is characterized by Parman or fluted projectile points found near Lake Davis, Eagle Lake, Lake Almanor and other locales (Elliott 2001).

Starting about 10,000 BP in California and the Great Basin is the Western Pluvial Lakes Tradition, which correlates with fossil lakeshores, and is characterized by a diverse lithic tool assemblage and long-stemmed projectile points (Bedwell 1970). A climatic warming, called the Altithermal, contributed to significant environmental and human responses by approximately 8,000 BP (Kowta 1988). At this point, the pluvial lakes began to dry out and forests receded to higher elevations. Human subsistence patterns, no longer tied to lakeshore resources, are believed to have then shifted to the semi nomadic utilization of seasonal resources (Kowta 1988).

The Milling Stone Culture existed in California between 8,000 and 5,000 BP (Wallace 1978). The Native Americans of this tradition subsisted on seeds and root crops, supplemented by smaller mammals, much like the early inhabitants of southeastern

Oregon to the north. In Modoc National Forest, there appears to be a contemporary and similar cultural adaptation, but with some differences in food processing technology. Whereas Milling Stone Culture is characterized by milling stones (e.g., manos and metates made from cobbles), in Modoc National Forest most of the mortars are of the large basalt bedrock variety, probably due to the prevalence of this very common boulder in this area. After 5,000 BP the people of Northeastern California developed a diversified subsistence strategy. In addition to root crop, plant, and seed gathering, reliance on the hunting of quadrupeds and other small mammals increased (Wallace 1978).

Throughout the human history of this area, even after the introduction of the bow and arrow, projectile points became smaller in size. From the large Clovis points (up to 150 mm in length) to the late Rose Spring “Bird points” (arrow points) that are no larger than a child’s finger nail, a definite change in projectile point technology had taken place. Using obsidian hydration dating, a fairly decent point type chronology has been established on the Modoc National Forest (Figure 3). The most common point types I have encountered while surveying have been Rose Spring and Elko. Rose Spring points have been dated to 680 BC-AD1850 (this is the “terminal” date the Forest uses) and Elko points date 2,000 BC-AD1080 (Gates and Adkison 2007:207). Representative examples of Rose Springs and Elko points are illustrated in Figures 4 and 5.

Hunting and gathering was a huge part of the local people’s subsistence strategy (Stern 1998). In addition to the diverse populations of large game animals there were (and still are) hundreds of species of edible and useful plants (Kirk 1975). Some important species for indigenous people were: Epos, brodiaea bulbs, tiger-lily bulbs, wild

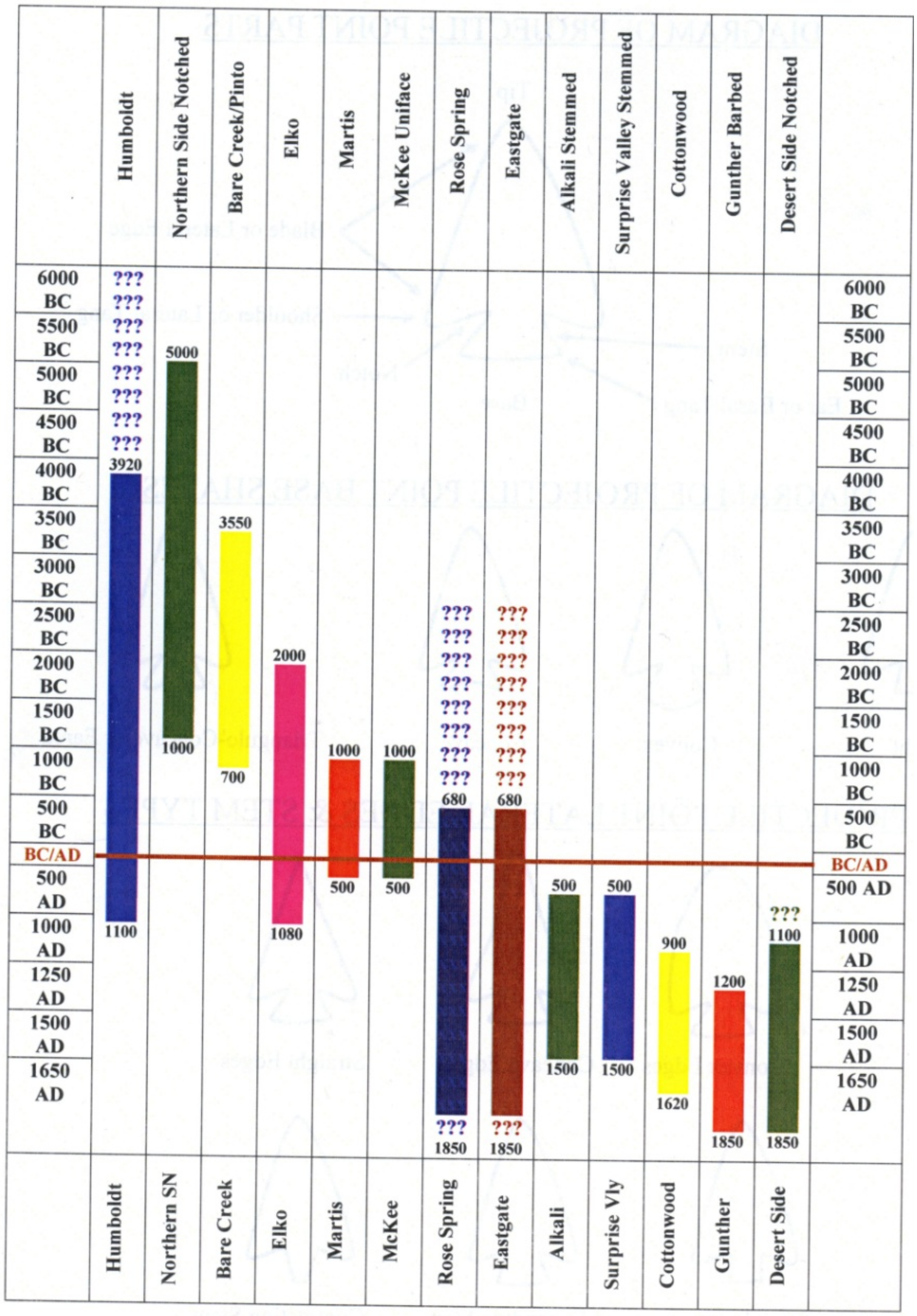

Figure 3. Modoc area Point Type Chronology (Gates and Adkison 2007:207).

onions, dogbane, milkweed, sunflowers, clover, thistle, juniper, water lily (the Modoc called these “wocas”), camas roots, tule reeds for baskets and sandals, and sagebrush bark for clothing (Olmsted and Stewart 1978).

Figure 4. Rose Spring Points from the Forest (photo by author).

Figure 5. Elko Points from the Forest (photo by author).

Historical Period

The native peoples that inhabited the Modoc National Forest in the historic period and earlier were the Modoc, the Pit River (or Achomawi), and the Northern Paiute (Brown 1945). Their existence remained rooted in procuring food and shelter and interacting with the other tribes of the general area for countless generations. This way of life changed dramatically with the arrival of Euro-Americans.

The Euro-American contact and settlement era of California began in the 1540s with Spanish exploration, mostly in search of gold and other loot (Pincetl 1999). The English followed shortly thereafter with Sir Francis Drake's expedition in 1579 (Pincetl 1999). For a period of 167 years (between 1602 and 1769) California remained largely ignored by the Europeans (Pincetl 1999). In 1769 the first permanent Spanish settlements appeared along the California coast (Castillo 1978). Over the next 80 years the Spanish unleashed a barrage of Catholic missionaries over most of California to "Christianize the savages" (Castillo 1978). In February, 1848, The Treaty of Guadalupe Hidalgo ceded California, New Mexico, and Arizona to the United States (Blanding 1888). Many Native Americans hoped for a relief from oppressive Mexican policies, only to find that the U.S. policies were as bad or worse. For example, in 1850 the legislature passed a law that stated that any Indian, on the word of a white man, could be declared a vagrant, thrown in jail, and have his labor sold at auction for up to four months with no pay (Castillo 1978). When gold was discovered at Sutter's Mill in 1849 an explosion of Euro-American settlement began in California. The great California Gold Rush had begun.

The first period of Euro-American commercialism in the area of Modoc National Forest began in the late 1820s when Hudson Bay fur trappers led by Peter Skene Ogden began collecting beaver and other pelts in the area (Brown 1945). The era following the fur trappers was characterized by explorations and emigrant trails. In the time period from 1842-1860 many railroad mapping and military relief expeditions were conducted. A famous expedition was led by John C. Fremont in 1846 (Denton 2007). It was during this trail blazing age that the historic Applegate, Lassen, and Burnett trails were carved into the landscape (Gates and Adkison 2007:97).

During the Spanish period of control of California, Native Americans resisted European occupation; in some cases this resistance turned violent. This resistance continued through the period of Mexican control and into the American conquest and control of California. In 1872-1873, one of the last and most notable of the episodes of Native American resistance was the Modoc War. Here a band of Modoc led by Captain Jack (Figure 6) waged a guerilla war on the U.S. Army troops trying to quell their rebellion (Johnston 1991). After being holed up in the extensive cave system of what is now Lava Beds National Park, U.S. Army troops, with the help of Native Warm Springs tribe scouts, captured Captain Jack and his warriors. Captain Jack and three others were subsequently hanged at Fort Klamath, Oregon, October 3rd, 1873 (Riddle 1998:149-197). Most of the remaining Modoc were exiled to Indian Territory in Oklahoma.

Beginning about 1864 Euro-American settlement began in earnest on the Modoc (Gates and Adkison 2007). People here made a living from the late 1800s through 1950s through cattle and sheep ranching (and its associated agriculture), logging, and mining.

The mining phase was not very successful, only lasting 25 years from 1910-1935 (Larry Shippen, personal communication, 2006).

Figure 6. Captain Jack as photographed in October, 1873 (Thompson 1971: 9).

The Archaeological Record in Modoc National Forest

Some of the earliest recorded cultures took advantage of the Blue Mountain obsidian quarry, which is located on the Modoc National Forest. Blue Mountain obsidian was used extensively for thousands of years as evidenced by an unfinished Clovis point I recovered in August 2006 (Baughman 2006). Clovis points were used by Paleo-Indians to hunt Pleistocene megafauna (mammoths and mastodons) and other large game such as bison, toward the end of the last ice-age. They are generally thought to date between 11,000 and 10,800 BP (Waters and Stafford 2007). Unfortunately, the point I recovered cannot be dated with obsidian hydration (OH) dating because 50 years ago a forest fire raged through the area where I recovered the point and it reset the OH date (Skinner

2006). For lack of a well-established age, the California SHPO and other top archaeologists are calling this point "Clovoid." Blue Mountain obsidian is represented in points I have recovered from the Paleo-Indian period all the way up through the terminal period (European contact).

At present there are about 8,091 recorded archaeological sites on the Forest with roughly 30% of the Forest lands inventoried (Gerald Gates, personal communication, 2013). This averages a site density of roughly one archaeological site per 60 acres. If the predicted site density holds at one site per 60 acres, then the Modoc National Forest may contain about 26,666 total archaeological sites. Gerry Gates, Modoc National Forest Archaeologist believes this number to be too low and that it will be closer to 30,000 to 35,000 total sites.

More than 200 archaeological sites have been excavated on Modoc National Forest over the past 35 years; most for pipeline projects (PGE-PGT and Tuscarora), power line projects (COTP, BPA/Malin-Warner and Alturas Powerline), and the OTH-B Radar Installation by private consultants, and in-service for land exchanges, damage assessments, and Section 110 projects (Gates 2007). The site types on the Modoc National Forest are; 6,150 prehistoric, 1,375 historic, and 566 dual component sites (Gates 2013).

When discussing archaeological sites it is important to note that the actual definition of a site varies depending on the government agency and even within each of the agencies. The current definition of a prehistoric "site" on the Modoc National Forest (Gates and Adkison 2007:1) is 10 or more unmodified waste flakes in a limited geographical area (a 10 to 20 meter radius); or one definite artifact (a "tool") plus five or more unmodified waste flakes; or an isolated cultural feature (bedrock or portable mortar, bedrock or portable milling slick, etc.). By this definition, based on personal knowledge I am aware of sites within the boundaries of the Modoc National Forest ranging from the minimum of 10 flakes all the way to large permanent villages with standing rock circle house remains. This covers a significant percentage of the 1,979,407 acres that make up the Modoc (Modoc National Forest 2007a). Other agencies around the country consider as little as two waste flakes a site (Washington State Department of Archaeology and Historic Preservation 2009). Due to the overall density of sites on the Modoc National Forest a definition that narrow would likely cover the majority of the Forest in archaeological sites.

History and Present Uses of the Modoc National Forest

The Modoc National Forest was created by Theodore Roosevelt on November 29, 1904 as the Modoc Forest Reserve and the Warner Mountain Forest Reserve (Brown 1945:18). Four years later in 1908 he combined these two, added 570,000 acres and proclaimed the area Modoc National Forest (Brown 1945:19). The Forest is named after the local Native American tribe whose ancestors have lived on and around the forest for thousands of years. With a private land exchange, the Forest as we know it today achieved its maximum land area of 1.9 million acres on June 30, 1944 (Brown 1945:21).

Modoc National Forest's motto is "The Land of Many Uses". There has been a long history of using the land for multiple purposes. Some of these uses include: cattle grazing, hunting, fishing, camping, scientific research, wildlife habitat, timber harvesting, and in the case of Native Americans, as a home. Although historic timber sale records are incomplete we know that logging operations have been occurring on the Forest since shortly after the Forest was created. Millions of board feet have been harvested from Modoc National Forest over the years. Trees harvested from the Modoc provide many uses, such as building materials, bio-fuels, firewood, etc. Some timber harvesting sales involve healthy trees while others are post-forest fire salvage operations.

The Modoc National Forest Land Management Plan (USDA Forest Service 1991) recommends a target of 45.5 million board feet of timber harvest per year. At present, due to economic, resource protection, and many other factors, the Modoc National Forest only produces about 20 million board feet of timber annually (Gerald Gates, personal communication, 2013). Most of the timber sales I have witnessed on the Modoc involve ponderosa pine and white fir. There is a large project which is still in the planning stages concerning massive juniper removal, one small component being the Fender Hazardous Fuels Reduction – Juniper Thinning Project which involves 643 acres of land densely covered in archaeological sites (Asrow 2004).

The vast number of archaeological sites near water sources presents a problem to timber harvesting due to the fact that the availability of water in these areas has also caused significant growth of prime timber stands. Some of the highest concentrations of “flag and avoid” areas on the Forest are near water sources. Timber harvesting in the winter time, when there is a layer of snow on the ground, especially in the higher elevations, may help mitigate damages not only to archaeological sites but also to local plant life. In addition to mitigating damage to archaeological sites by harvesting design criteria, by recording the quantity, location, and obsidian type, archaeological sites consisting of sparse lithic scatters can be determined ineligible for the National Register of Historic Places and a mitigated timber project can be allowed on these sites.

In addition to timber harvesting, hunting on Modoc National Forest is booming. Although there are no more beavers, hunting wild game such as mule and white tail deer, elk, pronghorn, and wild turkey, is still a very popular sport on the Modoc. Ranching is still thriving on and around the Forest. There are about 1 million acres of designated rangeland on the Forest (USDA Forest Service 1991). Modoc National Forest truly is "The Land of Many Uses".

CHAPTER III

LOGGING AND ARCHAEOLOGICAL SITES

Beginning about 1864 Euro-American settlement began in earnest on the Modoc (Gates and Adkison 2007). People here made a living through cattle and sheep ranching (and its associated agriculture), logging, and mining. Although the mining phase was not successful, only lasting 25 years from 1910-1935 (Gates 1983), ranching and timber harvesting are still thriving on and around the Forest. Modoc National Forest truly is "The Land of Many Uses."

Of all these uses, timber harvesting arguably has the largest impact on the environment. There has been a growing interest among researchers on the environmental effects of potential harvesting practices, in the spatial context of many management questions and in demands for clear estimates of uncertainty about harvesting effects (Bennett and Adams 2004). A poorly planned timber cut has the potential for dramatic impacts on a wide range of biological, floral, faunal, and cultural resources as well as the geomorphic and hydrologic systems within the area of potential effect of the timber sale. The effects of a timber removal project are far greater than just the particular area in which the trees will be cut. Many other factors must be considered when evaluating the area of potential effect of any timber harvesting operation. Just a handful of these include: staging areas for heavy machinery, temporary storage areas for downed timber, transportation routes for tractor trailers to pick up the timber, as well as getting industrial equipment to and from the harvest site (Greulich 1999). The area of effect is greatly increased if the proposed operation is near a waterway. Effects have to be taken into account up and downstream from the project.

The three stages of the logging operation most likely to impact archaeological sites are the felling, processing, and stump to landing periods. During the felling period timber companies use chainsaws, harvesters (Figure 7), and/or feller bunchers (large heavy machines, either tracked or rubber tired, with attachments to cut the trees in place; Figure 8) to cut down the trees (Harvey and Strain 1993). The processing period consists of two different operations; the first is the de-limbing of the trees and the second is called bucking. Bucking a tree means cutting it into log length sections. De-limbing usually takes place at the site where the tree is felled. Bucking can take place where the tree is felled or at the landing site (Greulich 1999). One of the most destructive periods of a logging operation to an archaeological site involves moving the logs from the stump to the landing area. There are several different methods in common use: tracked or rubber wheeled vehicles can pull, carry, or shovel the logs; cable systems can be used to drag the logs, or they can be carried out by helicopter. The last method is very costly but has been used in areas to which it is especially hard to get heavy machinery (Millard 2001). Timber harvesting is big business in Northern California but the effects of this business on archaeological sites has not been thoroughly examined,

Timber harvesting is very important to the Northern California economy. The forest products industry represents about 13% of personal income and about 16% of total jobs in Northern California (Laaksonen-Craig and McKillop 2003:10). Federal law as it exists today requires that any project undertaken on federally owned land that "significantly affects the quality of the human environment" must have an assessment

Figure 7. John Deere 759JH Tracked Harvester (John Deere 2007a).

completed prior to commencement of operations to uncover the possibility of negative impacts (United States Congress 1969). Included in the assessment are natural as well as cultural resources. Even a timber company that follows the rules and has this assessment completed may not be able to undertake its desired timber cut due to the conservative

Figure 8. John Deere Forestry-959J Tracked Feller Buncher (John Deere 2007b).

archaeological site protection policies on Region Five of the USDA Forest Service. Laws such as Section 106 of the National Historic Preservation Act (NHPA) preclude any undertaking on public land before such things as archaeological sites are taken into account (United States Congress 1966).

The current tendency in Region Five follows a "flag-and-avoid" approach to archaeological site protection (USFS 2001). While completing the assessment for a particular project, if any site that could be eligible for the National Register of Historic Places is found, Forest Service archaeologists flag the boundaries of the site, plus a five to ten meter buffer to warn timber crews to "keep out." Within the boundaries of this flagged area very few activities are allowed. Any site that has not gone through a formal evaluation of eligibility has to be protected as if it were eligible – "flag-and-avoid" or "over-the-snow" are basically the only options permitted. However, under special circumstances, such as under the Regional Programmatic Agreement for treatment of dangerous trees within archaeological site boundaries and in the Hazardous Fuels Protocols (Forest Service 2001), we have the ability to "flag-and-treat." This tool gives us the ability to "treat" within the flagged archaeological site boundaries using prescribed logging methods designed to avoid or minimize surface disturbances. Examples of "flag-and-treat" methods are directional felling of timber away from the site, and using hand tools to thin brush or small trees within site boundaries. Also, occasionally we allow felling of trees if the operators can achieve full suspension to remove them; otherwise they have to fell each tree and leave it in place.

The wide ranges of archaeological site types that exist on the Modoc National Forest necessitate different kinds of timber harvesting methods. Sites with very little surface deposits may allow higher impact operations to be performed there, while sites that are rich in surface deposits need to be handled much more delicately. Other factors that might influence logging impacts are the nature of the site matrix (e.g., texture, moisture), on-site vegetation, logging techniques, and the nature of the surface artifacts that might be affected (e.g., their visibility, fragility).

Pertinent Experiments

A number of experiments have been undertaken that may be pertinent to modeling the impacts of timber harvesting on archaeological sites on the Modoc National Forest.

There have been a large number of studies on the effects of trampling on the archaeological record (e.g., Gifford Gonzales 1985; McBrearty et al. 1998; Nielson 1991; Pryor 1988; Tringham et al. 1974). These studies have generally employed placement of replica artifacts and allowed humans to walk over them repeatedly, then measuring artifact movement and/or damage. Below I review five of these human trampling studies in chronological order before moving on to experiments on equipment damage more directly pertinent to the thesis study.

Ruth Tringham and others (1974) conducted a series of experiments titled "Experimentation in the Formation of Edge Damage: A New Approach to Lithic Analysis." These early experiments focused on edge damage to European chalk flint through various human processes, including trampling. Variables that they systematically tested included: action, worked material, angle of edge and grip. Many trampling experiments that followed over the years attempted to recreate and/or disprove Tringham's results. Tringham found that edge damage due to trampling was completely random and occurred only on the side of the flake that was face down (away from the trampler's shoes). She concluded that it is possible to discern between edge damage caused by human trampling and edge damage caused by deliberate knapping.

Gifford-Gonzalez and others (1985) conducted an experiment titled "The Third Dimension in Site Structure: An Experiment in Trampling and Vertical Dispersal." This study focused on a variety of material including stone, bone, and ceramic and the effect that human trampling had on the vertical disposition of these materials in different soil types (a loam site and a sand site). There was an 81.2% recovery rate of artifacts after their experiment concluded. Between the two soil types 73.3% of the pieces were recovered at the loam site and 89.1% of the pieces were recovered at the sand site. The loam site tended more toward horizontal dispersal than vertical dispersal. Only 1.4% of the artifacts penetrated more than 2 cm below the surface; 94% of the artifacts lay 1 cm or less from the surface. After treading on the original 0.1 cm layer of loose loam the treading disturbance increased the loose loam surface to a depth of 2.5 cm. Although the loam site's substrate was not initially conducive to easy burial of small artifacts, the very process of human circulation on the site created a shallow, loose layer that promoted entrapment of these pieces. By contrast the loose sand of the second site was a highly effective artifact trap. A total of 40% of the artifacts at the sand site penetrated to a depth of 3-8 cm below the surface. The experiment showed that the moister the sand became the smaller the vertical movement of the artifacts.

Gifford-Gonzalez et al. modeled their artifact assemblages to resemble a natural lithic scatter at a core reduction site, because of this there were a greater number of small, light lithic flakes than larger heavier ones. The researchers found that they were unable to determine if weight played a significant role in the amount vertical movement of artifacts throughout the soil during the trampling experiment. They suggest that a future experiment should include an equal number of large heavy artifacts and small light artifacts. Their experiment suffered a serious setback when their entire set of edge damaged pieces was mistakenly thrown away before a full analysis of edge damage could be accomplished. They found only 61 pieces (3.8%) out of the 1,624 recovered pieces showed edge damage. To more easily see evidence of edge damage the researchers spray painted the obsidian artifacts bright fluorescent colors and planned to analyze new damage to them after the experiment. Their conclusion is that treadage by humans can cause substantial downward migration of objects in loose sandy substrates. Variations in substrate, in the intensity of human activity, and in the resulting interactions of objects with both substrate and one another may produce disparate distributions and damage patterns.

An experiment by Pryor (1988) titled "The Effects of Human Trample Damage on Lithics: A Consideration of Crucial Variables" used 900 obsidian flakes at two different sites; one with sandy soil and the other with loamy soil. He analyzed the damage to the lithics caused by an increasing number of trampling events. Pryor was trying to come up with a realistic and widely applicable set of criteria for trample damage. Pryor found that under dry conditions artifacts tend to act as passive elements. He also found that very little edge damage to lithics was caused by human trampling and that the damage that was caused was almost completely random. He concluded that lithic edge damage caused by human trampling could readily be discerned from damage caused by utilization.

A fourth experiment of human trampling on an artifact assemblage was undertaken by Axel E. Nielsen (1991). The study, entitled "Trampling the Archaeological Record: An Experimental Study," focused on many material types (stone, bone, ceramic, wood, and brick), and the effect of human trampling on the horizontal and vertical dispersal of this material on a hard packed soil surface as well as a recently watered surface. Nielsen also studied the damage caused by this trampling. An interesting conclusion found by this experiment was that, similar to Gifford-Gonzalez et al's 1985 experiment, treading on soil with a thin layer of loose surface substrate increased the thickness of the loose substrate layer. Nielsen's loose layer grew to 1-2cm thick. Nielsen also measured the penetrability of the soil and found that treading increased the penetrability by 14%. Prior to the experiment it was believed that human trampling would compact the surface layer causing it to be more impermeable to artifacts. It is important to note that this result could only be replicated on dry substrate. Moist to wet substrate doubled in compaction and became much more impermeable, however once this substrate dried out the former results were observed. Nielsen found that the dryer the substrate the greater the amount of size sorting of artifacts vertically within the soil, with smaller artifacts penetrating deeper under the surface. Length and/or weight were not found to play a significant role in vertical displacement within the substrate. Nielsen found that bone moved the farthest horizontally followed by ceramics and finally lithics moved the least. Concerning damage to lithics, Nielsen found that the dryer, more compact surfaces yielded more damage than the wetter, looser substrates.

An experiment by McBrearty et al. (1998) was titled "Tools Underfoot: Human Trampling as an Agent of Lithic Edge Modification." This was an experiment that measured trampling damage on chert and obsidian. Their experiment involved two 3 x 3 m units where eight individual trampling runs were made. Four runs involved 200 artifacts placed in the central 1 m^2 of the cleared area and the other four runs were made up of 500 artifacts in the central 1 m^2 of the cleared area. Rubber-soled shoes were used during the experiment. Each of the test areas had different soil types. The first was a sandy substrate at Light House Point Beach on Long Island Sound near New Haven, Connecticut and the second was a loam substrate at East Rock State Park in New Haven, Connecticut. Lithic damage was the goal of this experiment so positional data was not recorded. The results of their experiment showed that less damage occurred in sand than in loam and that trampling both increases the number of artifacts and reduces their mean size.

Although these trampling studies provide some useful information, experiments involving mechanical equipment would be more pertinent to evaluating logging impacts. Unfortunately, very few studies have measured the effects of mechanical equipment (other than plows or soil loss/deflation due to off-road vehicles) on surface archaeological sites (Table 1). I discuss the studies in Table 1 below.

Table 1. Experiments on Mechanical Equipment Damage to Surface and Near-Surface Sites

Equipment	Artifacts	Depth	Measurements	Reference
Tracked bulldozer and anchor chains	Replica chert flakes	Up to 50 cm (looking at root holes)	Breakage, vertical and horizontal movement	DeBloois et al. 1974
Tracked bulldozer with scarification shovel attached	Metal washers	Surface to 18 in (when trees were uprooted)	Vertical and horizontal movement	Gallagher 1978
Feller-buncher, grapple skidder, cut-to-length forwarding system	Replica lithics, ceramics, and fauna	3-20 cm	Breakage, vertical and horizontal movement	Minnesota Forest Resources Council 1998
Feller-buncher, tracked bulldozer	Ceramic tiles	Surface	Horizontal movement only	Foster-Curley 2008
Compression testing box (models wheel traffic)	Charcoal, shell, ceramics, flakes, points	(models burial)	Damage	McBride and Mercer 2012

DeBloois (1974) conducted a study concerning chaining of pinion pine and juniper trees. Chaining differs from timber harvesting in the fact that trees are not harvested. A chain is connected between two vehicles and dragged across a plot of land. The goal of chaining is to remove all small trees, brush, and ground cover in preparation for tree planting. DeBloois was interested in analyzing three factors; tree uprooting, chain travel, and the location of caterpillar tractor paths. He was concerned with how tree uprooting, chain travel, and the location of caterpillar tractor paths affected artifact breakage, horizontal displacement, and subsurface churning. His results were not surprising; artifacts tended to fall down the holes where the trees were uprooted, they tended to travel farther horizontally when directly in the path of the chain travel, and they were pushed in linear rows on the sides of the caterpillar tractor paths.

Former U.S. Forest Service archaeologist Joseph Gallagher (1978) conducted an experiment on the Sawtooth National Forest in Idaho. Gallagher used metal washers in place of lithics to analyze their movement caused by a tracked bulldozer. Gallagher did not study the amount of damage to the washers. His experiment studied the vertical and horizontal movement of washers at the surface, as well as pre-buried at depths of 1, 3, and 6 inches. His experiment utilized a single grid that was 54-feet on each side. He dug postholes 6-feet apart in a grid which resulted in 99 total holes with four washers in each hole (396 washers total). Gallagher found that the most significant surface damage occurred when trees were uprooted, the bulldozer applied extra power to get out of a "soft spot," or the bulldozer turned on one track. Gallagher's experiment showed that the washers on the surface moved an average of 20.5 inches horizontally and were buried an average of 2.5 inches beneath the surface. Gallagher concluded that scarification is a serious source of adverse impacts to cultural resources and that an archaeological site with a matrix of 6 inches or less beneath the surface ". . . would be markedly altered, probably to the point that the artifacts original spatial relationships could not be interpreted reliably" (Gallagher 1978:294). Two recommendations he had after completing his experiment were to use a material that better replicated lithics and/or ceramics and to place washers closer together to get better data on washer movement.

The Minnesota Forest Resources Council (1998) conducted an experiment titled "Effects of Timber Harvest on Archaeological Sites." Their experiment utilized lithic, ceramic, and bone to replicate the types of archaeological assemblages normally found in Minnesota. Each artifact was painted with fluorescent paint to aid in recovery and individual numbers were written on each. Photocopies were made of all artifacts to document their condition prior to the experiment. The researchers utilized six plots during the experiment: four plots were within the timber harvest and utilized a feller-buncher and grapple skidder, one plot was also within the timber harvest but utilized a cut-to-length/forwarder system, and the final plot was used as a control (no timber harvest was conducted there). Each of their plots measured 8 feet by 12 feet and 48 artifacts were placed at each. Each artifact was buried between 3 and 20 cm deep. During the timber harvest four of the researcher's datums were damaged and moved by timber harvesting equipment. Only two of the plots could be measured for accurate vertical movement of artifacts. The datum for Plot 1 and Plot 3 remained intact and each of the artifacts within these plots were measured for vertical movement.

After harvest, they measured the results (Minnesota Forest Resources Council 1998). Plot 1 was the control plot and it was found that each artifact's vertical movement was less than two centimeters (this may have been data error introduced by the researchers themselves). No damage was mentioned on this plot's artifacts. Plot 2 utilized a feller-buncher and out of the 48 artifacts placed here 44 were recovered and only three showed damage. About 15 artifacts were buried in the soil at an average depth of 2-4 cm. Plot 3 utilized a feller-buncher and showed signs of compaction. The artifacts that were buried here seemed to be recovered at shallower depths. Seventeen percent of artifacts in this plot were missing. Plot 4 utilized a cut-to-length system and was found to be compacted after harvest. All 48 artifacts were recovered and only one artifact was damaged. The depth of the artifacts did not change significantly. Plot 5 utilized a feller-buncher and was placed on a skid trail on a 10% slope. This plot saw heavy surface disturbance. Of the original 48 artifacts placed 42 were recovered. Four artifacts were broken. Plot 6 was placed on a skid trail with a 15% slope and utilized a grapple skidder. Unlike Plot 5, this plot showed minimal surface disturbance. Plot 6 had five missing items and two broken ones.

The Minnesota Forest Resources Council (1998) experiment showed that only 4% of the artifacts in all plots moved a significant vertical distance and that this was mostly caused by changes in the soil above them rather than actual artifact migration. Twenty-one items (9.6%) were not recovered and the researchers assume that this was due to significant horizontal displacement. Damaged items amounted to only 4.6% of the total recovered items. The researchers concluded that equipment traffic patterns were the most important factor in explaining the observed variations in artifacts displacement and alteration.

Cheryl Foster-Curley (2008) conducted an experiment on Bureau of Land Management property near the Modoc National Forest utilizing ceramic tiles to simulate a prehistoric lithic scatter. Foster-Curley studied the effects of timber equipment (a tracked bulldozer) on archaeological sites, analyzing the movement of the tiles but not the damage. Her study suffered from the fact that she did not place a metal washer on her tiles and therefore lost many tiles during the timber operation (Foster-Curley 2008). Only 52% of the ceramic tiles that were placed in the study plot were relocated. The plot was laid out in a grid pattern in loose loamy soil and a bulldozer was repeatedly driven over it from all directions. Several turns were made on top of the study plot. This resulted in heavy rutting of the surface and presumably many of the tiles being covered with soil. Of the tiles recovered, movement tended to be greatest near the center of the plot. Foster-Curley hypothesizes that this was due to a bottle-neck effect where more equipment passes were made nearer the center of the plot. She found that the average horizontal movement of the ceramic tiles recovered was about 20 cm but thinks that this statistic is skewed due to the near lack of movement near the edges of her plot. She warns that due to 48% of her ceramic tiles not being recovered, the results of the experiment could be flawed.

R.A. McBride and G.D. Mercer of the University of Guelph, Guelph, Ontario, Canada, conducted an interesting study recently titled "Assessing Damage to Archaeological Artefacts in Compacted Soil Using Microcomputed Tomography Scanning" (McBride and Mercer 2012). The experiment utilized micro-CT scanning equipment to analyze damage to artifacts which were placed in a laboratory compression testing box and then subjected to different levels of surface pressure. The different pressures simulated the effect that various models of heavy construction equipment would have when driven over subsurface artifacts. The researchers concluded that lithic material was largely immune to damage from stresses up to 600 kPa. Shell fragments exhibited the greatest degree of damage. Pressure as little as 50-100 kPa caused minor structural damage while significant breakage occurred at pressures of 300-600 kPa. Micro-CT scans were found to be useful to identify breakage of artifacts without actually excavating them, however, more subtle damage is nearly impossible to analyze without excavation and closer study of the artifacts.

CHAPTER IV

METHODOLOGY

This thesis project attempted to model the damage that logging activities could do to typical surface archaeological sites in the Modoc National Forest through an experiment. The experiment involved creation of four experimental surface artifact scatters, three placed in different areas of a proposed timber cut, and the fourth placed as a control in an area with no proposed cut. After creation of the experimental site models, timber cuts were completed and then each site, including the control, was evaluated for artifact damage and movement. The timber sale did not involve a clear-cut; roughly 40% canopy cover was left in place for wildlife habitat. No trees under 8 in in diameter were harvested.

The four experimental sites were each 15 meter by 15 meter (225 m^2) units. This unit size is very representative of the lithic scatters found on the Modoc National Forest, based on my personal experience, and followed Gallagher's (1978: 294) recommendation of tighter artifact placement. All four units had 1-inch by 1-inch bright yellow glass mosaic tiles (Figure 9), each with a small metal washer glued to the back, spread out in a 1-meter grid pattern prior to the beginning of the timber project. Following Gallagher's (1978: 294) recommendation that a material that better replicated lithics be used, glass tiles were used to simulate volcanic glass (obsidian). I used bright yellow tiles so they would be more easily visible and not be mistaken for true prehistoric cultural material long after my study was complete if I was unable to relocate all 900 of my tiles. I used the thinnest glass mosaic tiles that I could find, 1/16th of an inch thick to simulate the lithic material present on the Modoc National Forest (obsidian). I glued a small metal washer to the back of each so I could relocate tiles by metal detector if they were covered by surface materials. A total of 225 tiles were laid at each of the four study areas.

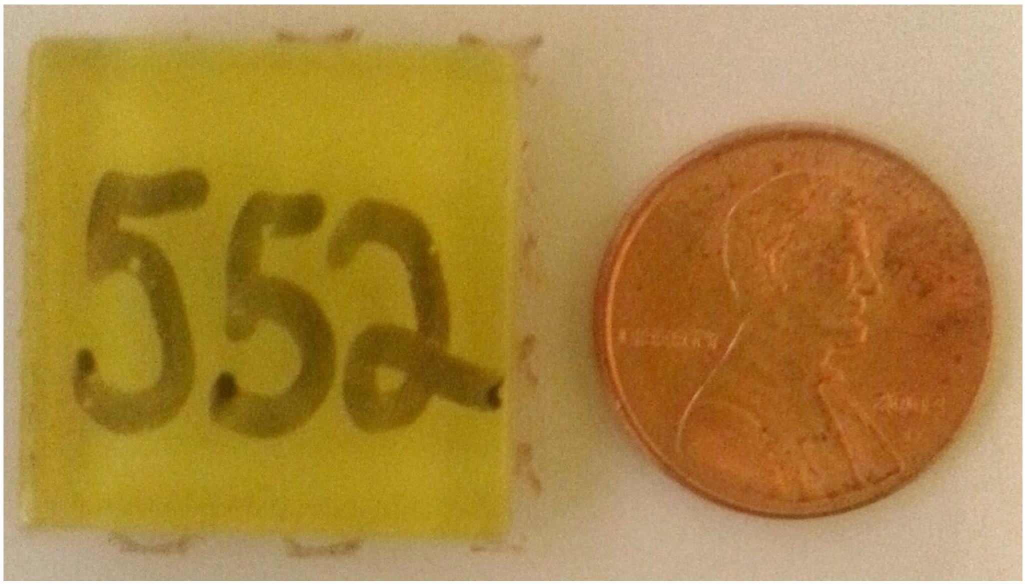

Figure 9. Photograph of a glass mosaic tile used in the experiment to model an obsidian artifact.

The tiles were individually numbered and their locations were mapped so I could individually analyze both the damage to each tile and the three-dimensional movement of each tile. To do this, first I and Jeanette Boggess set up a 15 x 15 m square for each grid, oriented with true north using a Silva compass and two tape measures. The square had 18 in pieces of rebar placed at the corners and was lined with string. Next, I used a tape measure to split the square into 1 x 1m grids, and placed a tile at each intersection. A 1 m by 1 m spacing was used to ensure that timber harvesting equipment would not pass between the tiles.

Since I planned to remove the rebar corner markers for the experiment, I needed to set up a permanent horizontal datum to measure movement from this initial setup. The datum set for each plot was an 18 in long piece of rebar, driven flush into the ground near the northeast corner of the plot. The distance and bearing from the northeast corner of the plot to the datum was taken using tape measure and Silva handheld compass and noted for use later in GIS mapping. Although I tried to place each datum exactly 20 ft at 45° Azimuth from the northeast corner of each plot, this was only possible at Plot 4 due to obstructions such as trees and large rocks. In the other three plots, I placed the datum as close to 45° and 20 ft as I could manage. Datum locations were also mapped with a Garmin E-Trex Vista HCX GPS unit. The rebar datums and corners were left in place during the timber cut and covered with a rock to protect them as well as the timber harvesting equipment. Initial vertical locations were all on the top of the ground surface. There were no vertical datums used in the project. After the timber cut, the datum rebar for each plot was relocated. Final horizontal locations of each tile were mapped in using a Criterion laser surveyor and a prism pole to provide bearing and distance to each tile from the plot rebar datum.

Soil type and description; as indicated by the USDA Forest Service soil map for this area (Modoc National Forest 2008) was noted at each of these plots. As I was setting up the plots on August 15, 2008, I also noted the slope, if any, at the center of each of the plots using a Silva hand-held compass with clinometer. Noting these things is important due to the fact that these conditions may affect the results of the study. Soil type and condition (for example, damp, muddy, dry, etc.) may affect the vertical movement of the tiles. The damper or more refined the soil the higher the potential for vertical movement of the tiles. Slope may affect the horizontal movement of the tiles through the process of erosion. Wherever possible I placed the study units on flat ground.

While out in the field I collected soil samples from the center of each plot for analysis at the Natural Resource Conservation Service (NRCS) soil laboratory in Quincy, California. Soil samples were collected from each plot by first scraping away any organic duff, and then troweling soil into a gallon-size Ziploc bag until it was full. Once back in the laboratory, I used a Mettler PC 2000 digital scale to weigh my soil samples prior to analysis. Soil sample weights were: Plot 1 = 497.33 g, Plot 2 = 490.88 g, Plot 3 = 423.97 g, Plot 4 = 494.49 g. I then used a stack of five eight-inch brass soil sieves; three Soiltest, Inc. (#s 10, 8, & 4) sieves and two W.S. Tyler Company (#s 100 & 30) sieves. I placed the stack of sieves in a Ro-Tap Testing Sieve Shaker Model B for 2 minutes each. I then measured the weight of the soil that remained in each sieve as well as the very fine (<149 microns) soil that fell through all of the sieves using the same digital scale. The data collected from this experiment was used to test my hypothesis that coarser soil (larger particles) would cause more horizontal movement, more vertical movement, and more scratch damage. Table 2 illustrates the soil sample weights for each particle size.

To provide additional information for before and after the timber sale, I took several photographs. For each of the four plots, I took an overview photo of the entire plot and a ground photo at the northwest corner of the grid. This was done both before the sale (Figure 10-18) and also after the sale and harvesting were completed (see

Table 2. Soil Particle Sizes for Each Plot

	Size Fraction Weight (g) and Percentage			
Particle Size	Plot 1	Plot 2	Plot 3	Plot 4
< 149 µm Passed thru sieves	5.53 (1.11%)	94.17 (19.18%)	67.87 (16.01%)	45.76 (9.25%)
149 - 590 µm #100 sieve	96.38 (19.38%)	138.72 (28.26%)	70.73 (16.68%)	125.96 (25.47%)
590 µm - 2 mm #30 sieve	174.85 (35.16%)	158.91 (32.37%)	127.73 (30.13%)	173.10 (35.01%)
2.0 - 2.36 mm #10 sieve	30.58 (6.15%)	16.75 (3.42%)	78.83 (18.59%)	25.73 (5.21%)
2.36 - 4.75 mm #8 sieve	112.29 (22.58%)	45.21 (9.21%)	58.20 (13.73%)	89.32 (18.06%)
≥4.75 mm #4 sieve	77.70 (15.62%)	37.12 (7.56%)	20.61 (4.86%)	34.62 (7.00%)

Figure 10. Photograph of the northwest corner of Plot 1 prior to the timber sale.

Figure 11. Photograph of Plot 1 facing southeast prior to the timber sale. The white string outlines the experimental plot.

Figure 12. Photograph of the northwest corner of Plot 2 prior to the timber sale.

Figure 13. Photograph of Plot 2 facing east prior to the timber sale. The white string outlines the experimental plot.

Figure 14. Photograph of Plot 2 facing southeast prior to the timber sale. The white string outlines the experimental plot.

Figure 15. Photograph of the northwest corner of Plot 3 prior to the timber sale.

Figure 16. Photograph of Plot 3 facing southeast prior to the timber sale. The white string outlines the experimental plot.

Figure 17. Photograph of the northwest corner of Plot 4 prior to the timber sale.

Figure 18. Photograph of Plot 4 facing southeast prior to the timber sale. The white string outlines the experimental plot.

Chapter V). For continuity I tried to take the photographs from the same location and angle each time. Two cameras were used, a Kodak C663 and a Samsung Digimax A7.

The three experimental plots were placed in different areas of a single proposed timber sale; one was close to the log landing, the next was at a location near the center of the timber sale area, the third was at a site far away from the log landing. I mapped the location of the center of each plot and the location of the nearest log landing prior to the experiment with a Garmin E-Trex Vista HCX GPS unit (see Figure 19). I instructed the timber crew leaders at each site as to what the study entailed and that they should conduct business as usual and act like the tiles were not even there. Plot 4 was a control area where no timber project was planned. This unit revealed the effects of natural processes such as cattle grazing on the archaeological site. This data demonstrated a baseline from which to measure the results of the first three areas.

One of the intended purposes of my experiment was to compare the effects of different types of harvesting equipment on lithic scatters (e.g., metal-tracked vs. rubber-tired equipment). To allow for this comparison, I made arrangements with the Forest Service Contracting Officer's representative Glenn Martin prior to the harvest for them to only use a metal-tracked vehicle in Plot 1, a rubber-tired vehicle in Plot 2, and both in Plot 3 (they needed to use both anyway due to the close vicinity of the log landing). Two different pieces of equipment were used, a Caterpillar D5K metal-tracked Hi Track Skidder-Dozer (Figure 20), and a Caterpillar 518 rubber-tired Skidder (Figure 21). The Caterpillar D5K is a metal-tracked bulldozer with a 100 horsepower engine and an

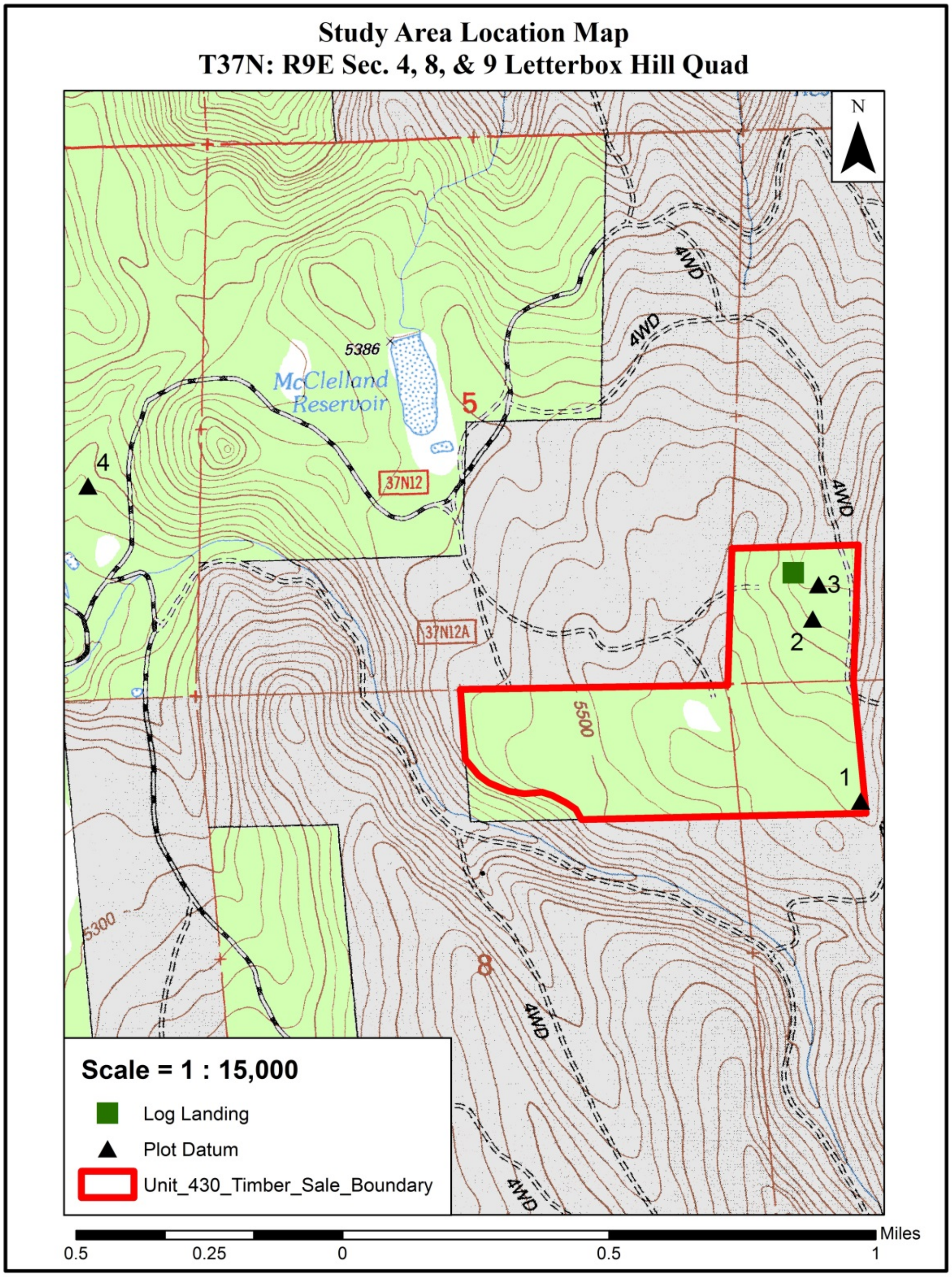

Figure 19. Location of the experimental plots and timber sale.

Figure 20. Caterpillar D5 Hi Track Skidder-Dozer used on Plots 1 and 3.

Figure 21. Caterpillar 518 Skidder used on Plots 2 and 3.

operating weight of 9,408 kg (Caterpillar 2009). The Caterpillar 518 is a rubber-tired skidder tractor with a 120 horsepower engine and an operating weight of 9,698 kg (Orlemann 2000).

The pressure of the tires or tracks of these pieces of equipment on the ground is unknown, but there is some information about vehicle pressure and lithics. It was discovered that in the McBride experiments (2012) lithics were basically immune to vertical pressure up to 87 PSI. Ground pressure for loaded timber harvesting equipment usually falls in the range of 60 to 100 PSI depending on the type of equipment and the weight of the load (Greulich 1999). Metal-tracked equipment tends to fall between 60 and 90 PSI while rubber-tired equipment is 80 to 100 PSI (Greulich 1999).

After the timber project was over I proceeded to the study areas and attempted to locate each of the glass tiles. Since they were all individually numbered and placed by measurement off of a datum, I would be able to ascertain their horizontal movement in relation to that datum. I mapped the horizontal location of each tile by using a laser surveyor and prism pole that measures distance and bearing from the datum. Since the 18 in rebar datums at each corner as well as the 18 in rebar datum had not been disturbed, the experimental datum for each plot was assumed not to have moved from its original pre-experiment location, which appeared reasonable given the lack of apparent damage in all four cases after the sale. When tiles were not visible on the surface, I used a Whites Spectrum XLT metal detector to locate them, and excavated away duff or dirt to expose them in place. I measured vertical movement with a tape measure from the uppermost adjacent ground surface. The total search area for the tiles covered the entire 15 m by 15 m plot plus a 10 m wide buffer around the plot. It was assumed that any tile that moved beyond this area would be considered "lost." In an actual prehistoric lithic scatter it is doubtful that artifacts moving farther than this distance would be recovered.

A third parameter I checked was damage to the tiles themselves. After collecting the tiles in the field, I returned them to the lab where I recorded three variables of damage: breakage, scratching, and loss. I noted any breakage of the tiles by visual inspection and noting any significant removal of edge margins (chipping was not recorded, only fracture). For scratching damage, I separated each tile into one of six separate categories; 0-5%, 6-10%, 11-20%, 21-30%, 31-40% and 41-50%+ of the surface scratched. To make this part of my analysis less subjective I used a technique developed by Todd (1993) to examine root etching on bone at his investigation of a quadruped kill site in Utah. Todd separated his root etching into six different categories; 5, 10, 20, 30, 40 and 50 percent etched with the use of a set of diagrams (Figure 22). I used these diagrams to guide my record; for example, if it looked closest to the 40% diagram, I recorded it as 40% (technically 31-40%). Finally, I noted how many tiles were actually recovered versus how many disappeared during the timber project. Some tiles were probably picked up in the treads of the equipment, carried away by forest animals or simply not relocated.

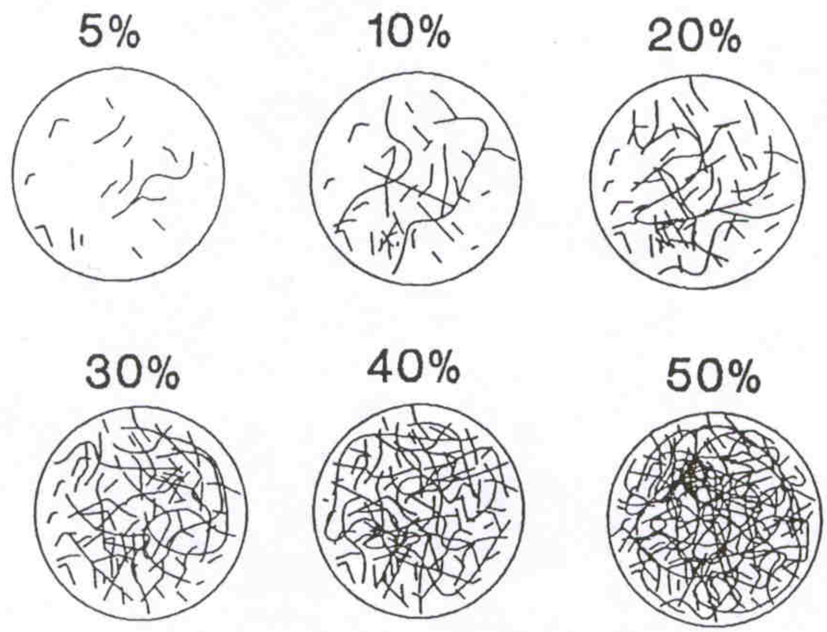

Figure 22. Chart for visual estimation of scratch coverage on tiles (Todd 1993:Figure 75). This chart was originally developed for use in quantifying root etching cover.

After compiling the results from the three study areas I made maps, charts, and graphs to visually show the vertical and horizontal movement and the breakage percentages for all the relocated tiles from each site. I compiled an Excel spreadsheet database of my variables and the resultant value descriptions.

The data resulting from my study was: description of where tile ended up (nominal scale), measurement of scratching on tiles from none to heavy (ordinal scale), tile number (nominal/interval scale; normally this would be only a nominal variable but each individually numbered tile was laid out in sequence making the tile number a significant factor in spatial location); and the x-y-z coordinates of the tiles themselves measured off of a known datum (ratio scale).

I used ArcGIS software to map the before and after study sites. The laser surveyed positions of the tiles were imported from the Excel spreadsheet into the ArcGIS program and a two-dimensional model of all four study areas was created. This shows a visually dynamic view of what actually occurred during the timber harvest.

To begin, I first entered the GPS location for each plot datum. Next, I used the compass bearing and distances to establish the northeast corner of each grid. I placed a point at this location in GIS, and then placed points for the tiles at even 1 m intervals in a 15 x 15 m grid oriented north-south. To plot the map locations of the tiles after the experiment, I used the same datum GPS coordinates plus the individual bearing and distances to each tile from the laser surveyor. These data were imported into GIS from a hand-typed Excel file created from notes taken during the surveyor work. I placed points at the end of each bearing-distance line in the same way as for the "before" points. Now there was a complete set of "before" and "after" points.

As this was completed, I noted that there appeared to be some systematic error in the data, because a large number of tiles in each plot (including the control) appeared to move a similar direction and distance. Since this was very unlikely (especially for the control plot), I created a solution to correct for this systematic error probably created by the fact that the starting locations were mapped less accurately (with one corner shot with Silva compass and tape) than the ending locations (shot with the laser surveyor). My solution was to move the entire set of "before" points as a group until they matched the "after" points that remained in the original 1meter by 1 meter grid pattern (the tiles that had not moved) as closely as possible. This showed many tiles as not moving, and a smaller number moving in a less patterned way.

Because the control plot final map still showed some movement of most tiles, when this is not likely, I decided to use the distance apparently moved in the control plot as a filter for actual movement in all plots. That is, no apparent distance moved in any of the experimental plots was counted as an actual movement unless it was greater than the movement in the control plot. Since the control plot showed many tiles moving 0-44 cm and just one moving over a meter, 18 cm was used as the cutoff for this study as it was the average apparent horizontal movement of tiles in the control plot not counting the single tile that moved over a meter.

At the conclusion of the experiment, the tiles and rebar markers were removed from Plots 1-3. Any tiles remaining in the harvest area are those that moved more than 10 m from the plots and were never found. The tiles and rebar for the Plot 4 control were left in place for future monitoring by Modoc National Forest.

CHAPTER V

RESULTS

The experiment involved four plots, each with 225 tiles placed on the surface in a 15 x 15 m grid. One plot was held as a control and three plots were subject to timber-harvesting activities, with Plot 3 near the log landing, Plot 2 near the center of the timber sale area, and Plot 1 far away from the log landing. The plots were set up on August 15, 2008, harvest activities took place between August 25, 2008 and September 5, 2008, and the tiles were mapped and recovered on September 14, 2008. During this time it is important to note that no precipitation occurred that would affect the compaction of the soil substrate and may cause vertical tile movement. After the harvest, movement and damage were recorded on all recovered tiles. Results are summarized in Table 3.

Table 3. Summary of Results

Plot (dist. to landing)	Tiles Recovered	Movement (cm)		Damage	
		Horizontal[1]	Vertical	Breakage	Scratching
1 (724 m)	212 (94%)	4-474 (mean 44) "none"= 20%	0-7 (mean 0.4)	None	0-50% (median 10%)
2 (159 m)	126 (56%)	4-1,140 (mean 147) "none"= 6%	0-9 (mean 1.8)	None	0-50% (median 5%)
3 (83 m)	119 (53%)	2-1,290 (mean 148 "none"= 16%)	0-12 (mean 1.0)	1 tile	0-50% (median 5%)
4 (control)	225 (100%)	0-135 (mean 18) "none" > 99%	None	None	No damage

[1] Experiment contains a margin of error of ±18 cm. In other words, the 18 cm average apparent movement of the control plot artifacts (excluding the one that did clearly move) was used as an estimate of measurement error for "before" vs. "after" tile locations for this experiment

The center of Plot 1 was located at Universal Transverse Mercator coordinates 672,508 m Easting and 4,547,596 m Northing in Zone 10 using the 1983 North American datum. The elevation was 5,590 feet above MSL. There was a northwest aspect 1° slope. The soil consisted of hard pack silty loam with many 6-18-inch diameter basalt rocks. There were six fallen logs in the plot with diameters ranging from 3-12 in. The plot also included two junipers, one 4 in and one 7 in dbh (diameter at breast height), and eight pines ranging from 3-10 in dbh. Plot 1 utilized a Caterpillar D5 metal-tracked Hi Track Skidder-Dozer.

Plot 1 was 724 m at 166° Azimuth from the nearest log landing (all plot and log landing bearings and distances were calculated from GPS locations using ArcGIS). It was the furthest plot within the timber sale from the log landing. Based on my pre-experiment hypothesis this plot should have seen the smallest amount of horizontal tile movement and had a lesser amount of damage due to the great distance from the log landing. I hypothesized a bottle-neck effect the closer to the log landing one gets. This would cause a greater amount of tile movement and damage.

Of the 225 tiles that were laid out at this plot 212 (94%) were recovered. A total of 157 (74.1%) of these were found visible at the surface and 55 (25.9%) were buried and recovered with the assistance of the metal detector. The remainders were presumably lost either because they were carried away on equipment tires or on the logs themselves, picked up by timber workers, or were simply buried and not found in the time of the study. Horizontal movement ranged from none (20.3%) to 474 cm, as shown in Figure 23. (Remember that "none" here includes all with apparent movement less than 18 cm.)

All of the tiles showed at least minor scratch damage, but none were broken. The distribution of scratch damage %surface coverage estimates is provided in Figure 24.

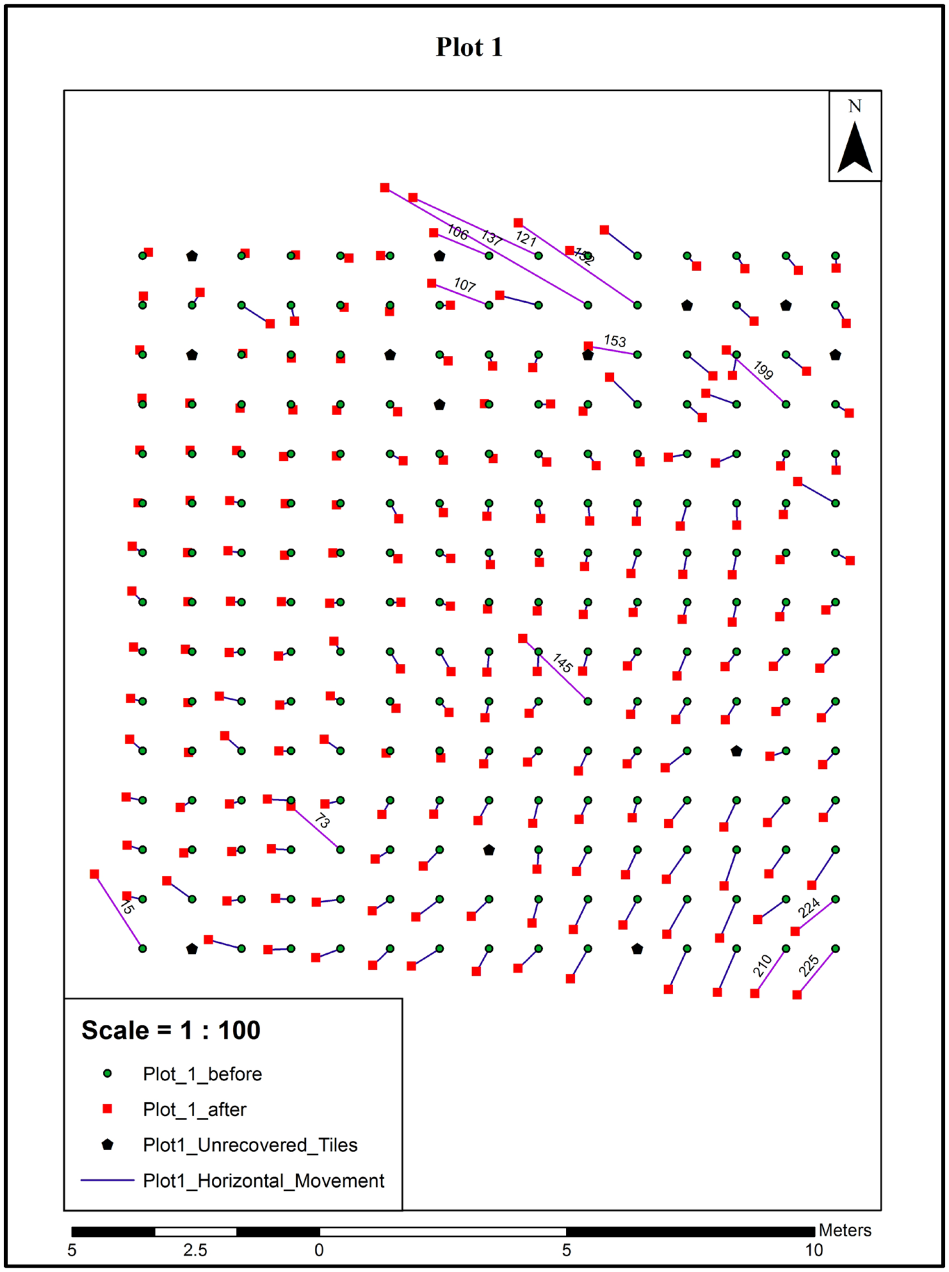

Figure 23. Movement of tiles in Plot 1. Artifacts that moved more than 1 m are numbered.

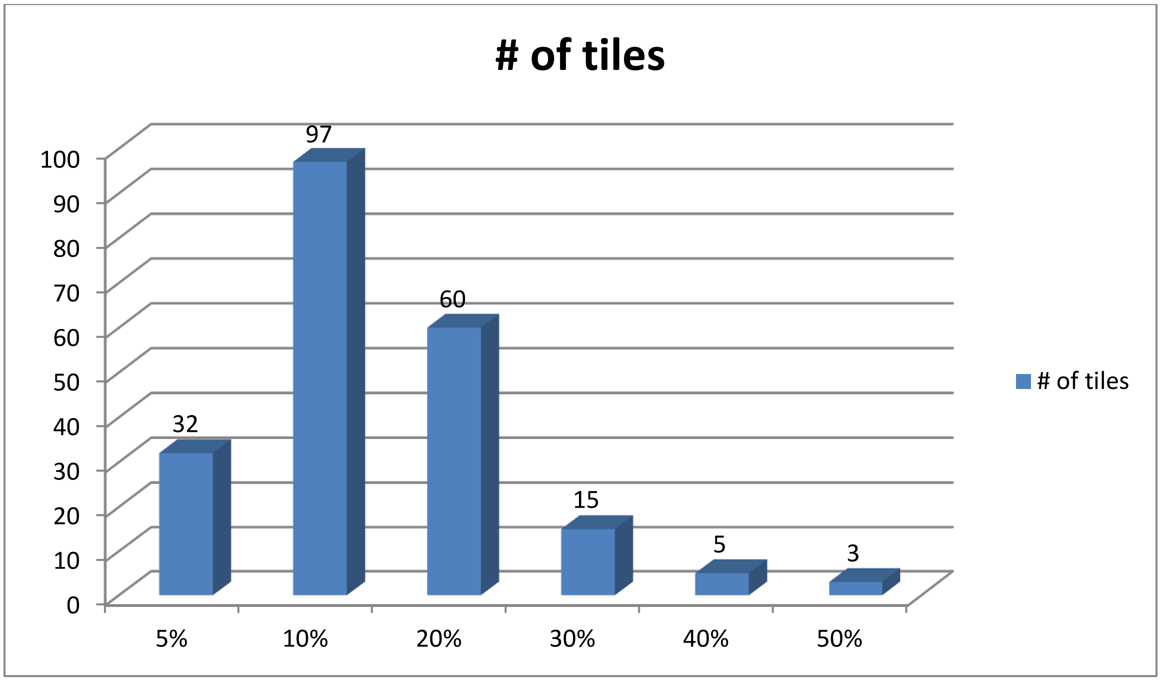

Figure 24. Distribution of scratch damage to tiles in Plot 1. Note that for all such graphs, 5% means 0-5%, 10% means 6-10%, 20% means 11-20%, 30% means 21-30%, 40% means 31-40%, and 50% means 41%+.

Plot 2 was placed nearer to the log landing than Plot 1. The center of Plot 2 was located at Universal Transverse Mercator coordinates 672,433 m Easting and 4,548,158 m Northing in Zone 10 using the 1983 North American datum. The elevation was 5,508 feet above MSL. There was a northwest aspect 6° slope. The soil consisted of moderately packed silty loam with a few, mostly sub-surface basalt rocks with diameters 2-30 in. About 33% of the ground was covered by mahala mat (*Ceanothus prostratus*). There were four manzanita bushes as well as a bitterbrush bush within the plot boundaries. There also were nine 4-15 in dbh cedar trees and two 7-15 in dbh pines. Cow and deer scat was present within Plot 2. Plot 2 utilized a Caterpillar 518 rubber-tired Skidder. The center of Plot 2 was 159 m at 163° Azimuth from the nearest log landing. It was the second furthest plot from the log landing. Based on my pre-experiment hypothesis this plot should have had a medium amount of horizontal tile movement and tile damage due to its central distance from the log landing.

Of the 225 tiles that were laid out at this plot 126 (56%) were recovered. A total of 61 (48.4%) of these were found visible at the surface and 65 (51.6%) were buried and recovered with the assistance of the metal detector. The remainder was presumably lost either because they were carried away on equipment tires or on the logs themselves, picked up by timber workers, or were simply buried and not found in the time of the study. Horizontal movement ranged from none (4.7%) to 1,140 cm, as shown in Figure 25. All of the tiles showed at least minor scratch damage, but none were broken. The distribution of scratch damage %surface coverage estimates is provided in Figure 26.

Plot 3 was placed close to the log landing. The center of Plot 3 was located at Universal Transverse Mercator coordinates 672,453 m E x 4,548,254 m N in Zone 10 using the 1983 North American datum. The elevation was 5,496 feet above MSL. There was a northwest aspect 1° slope. The soil consisted of soft pack slightly moist silty loam with very few, mostly sub-surface basalt rocks with diameters from 3-8 in. Ground cover was mostly bare dirt with light grasses and some pine duff on the south side of the plot. There was one 12 in dbh pine within the plot. Cow scat was seen within Plot 3. Plot 3 utilized both the Caterpillar D5 metal-tracked Hi Track Skidder-Dozer and the Caterpillar 518 rubber-tired Skidder. The center of Plot 3 was 83 m at 127° Azimuth from the nearest log landing. It was the closest plot to the log landing. Based on my pre-

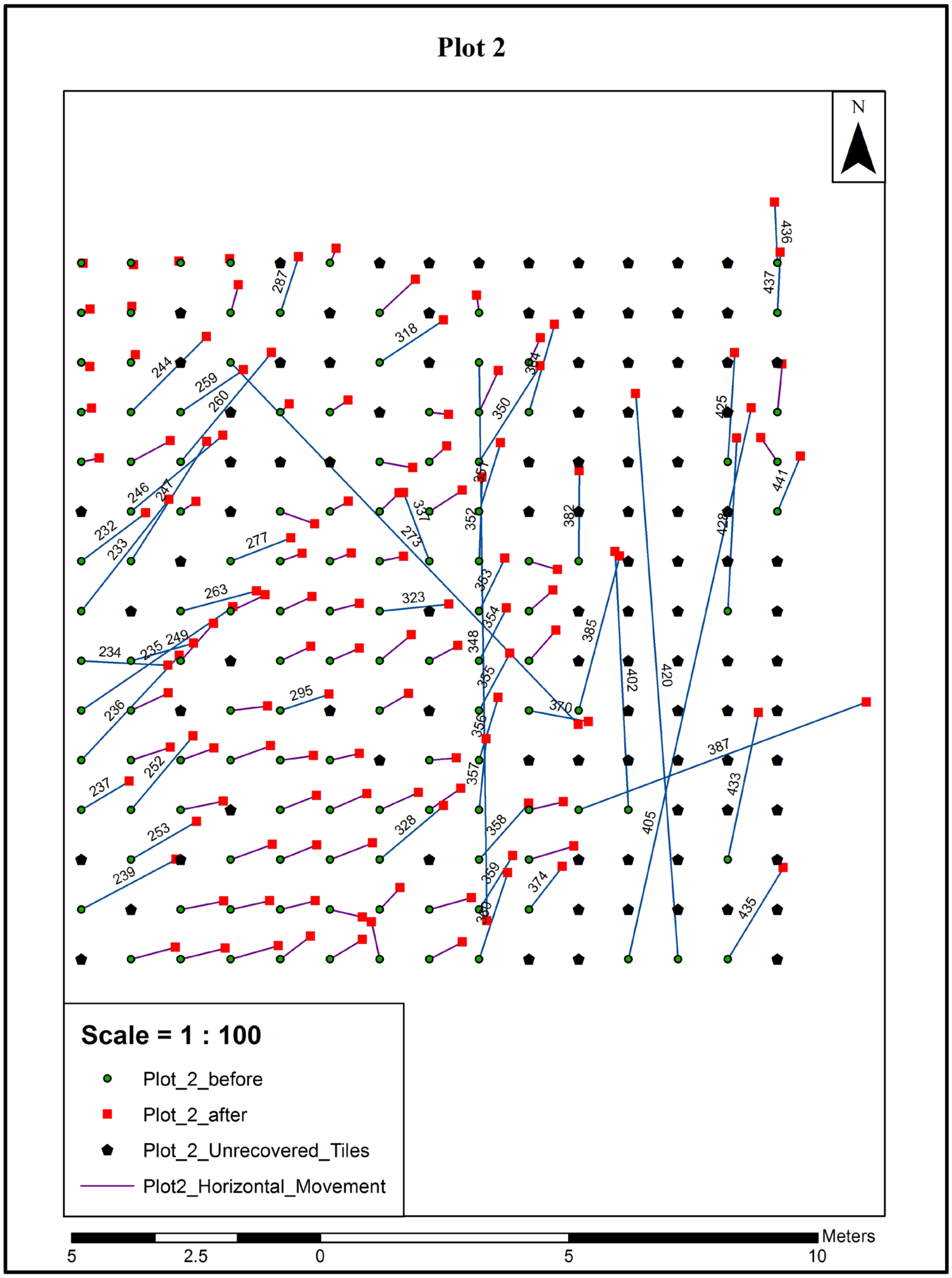

Figure 25. Movement of tiles in Plot 2. Artifacts that moved more than 1 m are numbered.

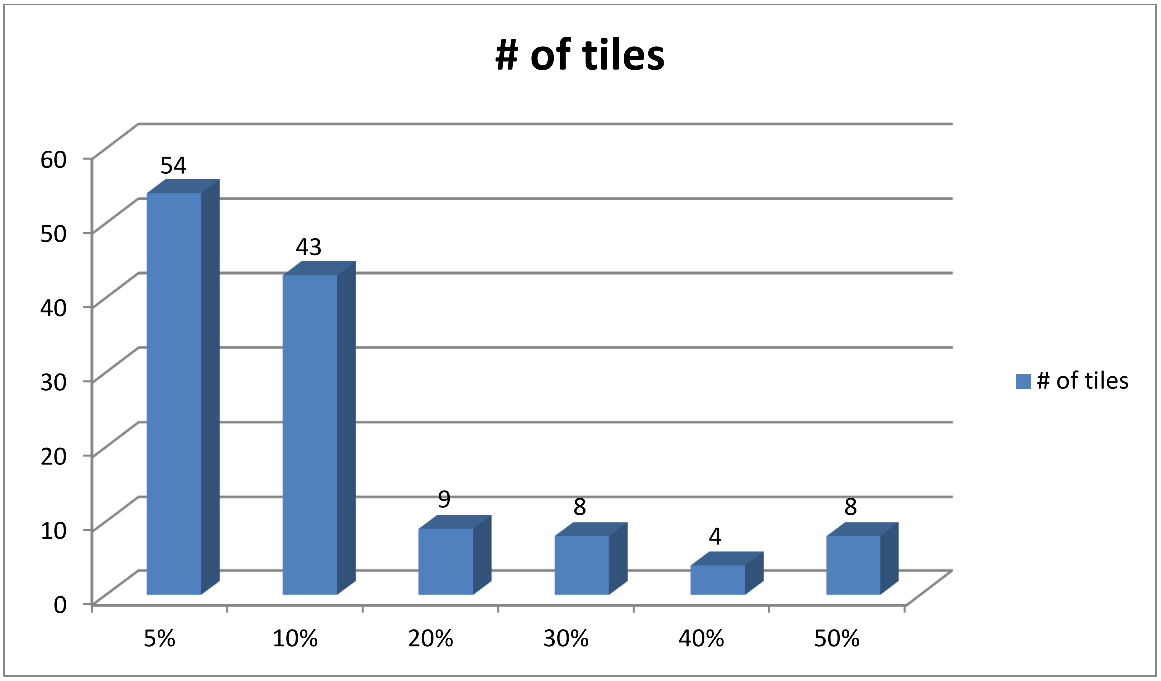

Figure 26. Distribution of scratch damage to tiles in Plot 2.

experiment hypothesis this plot should have seen the greatest amount of horizontal tile movement and had the most amount of damage due to the short distance from the log landing.

Of the 225 tiles that were laid out in Plot 3, 120 (53.3%) were recovered; 78 (65.0%) of these were found visible at the surface and 42 (35.0%) were buried and recovered with the assistance of the metal detector. The remainder was presumably lost either because they were carried away on equipment tires or on the logs themselves, picked up by timber workers, or were simply buried and not found in the time of the study. Horizontal movement ranged from none (15.8%) to 1,290 cm, as shown in Figure 27. (Remember that "none" here includes all with apparent movement less than 18 cm.) All of the tiles showed at least minor scratch damage, but none were broken. The distribution of scratch damage %surface coverage estimates is provided in Figure 28.

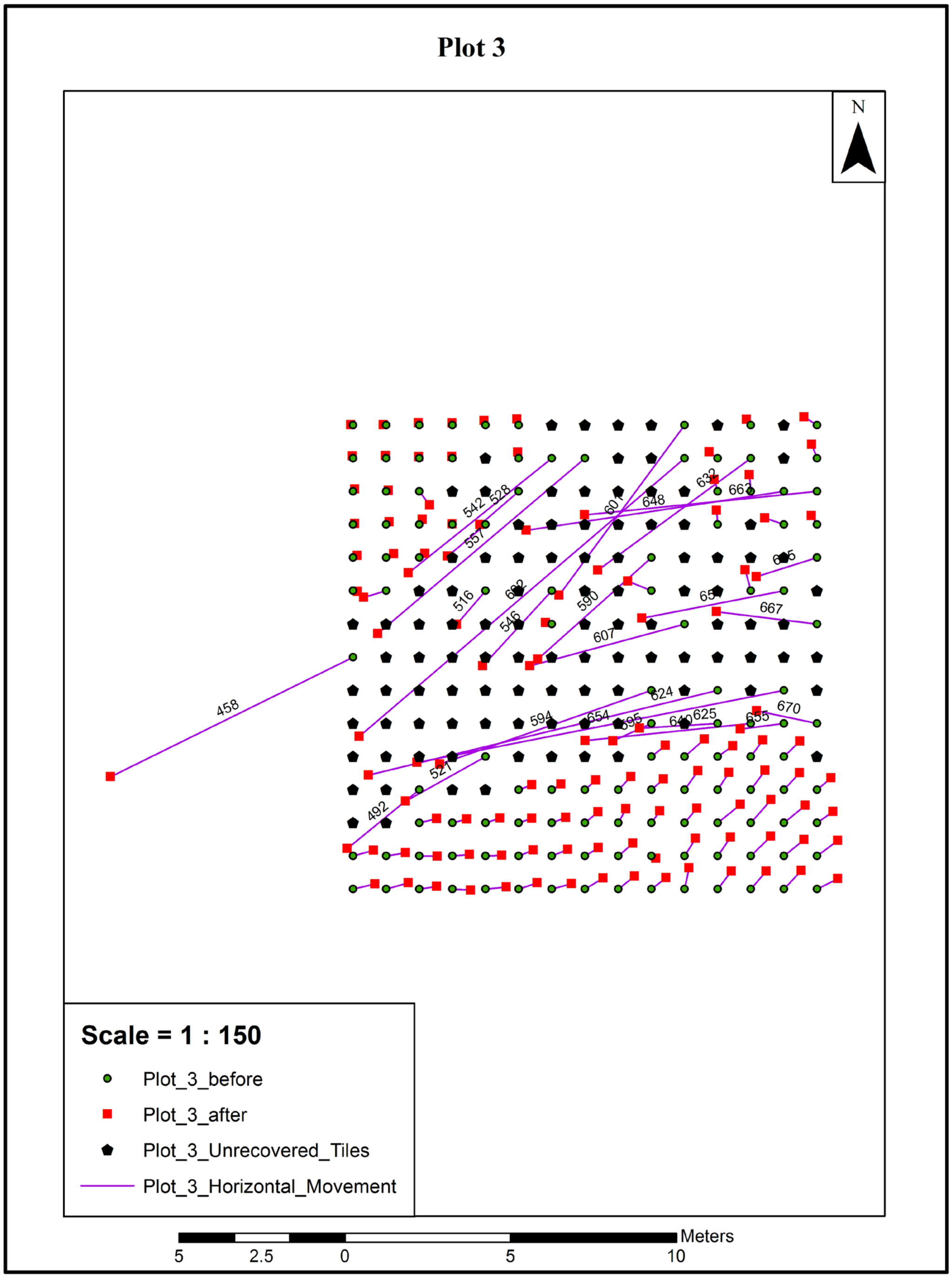

Figure 27. Movement of tiles in Plot 3. Artifacts that moved more than 1 m are numbered.

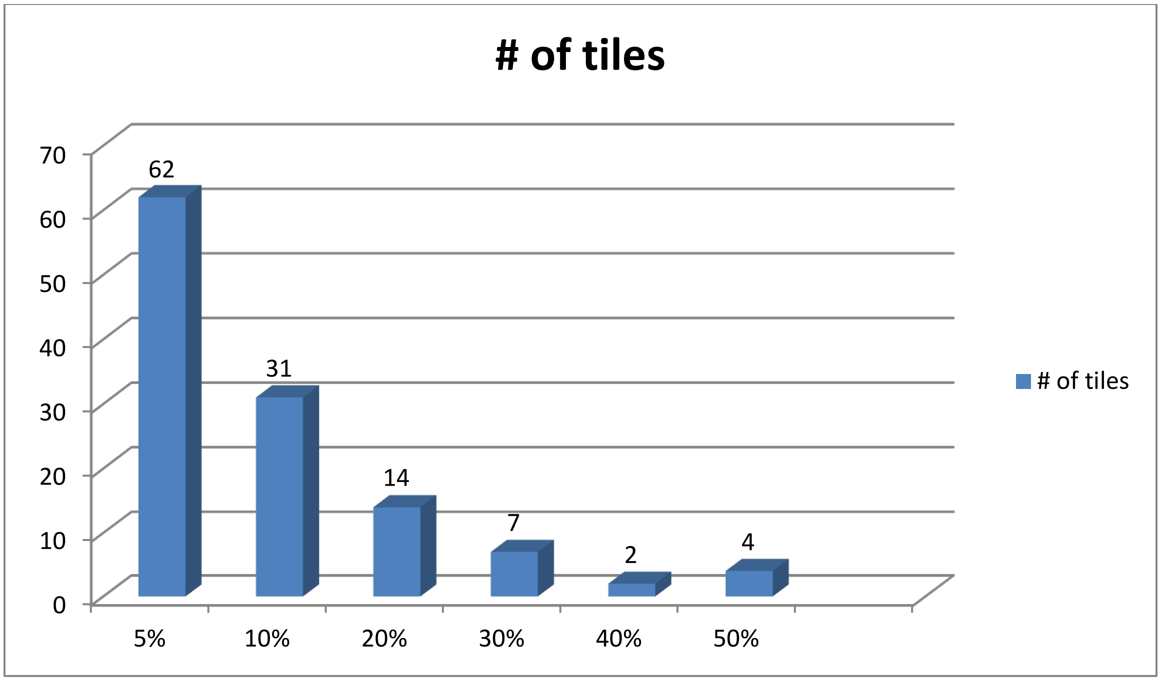

Figure 28. Distribution of scratch damage to tiles in Plot 3

One tile was broken in Plot 3, the only tile broken in the experiment. Tile 516 was found shattered on the side of a skid trail. It was so damaged that the tile number was just barely legible.

Plot 4 was my control plot and was not located within the timber sale boundaries. The goal of Plot 4 was to present a snapshot of what the tiles would do naturally within the environment so as to compare it with the plots within the timber sale. The center of Plot 4 was located at Universal Transverse Mercator coordinates 670,240 m E x 4,548,368 m N in Zone 10 using the 1983 North American datum. The elevation was 5,144 feet above MSL. There was a southwest aspect 2° slope. The soil consisted of hard packed silty loam with many 1 to 8-in diameter basalt rocks which were both surficial and sub-surface. The density of rocks in Plot 4 was nearly identical to Plot 1.

The ground cover consisted of scattered small sagebrush and grasses. There was a 1-in dbh juniper in the plot. Cow and horse scat was present within Plot 4. The center of Plot 4 was 2,154 m at 278° Azimuth from the nearest log landing. It was the furthest plot from the log landing.

Of the 225 tiles that were laid out at this plot, all the tiles were recovered on the surface. The horizontal movement of tiles in Plot 4 ranged from none (56.0%) to 135 cm, as shown in Figure 27. The average horizontal movement of the tiles in plot was 18 cm. Based on this control plot it was discovered that the margin of error contained in this experiment was ±18 cm. As I mentioned in Chapter 4, since the control plot showed many tiles moving an average of 18 cm and just one moving over a meter, 18 cm was used as the cutoff for this study. All of the tiles in Plot 4 remained on the surface (there was no vertical movement). There was no noticeable damage to the tiles in Plot 4. The only apparent change from the time the tiles were set down until they were recovered was the movement of one tile (no. 803, see Figure 29) a distance of 135 cm. This tile may have been moved by wildlife or perhaps the cattle that were grazing nearby.

Comparisons Between Plots

Overall the resultant data between the plots was quite interesting. Plot 1 was the furthest plot from the log landing and ended up with the least amount of horizontal movement (42 cm on average). Plot 1 also had the smallest average vertical movement, only 0.4 cm. Plot 1 had a moderate amount of tile damage, 10.9% of tiles were 30% scratched or higher.

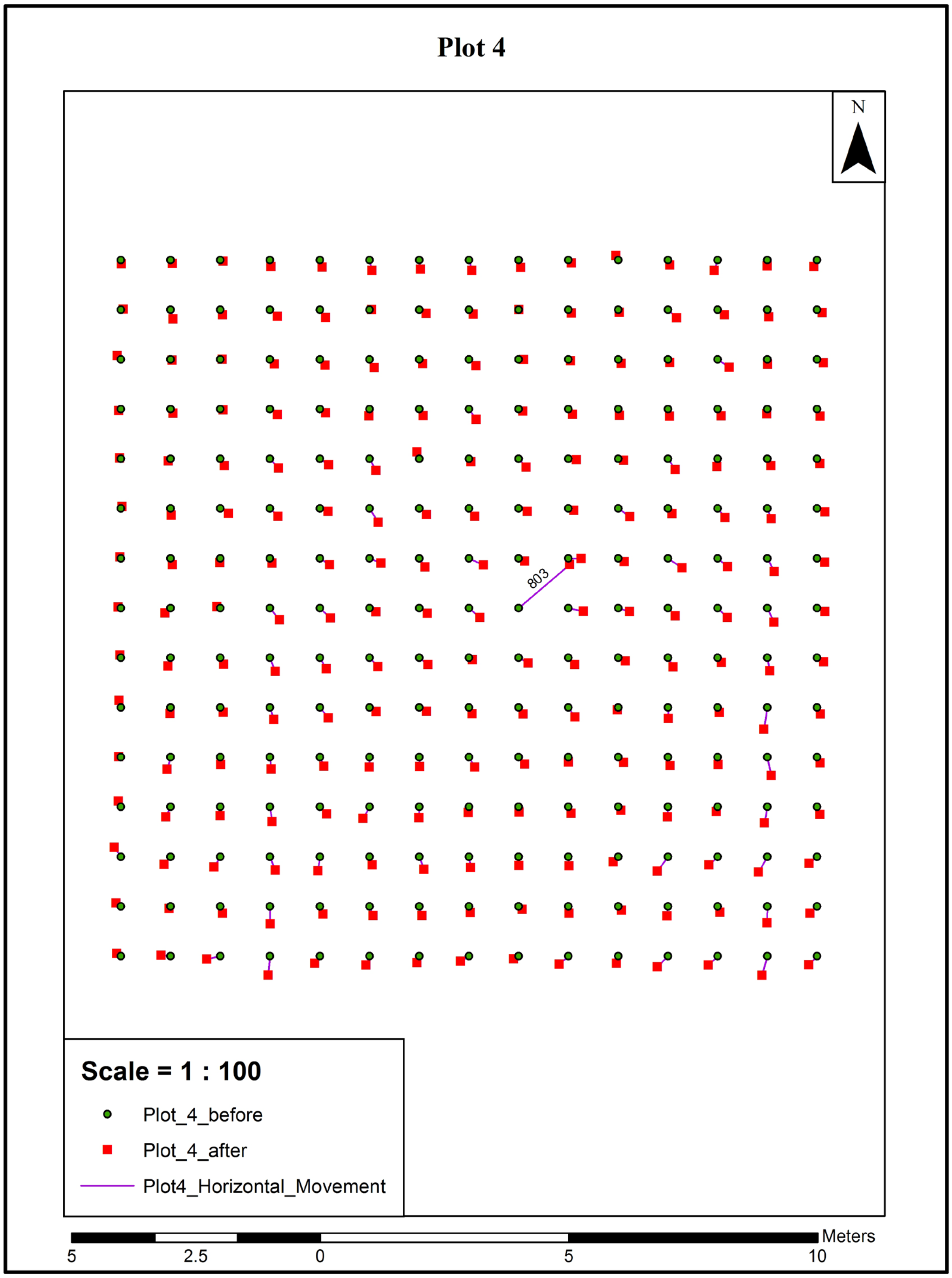

Figure 29. Movement of tiles in Plot 4. Artifacts that moved more than 1 m are numbered.

Plot 2, which was located the second farthest from the log landing, ended up with higher horizontal movement than Plot 1. The average horizontal movement of tiles in Plot 2 was 147 cm. Of the 225 tiles that were laid out at this plot 126 (56%) were recovered. This represented the middle number of tiles recovered between the three plots that were within the timber harvesting area although the number was just slightly higher than Plot 3. Remarkably Plot 2 had the largest average vertical movement (1.8 cm) and the highest amount of tile damage (15.8% of tiles were 30% or higher scratch damaged). A rubber-tired skidder was utilized in this plot. The incline here was the steepest at 6°. In addition, the soil was moderately packed silty loam with very few rocks in it. Any or all of these factors could have played a part in the large amount of damage and vertical movement of the tiles.

Plot 3 was the nearest unit to the log landing, just 83 meters away. Both the rubber-tired and the metal-tracked skidders traversed through this plot on their way back and forth to the log landing. The soil here was the softest packed and had the highest moisture content among all three active plots. Confirming Nielsen's findings (1991) this loose, moist substrate compacted quickly and inhibited some vertical movement; horizontal movement, however, increased. Plot 3 had the same average horizontal movement (147 cm) as Plot 2. Of the 225 tiles that were laid out at this plot 120 (53.3%) were recovered. This represented the smallest number of tiles recovered between the three plots that were within the timber harvesting area. Vertical movement averaged 1.0 cm, higher than Plot 1 but considerably less than Plot 2. Damage to tiles in Plot 3 was minimal, only 10.8% of tiles had 30% or higher scratch damage. This plot had the smallest overall tile damage of all three active plots. However, it also had the only broken tile in the experiment.

CHAPTER VI

CONCLUSION

The results of this experiment were quite interesting. Before the experiment I hypothesized that there would be a bottleneck effect the closer to the log landing one gets. I assumed that because of this bottleneck there would be more vertical and horizontal movement of tiles as well as more damage to the tiles. I further postulated that metal-tracked vehicles would do far greater damage and cause a greater amount of movement to the tiles than rubber-tired vehicles. I thought that the greater degree of slope the more movement and damage would occur to the tiles. I hypothesized that the looser the soil the greater amount of vertical movement but a smaller amount of horizontal movement would occur. Finally, I assumed that the more compact and rocky the soil, the smaller amount of vertical movement and a greater amount of horizontal movement would occur among the tiles and a greater amount of damage would occur to the tiles.

The experiment provided mixed support for my initial hypotheses, as described further below. Table 4 provides a summary. Some hypotheses were reasonably supported by the experiments, others were apparently disproved, and still others did not have sufficient data to make a determination.

The greatest amount of horizontal movement occurred in Plot 2. A rubber-tired vehicle was utilized in Plot 2 which was surprising based on the amount of disturbance seen at this plot. Surface damage was extensive within Plot 2. The greater amount of

Table 4. Hypothesis results.

Variable	Prediction	Results
Distance to log landing	Closer= more horizontal movement	Maybe: Plot 2 & 3 means> Plot 1
	Closer= more vertical movement	Maybe: Plot 2 & 3 means> Plot 1
	Closer= more scratch damage	No: Median Plot 1 > Plots 2 & 3
Vehicle type	Metal tracks= more horizontal movement	No: Metal tracks (Plot 1) mean < Rubber tired (Plot 2)
	Metal tracks= more vertical movement	No: Metal tracks (Plot 1) mean < Rubber tired (Plot 2)
	Metal tracks= more scratch damage	Yes: Metal tracks (Plot 1) median > Rubber tired (Plot 2)
Slope	Steeper= more horizontal movement	Yes: Steepest slope (Plot 2) mean > Plots 1 & 3
	Steeper= more vertical movement	Yes: Steepest slope (Plot 2) mean > Plots 1 & 3
	Steeper= more scratch damage	No: Plot 1 median > Plots 2 & 3
Soil texture	Coarser= more horizontal movement	No: Coarser (Plot 1) mean < Plots 2 & 3
	Coarser= more vertical movement	No: Coarser (Plot 1) mean < Plots 2 & 3
	Coarser= more scratch damage	Yes: Coarser (Plot 1) median > Plots 2 & 3

horizontal movement in this plot could be due to: 1) Rubber-tired vehicle, 2) 6° slope, 3) Moderately compact soil with few rocks, and/or 4) 33% mahala mat groundcover.

It would seem that the greater degree of slope would have caused the equipment operator to use higher RPMs and therefore cause more surface damage by the rubber-tired vehicle abrading the soil. This falls in line with Gallagher's results (1978) that found that as the bulldozer applied extra power more significant surface damage occurred. As in the Debloois experiment (1974) horizontal movement seemed to follow the direction of equipment travel and formed linear rows at the edges of the vehicles tires/treads.

The greatest amount of vertical movement occurred in Plot 3. It was no real surprise that Plot 3 saw the greatest vertical movement as the soil in this plot was much looser and softer-packed than the other plots. In addition to the lightly packed soil, both the rubber-tired and the metal-tracked vehicle transited through this plot, increasing the possibility for tile movement. This was also the closest plot to the log landing and therefore experienced the bottle-neck affect that I hypothesized. The shallow 1° slope would tend toward more vertical movement of tiles within the soil than horizontal movement, especially in looser substrates. I would agree with the results of the Minnesota Forest Resources Council's experiment (1998) that equipment traffic patterns were the most important factor in explaining the observed variations in artifacts displacement. The greatest movement could clearly be seen at the edges of vehicle tire/tread paths.

There was heavy scratching on some of the tile surfaces. Unlike the Gallagher study (Gallagher 1978) the glass tiles acted more like obsidian than his metal washers. The greatest amount of damage to tiles occurred in Plot 2. A total of 15.8% of the tiles in plot 2 sustained 30% or greater scratch damage as compared with 10.9% in Plot 1 and 10.1% in Plot 3. This was surprising based on the fact that only a rubber-tired vehicle was used in this plot, this was not the closest plot to the log landing, and the soil was not highly compacted and had few rocks within it. The most logical explanation for the greater amount of tile damage is the 6° incline causing the rubber-tired vehicle to use higher RPMs and exerting a higher degree of friction pressure on the tiles.

An analysis of the 15 total tiles that had 50% or more scratch damage revealed that all of these tiles except one (tile 618 from Plot 3) were relocated under the surface. The average vertical movement of these tiles was 4 cm. All of these tiles had at least some horizontal movement. The average horizontal movement of these tiles was 294 cm.

A comparison of the metal-tracked Plot 1 with the rubber-tired Plot 2 reveals that in this experiment the rubber-tired vehicle caused more damage, moved the tiles further horizontally, and caused 4.5 times the vertical movement as the metal-tracked vehicle. In conclusion, it is recommended that more caution be taken when protecting lithic scatters on inclines, in harder packed soils, and in substrates that contain a significant amount of rocks. It is further recommended that metal-tracked vehicles be used more frequently when possible, especially where no turns need to be made.

There are many circumstances where a "flag-and-treat" cultural resource management option would be preferable to a "flag-and-avoid" approach, providing that a proper examination of the archaeological site environment has been accomplished, i.e. degree of slope, soil type and content, soil moisture, and any other pertinent environmental factor. Also of extreme importance is to know the types of equipment to be used within the timber sale before an informed decision can be made.

In future experiments the effect of slope on lithic movement and damage should be studied more in-depth. Also a more scientific study of the effect that various soil types and soil conditions have on lithics would be beneficial to a greater understanding of the effects of timber harvesting on lithic scatters. The thickness of the duff layer should be noted in future studies as it could affect the outcome of those experiments. The control plot, Plot 4 for this experiment, was left in place for future research purposes. The long term effects of natural processes can be analyzed at this plot, such as natural vertical movement caused by freeze-thaw patterns, as well as heavy rainfall causing changes in compaction of the soil. In addition, horizontal movement could be periodically plotted over time. Finally, timber harvesting equipment continues to advance over the years, with newer vehicles tending toward lighter ground pressure than their predecessors. New experiments should focus on more advanced generations of timber harvesting equipment, in doing so our ability to make better informed cultural resource management decisions will advance in step with timber harvesting equipment technology, and perhaps resource managers will be able to assist equipment design engineers on how to build a better vehicle that will have the least impact on cultural resources as possible.

Negative effects to archaeological sites by various factors, including timber sales, can have a permanent impact on our ability to garner valuable information from these valuable assets. Some Native Americans consider loss of archaeological sites a loss of their history and culture. Once these sites are lost, their stories can never be retold.

With some prior knowledge of the archaeological site environment and the actual equipment to be used on the timber sale, it would be quite possible to work hand-in-hand with the timber companies to conduct a safe and far less damaging “flag-and-treat” style resource protection measure and open many more acres of public land to timber harvesting without significant impact on cultural resources. This would satisfy Section 106 of the National Historic Preservation Act and help many local economies around the country by providing much needed jobs and natural resources at a time in this country's existence when it is most urgently needed.

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APPENDIX I

TILE MOVEMENT AND SCRATCH DATA

One table is provided for each experimental plot below.

Plot 1 Experiment Raw Tabular Data

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
1	14	0.0	10
2	18	0.0	10
3	11	0.0	5
4	12	0.0	10
5	9	0.0	20
6	9	0.0	5
7	25	0.0	5
8	31	0.0	20
9	20	0.0	20
10	25	0.0	10
11	35	0.0	10
12	34	0.0	10
13	32	0.0	10
14	32	-6.5	20
15	179	-2.0	10
16 – NOT RECOVERED	-	-	-
17	30	0.0	10
18 – NOT RECOVERED	-	-	-
19	5	0.0	10
20	7	0.0	10
21	6	0.0	10
22	9	0.0	20
23	9	0.0	5
24	14	0.0	10
25	9	0.0	5
26	7	0.0	30

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
27	27	0.0	30
28	18	0.0	10
29	63	0.0	30
30 – NOT RECOVERED	-	-	-
31	9	0.0	10
32	69	-2.0	5
33	4	-2.5	5
34	9	0.0	10
35	11	0.0	20
36	24	0.0	5
37	27	0.0	10
38	22	0.0	20
39	25	0.0	10
40	46	0.0	30
41	45	0.0	5
42	25	0.0	5
43	20	0.0	10
44	30	0.0	20
45	69	0.0	30
46	9	0.0	20
47	33	0.0	5
48	7	0.0	10
49	12	0.0	10
50	16	0.0	10
51	11	0.0	10
52	14	0.0	5
53	20	0.0	20
54	27	0.0	30
55	24	0.0	10
56	25	0.0	20
57	47	0.0	20
58	40	0.0	10
59	31	0.0	10

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
60	46	0.0	20
61	18	-0.5	10
62	9	0.0	10
63	8	-0.3	30
64	14	-7.0	20
65	9	-0.5	10
66	9	0.0	10
67	15	0.0	10
68	22	0.0	20
69	25	0.0	10
70	23	0.0	10
71	40	0.0	20
72	33	0.0	10
73	133	0.0	10
74	49	0.0	10
75	53	0.0	20
76	19	-1.5	50
77	13	0.0	5
78 – NOT RECOVERED	-	-	-
79	22	0.0	10
80	30	0.0	30
81	36	0.0	10
82	21	0.0	20
83	22	0.0	10
84	41	0.0	20
85	19	0.0	10
86	9	0.0	5
87	33	0.0	10
88	35	0.0	10
89	43	0.0	20
90	48	0.0	5
91 – NOT RECOVERED	-	-	-
92	22	-2.0	10

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
93	22	-2.0	20
94 – NOT RECOVERED	-	-	-
95	15	0.0	10
96	21	0.0	10
97	25	0.0	5
98	23	0.0	5
99	47	0.0	20
100	30	0.0	20
101	15	0.0	10
102	31	0.0	10
103	47	0.0	5
104	60	0.0	20
105	67	0.0	20
106	121	-1.0	30
107	124	-1.5	30
108	24	-0.5	10
109	9	-0.5	40
110	13	0.0	20
111	27	0.0	10
112	24	0.0	10
113	14	0.0	10
114	42	0.0	10
115	34	0.0	10
116	29	0.0	5
117	47	0.0	10
118 – NOT RECOVERED	-	-	-
119	50	0.0	10
120	52	0.0	10
121	279	-1.5	10
122	81	-1.5	20
123	29	0.0	5
124	25	-1.0	50
125	24	0.0	20

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
126	31	0.0	20
127	20	0.0	5
128	18	0.0	10
129	40	0.0	10
130	31	0.0	20
131	32	0.0	20
132	48	0.0	20
133	40	0.0	40
134	50	0.0	10
135	57	0.0	40
136	38	-1.0	30
137	474	0.0	20
138 – NOT RECOVERED	-	-	-
139	17	-0.5	5
140	29	-1.0	10
141	36	0.0	10
142	29	0.0	10
143	26	0.0	20
144	41	0.0	5
145	183	0.0	20
146	45	0.0	20
147	43	0.0	20
148	50	-0.5	10
149	68	0.0	10
150	70	0.0	20
151	84	0.0	20
152	292	-0.5	20
153	100	-0.5	40
154	78	-3.0	10
155	17	0.0	10
156	37	0.0	20
157	44	0.0	20
158	22	0.0	10

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
159	35	0.0	30
160	30	-0.5	10
161	33	0.0	5
162	37	-1.0	20
163	56	0.0	10
164	60	0.0	5
165 – NOT RECOVERED	-	-	-
166	29	-0.5	10
167 – NOT RECOVERED	-	-	-
168	68	-0.1	10
169	41	-1.0	20
170	38	-6.0	50
171	48	0.0	10
172	45	0.0	5
173	36	0.0	10
174	53	0.0	10
175	43	-1.0	20
176	56	-1.0	10
177	60	0.0	20
178	73	0.0	10
179	81	0.0	10
180	90	0.0	10
181	32	-0.5	30
182	48	-0.5	20
183	43	-1.0	10
184	66	-0.1	5
185	46	-1.5	30
186	45	-0.5	20
187	46	-0.5	10
188	41	0.0	20
189	38	-1.5	20
190	44	0.0	10
191 – NOT RECOVERED	-	-	-

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
192	60	-0.5	10
193	77	0.0	20
194	86	0.0	20
195	97	0.0	20
196	39	0.0	5
197 – NOT RECOVERED	-	-	-
198	54	-2.0	20
199	163	-2.5	40
200	27	-4.0	20
201	24	-2.5	10
202	18	-3.0	20
203	32	0.0	20
204	39	0.0	10
205	29	-1.0	20
206	34	-0.5	10
207	58	0.0	10
208	60	0.0	5
209	70	0.0	10
210	110	0.0	5
211	26	0.0	10
212	43	-1.0	20
213 – NOT RECOVERED	-	-	-
214	33	-5.0	10
215	34	-0.5	10
216	88	0.0	10
217	34	-0.1	30
218	25	-2.0	10
219	46	-0.5	5
220	44	0.0	10
221	38	0.0	20
222	43	0.0	5
223	86	0.0	10
224	104	0.0	10

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage (%)
225	121	0.0	10
MEAN	**44**	**-0.4**	**15**

Plot 2 Experiment Raw Tabular Data

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
226	4	0.0	5
227	19	0.0	5
228	19	-4.0	5
229	22	-2.0	5
230	37	-2.0	30
231 – NOT RECOVERED			
232	162	-7.0	5
233	285	-3.0	10
234	175	-2.5	5
235	369	-3.0	20
236	289	-1.0	10
237	112	0.0	10
238 – NOT RECOVERED			
239	216	0.0	5
240 – NOT RECOVERED			
241	6	0.0	5
242	12	0.0	20
243	18	-3.0	10
244	215	-0.5	10
245	89	-3.0	10
246	240	-2.0	20
247	285	0.0	30
248 – NOT RECOVERED			
249	131	-0.1	40
250	82	0.0	10
251	83	0.0	10
252	194	-3.5	10
253	153	0.0	10
254 – NOT RECOVERED			

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
255	92	0.0	5
256	5	-3.0	10
257 – NOT RECOVERED			
258 – NOT RECOVERED			
259	152	-3.5	30
260	285	-3.0	5
261	37	-1.5	10
262 – NOT RECOVERED			
263	157	-4.5	20
264	100	-3.5	5
265 – NOT RECOVERED			
266	71	0.0	30
267	87	0.0	10
268 – NOT RECOVERED			
269	88	0.0	10
270	92	0.0	5
271	8	-1.0	5
272	59	-3.0	5
273	1,010	0.0	
274 – NOT RECOVERED			
275 – NOT RECOVERED			
276 – NOT RECOVERED			
277	130	-3.0	10
278	77	-0.1	10
279 – NOT RECOVERED			
280	75	0.0	20
281	85	-2.0	10
282 – NOT RECOVERED			
283	90	0.0	10

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
284	80	0.0	5
285	100	0.0	20
286 – NOT RECOVERED			
287	118	-2.0	10
288 – NOT RECOVERED			
289	25	-8.0	30
290 – NOT RECOVERED			
291	74	0.0	5
292	47	0.0	20
293	70	-5.0	10
294	68	0.0	10
295	103	-4.0	5
296	67	0.0	5
297	78	0.0	10
298	79	0.0	10
299	73	0.0	5
300	76	0.0	5
301	31	-4.0	5
302 – NOT RECOVERED			
303 – NOT RECOVERED			
304	44	0.0	5
305 – NOT RECOVERED			
306	43	0.0	5
307	46	0.0	5
308	61	0.0	5
309	65	0.0	10
310 – NOT RECOVERED			
311	61	0.0	5
312	81	0.0	10

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
313	92	0.0	5
314	67	0.0	5
315	76	0.0	5
316 – NOT RECOVERED			
317	99	-3.0	5
318	154	-5.0	50
319 – NOT RECOVERED			
320	68	-8.0	20
321	54	0.0	10
322	49	0.0	5
323	140	-8.0	10
324	82	-0.5	5
325	67	-3.5	5
326 – NOT RECOVERED			
327	85	0.0	10
328	168	0.0	5
329	60	0.0	10
330	77	0.0	5
331 – NOT RECOVERED			
332 – NOT RECOVERED			
333 – NOT RECOVERED			
334	39	0.0	5
335	47	0.0	5
336	79	-4.5	5
337	147	-4.0	10
338 – NOT RECOVERED			
339	65	0.0	5
340 – NOT RECOVERED			
341	54	0.0	5

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
342	77	0.0	10
343 – NOT RECOVERED			
344	87	0.0	10
345	75	0.0	10
346 – NOT RECOVERED			
347	35	-3.0	50
348	1,123	-0.5	40
349	92	-3.0	30
350	228	-1.0	5
351	145	-3.0	5
352	169	0.0	10
353	119	-1.5	5
354	119	-5.0	10
355	131	-4.0	10
356	132	0.0	5
357	143	0.0	10
358	151	0.0	10
359	127	0.0	10
360	183	0.0	5
361 – NOT RECOVERED			
362 – NOT RECOVERED			
363	55	-3.0	50
364	184	-0.5	30
365 – NOT RECOVERED			
366 – NOT RECOVERED			
367	60	-6.5	5
368	64	-7.0	50
369	82	-0.5	5
370	122	-0.5	5

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
371 – NOT RECOVERED			
372	71	0.0	10
373	94	-2.0	5
374	110	0.0	10
375 – NOT RECOVERED			
376 – NOT RECOVERED			
377 – NOT RECOVERED			
378 – NOT RECOVERED			
379 – NOT RECOVERED			
380 – NOT RECOVERED			
381 – NOT RECOVERED			
382	182	-4.0	50
383 – NOT RECOVERED			
384 – NOT RECOVERED			
385	321	-6.5	40
386 – NOT RECOVERED			
387	618	-5.5	5
388 – NOT RECOVERED			
389 – NOT RECOVERED			
390 – NOT RECOVERED			
391 – NOT RECOVERED			
392 – NOT RECOVERED			
393 – NOT RECOVERED			
394 – NOT RECOVERED			
395 – NOT RECOVERED			
396 – NOT RECOVERED			
397 – NOT RECOVERED			
398 – NOT RECOVERED			
399 – NOT RECOVERED			

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
400 – NOT RECOVERED			
401 – NOT RECOVERED			
402 – NOT RECOVERED	520	-3.5	50
403			
404 – NOT RECOVERED			
405	1,136	-5.0	20
406 – NOT RECOVERED			
407 – NOT RECOVERED			
408 – NOT RECOVERED			
409 – NOT RECOVERED			
410 – NOT RECOVERED			
411 – NOT RECOVERED			
412 – NOT RECOVERED			
413 – NOT RECOVERED			
414 – NOT RECOVERED			
415 – NOT RECOVERED			
416 – NOT RECOVERED			
417 – NOT RECOVERED			
418 – NOT RECOVERED			
419 – NOT RECOVERED			
420	1,140	-8.5	50
421 – NOT RECOVERED			
422 – NOT RECOVERED			
423 – NOT RECOVERED			
424 – NOT RECOVERED			
425	219	-4.0	5
426 – NOT RECOVERED			
427 – NOT RECOVERED			
428	349	-9.0	50

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
429 – NOT RECOVERED			
430 – NOT RECOVERED			
431 – NOT RECOVERED			
432 – NOT RECOVERED			
433	302	-4.0	30
434 – NOT RECOVERED			
435	215	-4.5	40
436	122	0.0	5
437	121	0.0	5
438 – NOT RECOVERED			
439	97	0.0	5
440	59	-5.5	10
441	121	-6.0	5
442 – NOT RECOVERED			
443 – NOT RECOVERED			
444 – NOT RECOVERED			
445 – NOT RECOVERED			
446 – NOT RECOVERED			
447 – NOT RECOVERED			
448 – NOT RECOVERED			
449 – NOT RECOVERED			
450 – NOT RECOVERED			
Mean	**148**	**-1.8**	**13**

Plot 3 Experiment Raw Tabular Data

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
451	7	0.0	5
452	7	0.0	5
453	8	0.0	5
454	6	0.0	5
455	14	0.0	5
456	14	0.0	5
457 – NOT RECOVERED			
458	815	-0.5	10
459 – NOT RECOVERED			
460 – NOT RECOVERED			
461 – NOT RECOVERED			
462 – NOT RECOVERED			
463 – NOT RECOVERED			
464	64	-1.0	5
465	68	0.0	5
466	8	0.0	5
467	8	0.0	5
468	7	0.0	5
469	12	0.0	5
470	26	0.0	10
471	71	0.0	10
472 – NOT RECOVERED			
473 – NOT RECOVERED			
474 – NOT RECOVERED			
475 – NOT RECOVERED			
476 – NOT RECOVERED			
477 – NOT RECOVERED			
478 – NOT RECOVERED			
479	59	0.0	5

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
480	70	0.0	5
481	7	0.0	5
482	4	0.0	10
483	52	0.0	5
484	18	-0.5	5
485	21	-3.0	5
486 – NOT RECOVERED			
487 – NOT RECOVERED			
488 – NOT RECOVERED			
489 – NOT RECOVERED			
490 – NOT RECOVERED			
491 – NOT RECOVERED			
492	281	-4.0	5
493	54	-1.5	5
494	54	0.0	5
495	53	0.0	5
496	6	0.0	10
497	5	-0.5	5
498 – NOT RECOVERED			
499	2	-2.0	5
500 – NOT RECOVERED			
501 – NOT RECOVERED			
502 – NOT RECOVERED			
503 – NOT RECOVERED			
504 – NOT RECOVERED			
505 – NOT RECOVERED			
506 – NOT RECOVERED			
507 – NOT RECOVERED			
508	45	0.0	5

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
509	52	0.0	5
510	55	0.0	5
511	14	0.0	5
512 – NOT RECOVERED			
513 – NOT RECOVERED			
514	149	-2.0	10
515 – NOT RECOVERED			
516	134	-2.5	50
517 – NOT RECOVERED			
518 – NOT RECOVERED			
519 – NOT RECOVERED			
520 – NOT RECOVERED			
521	276	-1.0	20
522 – NOT RECOVERED			
523	46	0.0	5
524	49	0.0	5
525	63	0.0	5
526	19	0.0	5
527	18	-1.5	5
528	154	-2.0	30
529 – NOT RECOVERED			
530 – NOT RECOVERED			
531 – NOT RECOVERED			
532 – NOT RECOVERED			
533 – NOT RECOVERED			
534 – NOT RECOVERED			
535 – NOT RECOVERED			
536 – NOT RECOVERED			
537	43	0.0	5

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
538	42	0.0	10
539	48	0.0	5
540	59	0.0	5
541			
542	555	0.0	30
543 – NOT RECOVERED			
544 – NOT RECOVERED			
545 – NOT RECOVERED			
546	308	-3.5	10
547	19	-3.0	10
548 – NOT RECOVERED			
549 – NOT RECOVERED			
550 – NOT RECOVERED			
551 – NOT RECOVERED			
552	32	0.0	5
553	46	0.0	10
554	52	0.0	5
555	61	0.0	10
556 – NOT RECOVERED			
557	819	-3.0	10
558 – NOT RECOVERED			
559 – NOT RECOVERED			
560 – NOT RECOVERED			
561 – NOT RECOVERED			
562 – NOT RECOVERED			
563 – NOT RECOVERED			
564 – NOT RECOVERED			
565 – NOT RECOVERED			
566 – NOT RECOVERED			

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
567	44	0.0	5
568	51	0.0	5
569	47	0.0	5
570	64	0.0	5
571 – NOT RECOVERED			
572 – NOT RECOVERED			
573 – NOT RECOVERED			
574 – NOT RECOVERED			
575 – NOT RECOVERED			
576 – NOT RECOVERED			
577 – NOT RECOVERED			
578 – NOT RECOVERED			
579 – NOT RECOVERED			
580 – NOT RECOVERED			
581 – NOT RECOVERED			
582	55	0.0	20
583	48	0.0	10
584	59	0.0	5
585	63	0.0	10
586 – NOT RECOVERED			
587 – NOT RECOVERED			
588 – NOT RECOVERED			
589 – NOT RECOVERED			
590	459	-5.5	20
591	77	-11.0	20
592 – NOT RECOVERED			
593 – NOT RECOVERED			
594	676	-3.5	40
595	127	-2.0	20

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
596	54	-1.5	10
597	49	0.0	10
598	44	0.0	10
599	16	0.0	30
600	56	0.0	5
601	637	0.0	30
602	1,290	-3.0	5
603 – NOT RECOVERED			
604 – NOT RECOVERED			
605 – NOT RECOVERED			
606 – NOT RECOVERED			
607	483	-1.5	40
608 – NOT RECOVERED			
609 – NOT RECOVERED			
610 – NOT RECOVERED			
611	80	-3.0	20
612	70	0.0	5
613	58	0.0	5
614	63	0.0	20
615	66	0.0	10
616 – NOT RECOVERED			
617	31	0.0	10
618	37	0.0	50
619	42	-9.0	10
620 – NOT RECOVERED			
621 – NOT RECOVERED			
622 – NOT RECOVERED			
623 – NOT RECOVERED			
624	1,084	-3.5	50

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
625	236	-5.0	20
626	56	-3.0	10
627	62	0.0	10
628	88	0.0	5
629	69	0.0	5
630	69	0.0	10
631	21	-3.5	20
632	572	-0.5	50
633	51	-0.5	5
634 – NOT RECOVERED			
635 – NOT RECOVERED			
636	65	-1.0	10
637 – NOT RECOVERED			
638 – NOT RECOVERED			
639 – NOT RECOVERED			
640	502	-2.5	30
641	62	-2.5	5
642	73	0.0	5
643	92	0.0	5
644	85	0.0	10
645	72	0.0	5
646 – NOT RECOVERED			
647 – NOT RECOVERED			
648	786	0.0	30
649	61	-0.5	10
650 – NOT RECOVERED			
651	436	-12.0	20
652 – NOT RECOVERED			
653 – NOT RECOVERED			

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
654	1,128	-3.0	30
655	133	-0.5	20
656	67	0.0	5
657	70	0.0	5
658	83	0.0	10
659	79	0.0	10
660	77	0.0	5
661	46	0.0	5
662	44	0.0	5
663	705	0.0	20
664	31	-2.0	20
665	192	-4.0	5
666 – NOT RECOVERED			
667	305	-0.5	5
668 – NOT RECOVERED			
669 – NOT RECOVERED			
670	186	-4.5	20
671 – NOT RECOVERED			
672	55	-3.0	10
673	59	0.0	10
674	78	0.0	10
675	70	0.0	5
Mean	**148**	**-1.0**	**12**

Plot 4 Experiment Raw Tabular Data

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
676	9	0.0	0
677	5	0.0	0
678	10	0.0	0
679	5	0.0	0
680	3	0.0	0
681	4	0.0	0
682	3	0.0	0
683	6	0.0	0
684	5	0.0	0
685	15	0.0	0
686	4	0.0	0
687	12	0.0	0
688	22	0.0	0
689	12	0.0	0
690	10	0.0	0
691	9	0.0	0
692	19	0.0	0
693	4	0.0	0
694	10	0.0	0
695	7	0.0	0
696	13	0.0	0
697	14	0.0	0
698	15	0.0	0
699	18	0.0	0
700	12	0.0	0
701	25	0.0	0
702	22	0.0	0
703	20	0.0	0
704	5	0.0	0

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
705	19	0.0	0
706	6	0.0	0
707	12	0.0	0
708	4	0.0	0
709	6	0.0	0
710	16	0.0	0
711	19	0.0	0
712	8	0.0	0
713	7	0.0	0
714	15	0.0	0
715	12	0.0	0
716	15	0.0	0
717	18	0.0	0
718	25	0.0	0
719	15	0.0	0
720	28	0.0	0
721	14	0.0	0
722	20	0.0	0
723	13	0.0	0
724	19	0.0	0
725	26	0.0	0
726	23	0.0	0
727	11	0.0	0
728	31	0.0	0
729	30	0.0	0
730	26	0.0	0
731	25	0.0	0
732	30	0.0	0
733	29	0.0	0

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
734	36	0.0	0
735	39	0.0	0
736	16	0.0	0
737	20	0.0	0
738	16	0.0	0
739	14	0.0	0
740	22	0.0	0
741	17	0.0	0
742	24	0.0	0
743	30	0.0	0
744	26	0.0	0
745	27	0.0	0
746	20	0.0	0
747	20	0.0	0
748	29	0.0	0
749	17	0.0	0
750	18	0.0	0
751	22	0.0	0
752	5	0.0	0
753	19	0.0	0
754	14	0.0	0
755	27	0.0	0
756	33	0.0	0
757	25	0.0	0
758	15	0.0	0
759	25	0.0	0
760	16	0.0	0
761	20	0.0	0
762	27	0.0	0

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
763	18	0.0	0
764	20	0.0	0
765	19	0.0	0
766	19	0.0	0
767	16	0.0	0
768	11	0.0	0
769	16	0.0	0
770	14	0.0	0
771	19	0.0	0
772	22	0.0	0
773	20	0.0	0
774	23	0.0	0
775	17	0.0	0
776	19	0.0	0
777	22	0.0	0
778	27	0.0	0
779	19	0.0	0
780	15	0.0	0
781	22	0.0	0
782	13	0.0	0
783	19	0.0	0
784	26	0.0	0
785	7	0.0	0
786	20	0.0	0
787	33	0.0	0
788	29	0.0	0
789	9	0.0	0
790	15	0.0	0
791	23	0.0	0

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
792	12	0.0	0
793	22	0.0	0
794	13	0.0	0
795	20	0.0	0
796	16	0.0	0
797	0	0.0	0
798	10	0.0	0
799	9	0.0	0
800	23	0.0	0
801	18	0.0	0
802	14	0.0	0
803	135	0.0	0
804	22	0.0	0
805	16	0.0	0
806	18	0.0	0
807	11	0.0	0
808	18	0.0	0
809	10	0.0	0
810	12	0.0	0
811	9	0.0	0
812	9	0.0	0
813	5	0.0	0
814	14	0.0	0
815	16	0.0	0
816	12	0.0	0
817	26	0.0	0
818	31	0.0	0
819	19	0.0	0
820	24	0.0	0

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
821	10	0.0	0
822	14	0.0	0
823	19	0.0	0
824	14	0.0	0
825	25	0.0	0
826	10	0.0	0
827	6	0.0	0
828	11	0.0	0
829	13	0.0	0
830	12	0.0	0
831	30	0.0	0
832	15	0.0	0
833	25	0.0	0
834	16	0.0	0
835	5	0.0	0
836	16	0.0	0
837	9	0.0	0
838	15	0.0	0
839	11	0.0	0
840	15	0.0	0
841	11	0.0	0
842	24	0.0	0
843	8	0.0	0
844	15	0.0	0
845	26	0.0	0
846	14	0.0	0
847	35	0.0	0
848	22	0.0	0
849	22	0.0	0

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
850	23	0.0	0
851	18	0.0	0
852	20	0.0	0
853	37	0.0	0
854	19	0.0	0
855	31	0.0	0
856	22	0.0	0
857	18	0.0	0
858	29	0.0	0
859	16	0.0	0
860	16	0.0	0
861	24	0.0	0
862	27	0.0	0
863	28	0.0	0
864	13	0.0	0
865	11	0.0	0
866	15	0.0	0
867	10	0.0	0
868	24	0.0	0
869	13	0.0	0
870	26	0.0	0
871	12	0.0	0
872	16	0.0	0
873	10	0.0	0
874	10	0.0	0
875	16	0.0	0
876	22	0.0	0
877	30	0.0	0
878	32	0.0	0

Tile #	Horizontal Movement (cm)	Vertical Movement (cm)	Scratch Damage
879	27	0.0	0
880	44	0.0	0
881	38	0.0	0
882	33	0.0	0
883	36	0.0	0
884	33	0.0	0
885	41	0.0	0
886	15	0.0	0
887	12	0.0	0
888	15	0.0	0
889	16	0.0	0
890	12	0.0	0
891	18	0.0	0
892	18	0.0	0
893	18	0.0	0
894	16	0.0	0
895	15	0.0	0
896	13	0.0	0
897	17	0.0	0
898	21	0.0	0
899	20	0.0	0
900	24	0.0	0
MEAN	**18**	**0.0**	**0**