



Change assessment of the Gallatin Petrified Forest, Montana
by James Roy Wilbur

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Earth Sciences

Montana State University

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Abstract:

The Gallatin Petrified Forest of Montana is a unique national resource. The extensive area of the fossil forests, the numerous petrified trees in upright positions, and the large number of vertical layers of "successive" forests is unparalleled in the world. Although a policy of collection by permit is presently in place, damage to outcrops of the petrified forest by indiscriminate collection is occurring. To assess the impact of this collection policy, a comparative examination of replicate photography of selected outcrops over a time period of 13 years was undertaken. This was followed by a field check of each outcrop to determine status, present condition, and to map its exact location. Results were then tabulated to determine the extent of changes or impacts over time and the locational factors related to these changes. Statistical tests were conducted to determine the relationship of these factors to the amount of natural- and human-induced change.

It was found that although considerable loss had resulted from collection since the policy was implemented, impacts were more severe before the policy existed. Natural erosion had a greater impact than human-induced change, but human impacts were additive to the natural changes. Size and slope of petrified outcrops were directly related to the amount of natural change occurring over time. Human-induced change was associated with the distance of the outcrops from the main trailheads and the outcrop size. Tests were inconclusive in demonstrating a relationship between change and the distance of an outcrop from a main trail or any elevation-based factor. This method for assessing change in the petrified resource provides a tool to continue monitoring impacts and evaluating future policy.

An analysis of the known outcrops through the use of low and high altitude photographs determined a spectral reflectance value for locating outcrops. An interpretive trail has been suggested to provide visitors with an accessible and informative viewing opportunity. Recommended changes in present management policy included expanding and clarifying the definition of outcrops protected from collection, making collection permits more available, posting of collection regulations on all trails in the area, and greater supervision of the area by U.S Forest Service personnel.

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
Management Policy	3
Photographic Survey	4
Objectives	8
STUDY AREA	9
Historical Accounts	10
Geology	12
Petrifaction	14
Vegetation	15
Modern Vegetation	15
Petrified Forest Vegetation	16
Climate	17
Present Climate	17
Climatic Effects	20
Land Ownership	21
Land Use	26
METHODS	29
Photographic Survey	29
Field Survey	30
Remote Sensing Analysis	31
Change Assessment	32
Data Analysis	33
RESULTS AND DISCUSSION	36
Field Survey	36
Field Observation	36
Visual Assessment of Change	40
Photographic Analysis	42
Statistical Comparisons	43
Remote Sensing Analysis	53
CONCLUSIONS	55
Recommendations and Rationales	56
REFERENCES CITED	63

TABLE OF CONTENTS-Continued

	Page
APPENDICES	71
Appendix A-Special Management Zone Regulations ..	72
Appendix B-Sample Form	76
Field Survey Data Form	77
Appendix C-Field Survey Data Tables	78
Petrified Forest Sites Field Checked	79
Human-Impacted Specimens Protected by USFS Petrified Wood Collection Regulations	84
Appendix D-Measured Data Factors Abbreviations ..	85
Appendix E-Measured Specimens Data Tables	87
Natural Change Sample Measurement Data	88
Human-Impacted Sample Measurement Data	89
Appendix F-Measurement Data Graphs	90
Appendix G-Regression Analysis Tables	95
Regression Analysis Results for Amount of Change per Year versus the Locational Factors for the Natural Sample	96
Regression Analysis Results for Amount of Change per Year versus the Locational Factors for the Human Sample	100

LIST OF TABLES

Table	Page
1. Monthly Temperature ($^{\circ}$ C) Means and Extremes for Yellowstone National Park Headquarters (Mammoth Hot Springs) at 1,902 m, for 1951-1974	18
2. Monthly and Total Precipitation Averages ($^{\circ}$ C) for Yellowstone National Park Headquarters (Mammoth Hot Springs) at 1,902 m and Rocky Creek Meadows (Soil Conservation Service Snow Course Site) at 2,487 m...	20
3. Sales of Petrified Wood Collection Permits	37
4. Visual Change Assessment Results	40
5. Specimens with Measured Areal Change by both Natural- and Human-induced Processes	43
6. Summary of Location and Measured Change Data	44
7. Regression Analysis Results Summary	47
8. Likelihood of Reflectance Values on Aerial Photographs and the Presence of Petrified Wood	54
9. Petrified Forest Sites Field Checked	79
10. Human-Impacted Specimens Protected by USFS Petrified Wood Collection Regulations	84
11. Measured Change and Locational Factors Abbreviations	86
12. Natural Changed Measured Sample Data	88
13. Human Impacted Measured Sample Measured Data	89

LIST OF TABLES-Continued

Table	Page
14. Regression Analysis Results for Amount of Change per Year versus the Locational Factors for the Natural Sample	96
15. Regression Analysis Results for Amount of Change per Year versus the Locational Factors for the Human Sample	100

LIST OF FIGURES

Figure	Page
1. Location Map of Gallatin Petrified Forest within the Greater Yellowstone Ecosystem, South-central Montana	2
2. Map of Northern Part of Study Area	6
3. Map of Southern Part of Study Area	7
4. Special Management Zone Land Ownership Map	22
5. Graph of Amount of Change per Year versus Initial Areal Measurement for Natural Change Sample	48
6. Graph of Amount of Change per Year versus Initial Areal Measurement for Human-Impacted Sample with outliers removed	48
7. Graph of Amount of Change per Year versus Slope for the Natural Sample	50
8. Graph of Amount of Change per Year versus Slope for the Human Sample	50
9. Graph of Amount of Change per Year versus Distance from Trailhead for the Natural Sample	51
10. Graph of Amount of Change per Year versus Distance from Trailhead for the Human Sample	51
11. Graph of Amount of Change per Year versus Distance from Main Trail for the Natural Sample ...	91
12. Graph of Amount of Change per Year versus Distance from Main Trail for the Human Sample	91
13. Graph of Amount of Change per Year versus Elevation of Specimen Site for the Natural Sample	92

LIST OF FIGURES-Continued

Figure	Page
14. Graph of Amount of Change per Year versus Elevation of the Specimen Site for the Human Sample	92
15. Graph of Amount of Change per Year versus Elevation Change from Trailhead for the Natural Sample	93
16. Graph of Amount of Change per Year versus Elevation Change from Trailhead for the Human Sample	93
17. Graph of Amount of Change per Year versus Elevation Change per 1000 m of Trail for the Natural Sample	94
18. Graph of Amount of Change per Year versus Elevation Change per 1000 m of Trail for the Human Sample	94

ABSTRACT

The Gallatin Petrified Forest of Montana is a unique national resource. The extensive area of the fossil forests, the numerous petrified trees in upright positions, and the large number of vertical layers of "successive" forests is unparalleled in the world. Although a policy of collection by permit is presently in place, damage to outcrops of the petrified forest by indiscriminate collection is occurring. To assess the impact of this collection policy, a comparative examination of replicate photography of selected outcrops over a time period of 13 years was undertaken. This was followed by a field check of each outcrop to determine status, present condition, and to map its exact location. Results were then tabulated to determine the extent of changes or impacts over time and the locational factors related to these changes. Statistical tests were conducted to determine the relationship of these factors to the amount of natural- and human-induced change.

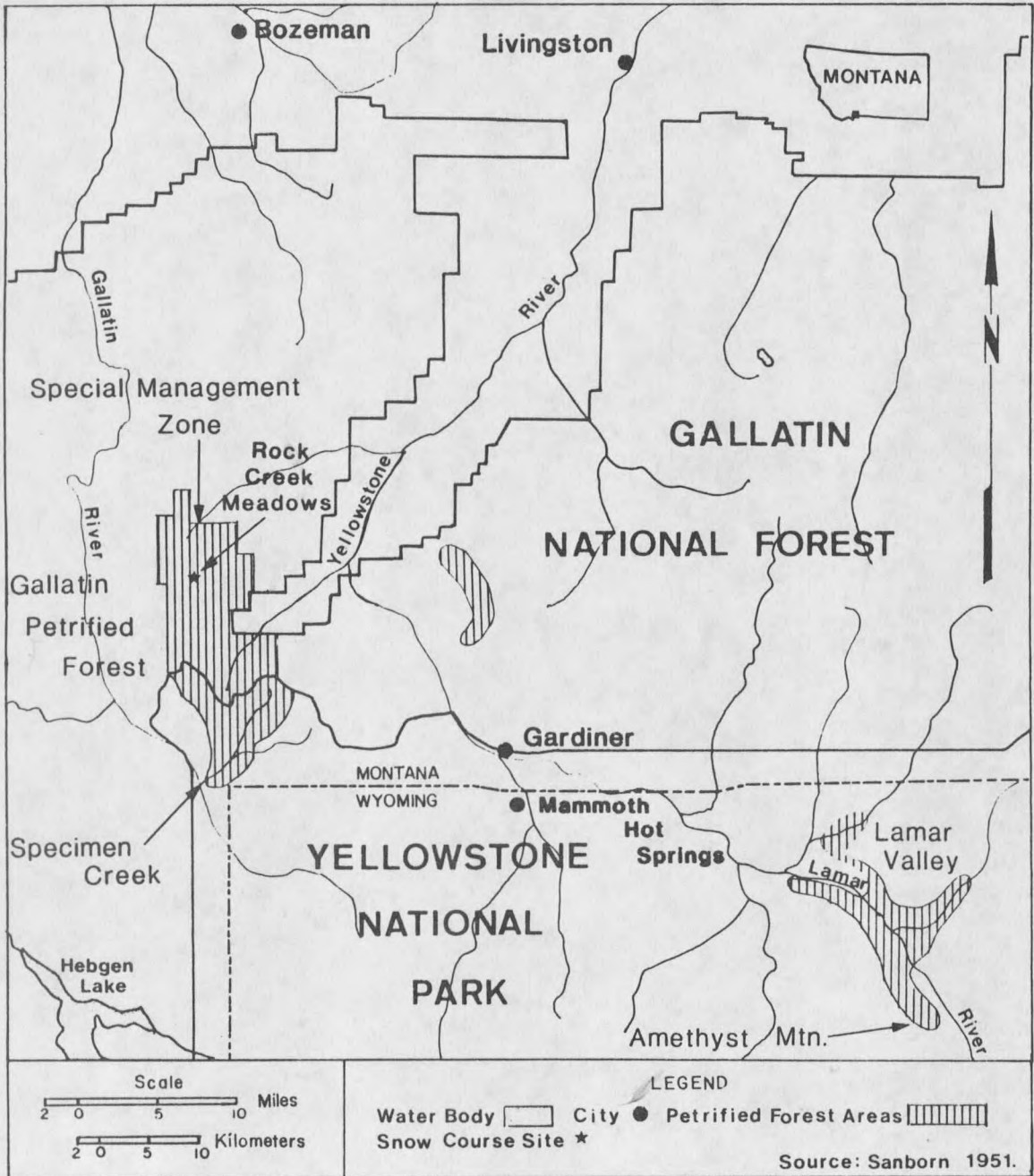
It was found that although considerable loss had resulted from collection since the policy was implemented, impacts were more severe before the policy existed. Natural erosion had a greater impact than human-induced change, but human impacts were additive to the natural changes. Size and slope of petrified outcrops were directly related to the amount of natural change occurring over time. Human-induced change was associated with the distance of the outcrops from the main trailheads and the outcrop size. Tests were inconclusive in demonstrating a relationship between change and the distance of an outcrop from a main trail or any elevation-based factor. This method for assessing change in the petrified resource provides a tool to continue monitoring impacts and evaluating future policy.

An analysis of the known outcrops through the use of low and high altitude photographs determined a spectral reflectance value for locating outcrops. An interpretive trail has been suggested to provide visitors with an accessible and informative viewing opportunity. Recommended changes in present management policy included expanding and clarifying the definition of outcrops protected from collection, making collection permits more available, posting of collection regulations on all trails in the area, and greater supervision of the area by U.S. Forest Service personnel.

INTRODUCTION

The Gallatin Petrified Forest, located in the Greater Yellowstone Ecosystem, is one of the most extensive and diverse forests of petrified trees in North America (Figure 1). The Gallatin Petrified Forest is a national resource that is exceptional in its unique characteristics. These characteristics include a large area with a diverse geography of fossil forests, a large number of petrified trees in upright positions, and numerous vertical layers of "successive" forests. In 1935, Chapman and Chapman (1935) wrote a popular description of the Gallatin Petrified Forest extolling its "abundant displays" and bemoaning its neglect due to inaccessibility and its proximity to the more widely publicized and accessible Lamar River area in Yellowstone National Park. Fisk (1976) comprehensively described the petrified forests in the Gallatin Range and agreed with Chapman and Chapman's (1935) observation of neglect due to the locality's isolation. Damage to outcrops by indiscriminate collection is referred to by several authors (Knowlton 1899; Chapman and Chapman 1935; Sanborn 1951; Ritland 1968; and Dorf 1980), however a quantification of the damage or amount of resource change over time of the resource has not been done to date. Sollid (1973) mapped a general area of petrified outcrops

Figure 1. Location Map of Gallatin Petrified Forest within the Greater Yellowstone Ecosystem, South-central Montana.



in the Porcupine Creek watershed and discussed management problems associated with commercial collection of specimens in the area outside the Park. Collection of specimens presently requires a permit, however no monitoring system has been established to measure the effect of loss of the resource resulting from this collection. Knowledge of the precise location and geographic extent of the forest is very limited and with collection allowed, the impact of the collection policy is unknown.

Management Policy

Prior to 1973, the Gallatin Petrified Forest within the Gallatin National Forest was managed with few, if any, guidelines. Collection of specimens was unrestricted and open to everyone, allowing unlimited exploitation. Collection for commercial purposes and by others occurred with reports of the use of excavating equipment, vehicles for transport, and dynamite. The use of these methods possibly caused significant damage to the petrified wood specimens as well as to the vegetation and soils of the area.

Concerned with the exploitation of this limited resource, the U. S. Forest Service, after several public meetings and an environmental analysis report, established the Gallatin Petrified Forest Special Management Zone in 1973 (Figure 1). Regulations (Appendix A) restricting

collection and use of the land within the Special Management Zone (SMZ) were implemented. Prior to adoption of these regulations the merits of prohibiting all collection of petrified wood in the SMZ were debated and considered by the U. S. Forest Service. The decision, however, to allow "hobbyist" collection was in part due to the fact that there was considerable public interest in allowing some form of collection of petrified wood to continue. The SMZ borders Yellowstone National Park to the south and the portion of the Gallatin Petrified Forest within the Park is protected against all forms of collection by Park Service regulations.

Photographic Survey

Having established the Gallatin Petrified Forest as a Special Management Zone, the U.S. Forest Service initiated a program of resource inventory in the SMZ. To accomplish this the U.S. Forest Service acquired the services of a volunteer, Theodore Van Dyne, in 1975 to search for petrified wood outcrops within the SMZ. The area Van Dyne surveyed was south of Trail Creek Trail to the Yellowstone National Park boundary and from the Gallatin Range central divide east to Specimen Ridge (Figures 2 and 3) (included portions of sections 22, 23, 24, 26, 27, and 35 of Township 8 South, Range 5 East). Once specimens were located, the volunteer numbered and photographed the outcrop and

indicated its location on an aerial photograph. Van Dyne took approximately 170 photographs and labelled 92 sites (he grouped two or three specimens in close proximity under one site number). Five years later, in 1980, a second volunteer, George Shabel, was recruited to go back and rephotograph the first series and to inventory a new area. This new area was the area adjacent to the trail from Buffalo Horn Pass to Ramshorn Peak and the southern slopes of Ramshorn Peak (Figure 2) including portions of sections 10 and 15 of Township 8 South, Range 5 East. At this time only 62 of the original 92 sites were located and rephotographed. At one site (#2-27), Shabel indicated evidence of exposed digging at nearly a dozen "medium size" pits where petrified wood has been removed and he witnessed a man hammering at one standing specimen.

In 1981, two volunteers, Mark Dosman and Ed Domanski, inventoried a third area. This area was located north of Trail Creek and Tom Miner Campground primarily on the southern face of the ridges of this area and in the Dry Creek drainage (Figure 2) including portions of sections 10, 13, 14, and 15 of Township 8 South, Range 5 East. They inventoried 71 sites. In 1985, a fifth volunteer, Ed Sparks, returned to the area of the 1975 survey to rephotograph the specimens he could locate. He was only able to locate and rephotograph approximately 40 of the previous sites, but added about 55 new sites. Unfortunately he

Figure 2. Map of Northern Part of Study Area in T.8S., R.5E. (USGS 1986).

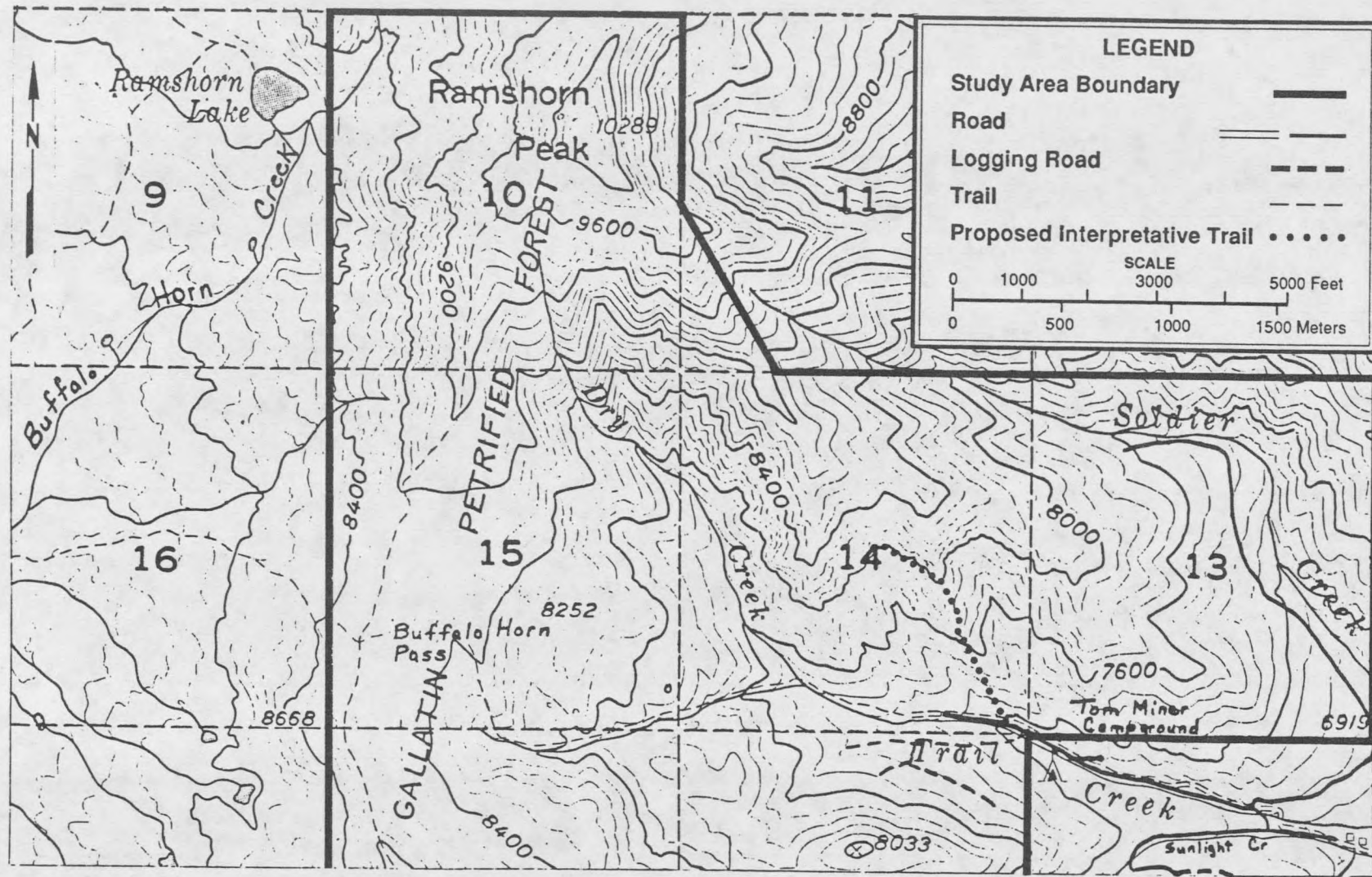
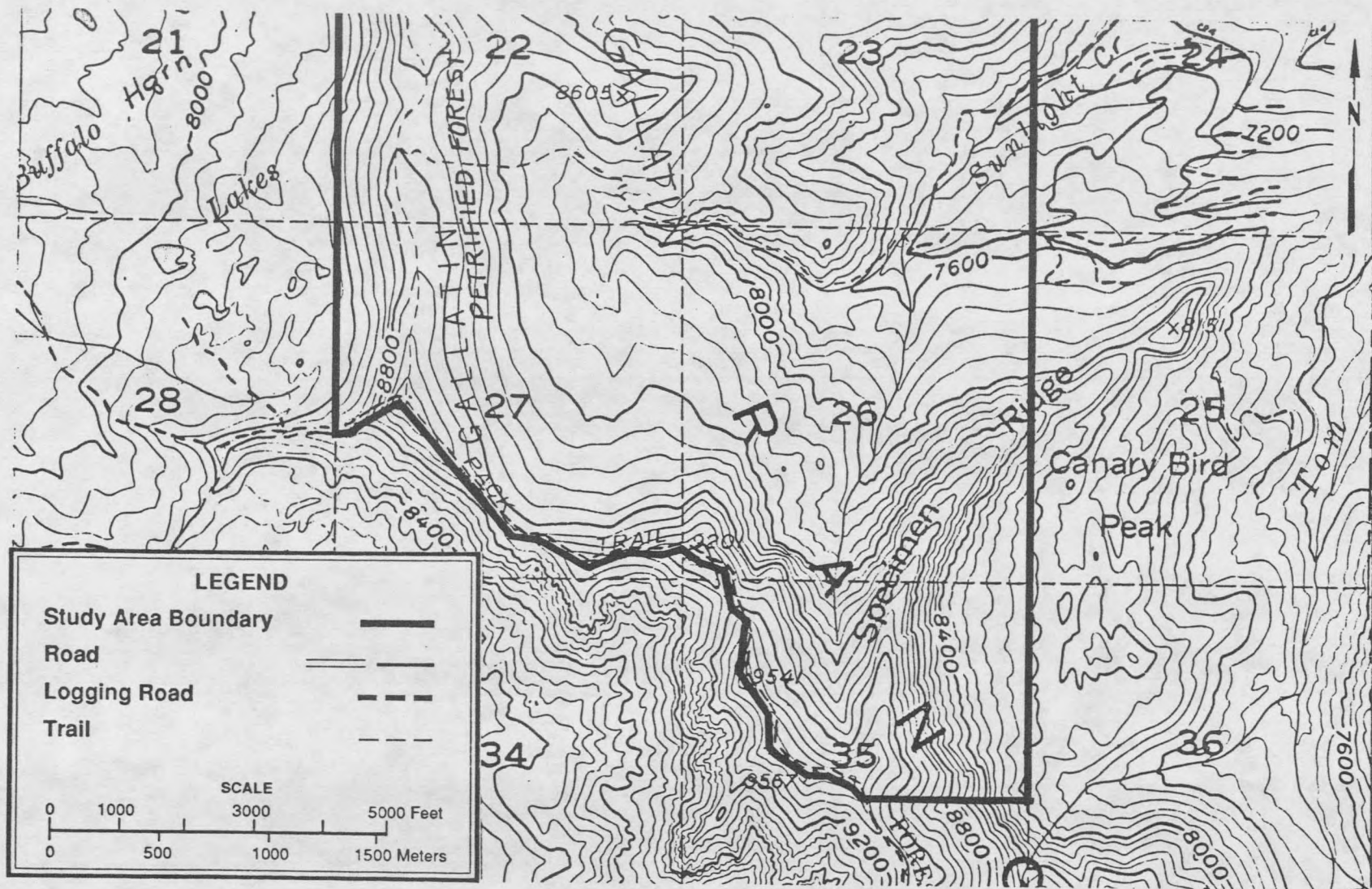


Figure 3. Map of Southern Part of Study Area in T.8S., R.5E. (USGS 1987).



either failed to mark those locations on an aerial photograph or the photograph has since been lost. Sparks returned in 1986 to rephotograph specimens in the area surveyed in 1981. At that time he located 16 of the original 71 sites and added 15 new sites. Overall, although some specimens were photographed over time, U.S. Forest Service managers realized that the inventory data that had been collected needed to be organized and analyzed and evident problems with the management policy needed to be addressed (Cowan 1988; Sollid 1988).

Objectives

The objectives of this study, therefore, included: 1) mapping the spatial distribution of the petrified forest outcrops in an area of the Special Management Zone of the Gallatin National Forest in south-central Montana. This included developing and testing a remote sensing technique to assist locating petrified forest outcroppings; 2) evaluating change over time within the U.S. Forest Service (USFS) photographic survey record of petrified forest outcrops; and 3) providing data and recommendations for improving management strategies of the Special Management Zone containing the petrified forest and for the location of a proposed interpretive trail.

STUDY AREA

The study area, approximately 15.2 square kilometers (9.5 square miles) in size, is located in the Gallatin National Forest and includes the crest of the Gallatin Range, north of the Yellowstone National Park boundary (Figures 2 and 3). This includes Ramshorn Peak and portions of the highland valleys to the east and west, the Buffalo Horn Creek drainage, and Tom Miner Basin respectively. The highest point in the study area is Ramshorn Peak (3136 m) and the lowest is in the Tom Miner Basin (2108 m) while most of the study area averages between 2400 and 2700 m.

This area was chosen because it has a history of documentation via the USFS photographic survey, it is an area where concern of impact is documented, it is accessible to the public, and it is a known location of good petrified wood specimens. The following Historical Accounts is presented to provide the reader with an understanding of the conditions of deposition, petrification, and exposure of the petrified specimens. Most of the research on the petrified forest has been carried out in the Lamar River valley area (Figure 1) of Yellowstone National Park, not in the Gallatin Petrified Forest.

Historical Accounts

The initial reports of fossilized plant remains in the Yellowstone area were made by the first white explorers such as Jim Bridger (Chapman and Chapman 1935; Dorf 1980). In 1878 the Hayden Survey Party made a scientific study of the region. A member of the party, W. H. Holmes, devoted much of his attention to outcroppings of petrified trees found within the Lamar River valley. The significance of finding stumps that were in an upright position led him to develop a theory that these were remains of successive living forests that were buried by ash falls and mud flows caused by nearby erupting volcanoes (Holmes 1879). Holmes stated that ten or more successive fossilized forests could be located in the area. This initial interpretation has not been convincingly challenged by further research. Further study by Dorf (1960, 1964, 1974, 1980) had led to suggestion that 27 or more successive buried forests have grown in one locality in the Lamar River valley. A dendro-chronologic study (Arct 1979) was conducted in the Specimen Creek area (Figure 1) in the Gallatin Petrified Forest crossdated individual trees on adjacent levels and constructed a 'floating' chronology. That study questioned the theory that each individual layer represents a successive forest.

Knowlton (1896b) first identified the species of a petrified specimen. Soon after, a detailed and nearly complete taxonomic study of the fossilized flora found in the Yellowstone region yielded 150 species with 81 species new to science at that time (Knowlton 1899). Knowlton divided the floras into three stages. Those found in the acidic rocks were dated as early Eocene or Fort Union in age. He compared the dates of the flora known from the Auriferous gravels of California with those from the intermediate layer and those found in the basic rocks underlying them as Miocene age (Knowlton 1896a, 1899, 1921). Revision of the timing of the Auriferous gravels led later researchers to extend the intermediate petrified tree dates back to the Eocene epoch (Read 1933). Dorf (1939, 1960, 1974, 1980) dated these floras using comparisons with the flora of the Green River Formation in Wyoming and other areas. He has dated the flora in the Sepulcher Formation of the Washburn Group as late Early Eocene and early Middle Eocene and the flora of the Lamar River Formation as early Middle Eocene.

Work analyzing plant species from fossilized specimens has continued, to the present, bringing the total known species found to nearly 200 (Conrad 1930; Read 1933; Andrews 1939; Beyer 1954; Dorf 1960, 1964; Fritz 1977; Fritz and Fisk 1978, 1979; Chadwick and Yamamoto 1984). Previous studies and reports mapped, popularized,

described, and documented the existence and location of the Gallatin Petrified Forest (Knowlton 1921; Morell 1929; Andrews 1939; Andrews and Lenz 1946; and Sanborn 1951).

One anomaly of the Yellowstone petrified forests still without adequate explanation is the total absence of any type of animal fossils (Hague 1896; Knowlton 1899; Chapman and Chapman 1935; Dorf 1960, 1974, 1980; Fisk 1976). Dorf's explanation (1980) that the animals out-migrated at the beginning of volcanic activity does not account for the absence of less mobile animals like land snails, insects, and amphibians (Fisk 1976).

Geology

Early geological investigators (Hague 1896; Hague et al 1899) in Yellowstone National Park described the deposits surrounding the petrified forest of the Lamar River area as coarse breccia and fine tuffs composed of hornbende-andesite, and hornbende-mica-andesite. These were considered the oldest extrusive flows in the Park.

Smedes and Prostka (1972), after extensive research into the stratigraphy of the Absaroka volcanic field of northwestern Wyoming and southwestern Montana, labeled the Tertiary volcanics the Absaroka Volcanic Supergroup. The oldest of these volcanics is the Washburn Group found in the north-central part of the Park. These volcanic rocks make up much of the northern Absaroka Range, the Washburn

Range and the Gallatin Range. In these areas the Washburn Group is more than 900 meters thick near the vent areas which are composite stratovolcanoes and shield volcanoes composed of flow breccia, lava flows, mudflows, avalanche debris, and tuff. The fossil wood and standing stumps are today found in alluvial facies which are thinner and composed of volcanic conglomerates and breccia grading outward from the vents into fine-grained alluvial beds containing volcanic sandstone and siltstone and air-fall tuffs. The Washburn Group is considered approximately fifty million years old or of Eocene age based on paleontological composition and sparse radiometric dating.

Numerous studies have been conducted to better define the depositional history of the fossilized trees (Ammons, Fritz, Ammons, and Ammons 1987; Arct 1979; Coffin 1976; Chadwick and Yamamoto 1984; DeBord 1977, 1979; Fritz 1977, 1980a, 1980b, 1980c, 1987; Fritz and Fisk 1978, 1979). The classical interpretation of burial of the successive forests in situ without any transport (Holmes 1879, Dorf 1960, 1964, 1974, 1980) was challenged by several researchers (Coffin 1976; Fisk 1976; Fritz 1977, 1980a, 1980b, 1980c) who advocated an interpretation that included transported trees. In 1980, the Mount St. Helens eruption, provided a valuable example of a depositional environment to study, with logs and uprooted trees transported and deposited upright by mud flows and in debris-dammed lakes

(Fritz 1980d; Harrison and Fritz 1982; Coffin 1983). Today there is general agreement on a combination of transported trees and burial in situ (Retallack 1981; Fritz 1981, 1983, 1984; Coffin 1983; Yuretich 1984a, 1984b; Ammons et al 1987).

Petrifaction

The process of petrification is the mechanism by which buried stumps, logs, and twigs are preserved by being transformed into stone. Petrification has been demonstrated in most cases to occur through mineral material filling the cavities and open spaces within the empty cells of plant tissue. The cellular walls of the wood are surrounded and embedded in more or less their original state by the petrifying mineral material. Growth rings and microscopic details of the original wood are usually preserved.

In this study area the petrifying mineral was almost always silica, or quartz (SiO_2), which originated in the volcanic sediments and was circulated through the buried trees by subsurface water (possibly hot water) (Dorf 1964a, 1964b). In a few exceptions, trees and other plant material have been petrified by a material that is calcareous (Read 1933).

Vegetation

Modern Vegetation

The Gallatin Range has a well developed altitudinal zonation of vegetation which is characteristic of the Northern Rocky Mountain region. The vegetation at the highest elevations is an alpine and subalpine meadow community type characterized by various grasses, forbs, and sedges, and is often bordered in places by stands of whitebark pine (Pinus albicaulis). The vegetation in the forested area below these meadows is principally a fir-spruce forest association dominated by subalpine fir (Abies lasiocarpa) and Engelman spruce (Picea engelmannii) which forms a climax forest. Associated with, but generally below the fir-spruce association are Douglas fir (Pseudotsuga menziesii), lodgepole pine (Pinus contorta), and quaking aspen (Populus tremuloides), found in both mixed and pure stands. Limber pine (Pinus flexilis) can be found in dry areas of the valley bottoms. At lower elevations and on dry south-facing slopes of lower ridges is a sagebrush-grass (Artemisia tridentata-Festuca idahoensis) community. Narrow-leaved cottonwood (Populus angustifolia), mountain alder (Alnus incana), and several willows (Salix spp.) form a riparian community along the streams of the area. The predominate understory shrubs of the modern-

day forest include juniper (Juniperus communis), buffalo-berry (Shepherdia spp.), huckleberry (Vaccinium spp.), wild rose (Rosa acicularis), gooseberry (Ribes spp.) wavey-leaved alder (Alnus sinuata), and sagebrush (Artemisia tridentata) (Fisk 1976a).

Petrified Forest Vegetation

In contrast, the species found as petrified specimens are quite different from the present day vegetation. Some of the most common genera identified in the petrified forests of the region include sycamores (Platanus spp. and Platanophyllum spp.), walnut (Juglans), magnolia (Magnolias), chestnut (Castanea), oak (Quercus), redwood (Sequoia), maple (Acer) and dogwood (Cornus). The modern relatives of these genera are common in forests of warm-temperate and subtropical climates. Modern tropical forest genera found preserved in the study area include fig (Ficus), laurels (Laurus, Laurophyllum, and Ocotea), and bay (Persea). Also found are present-day temperate species of pine (Pinus), hickory (Carya), elm (Ulmus), willow (Salix), and spruce (Picea). Trees not presently found in North America, but preserved by petrification, include relatives of the oriental katsura tree (Cercidiphyllum), the southeast Asian breadfruit tree (Artocarpus), the east Asian chinquapin (Castanopsis), and Pinaceae (Keteleeria) of central China (Dorf 1960, 1964, 1980; Fisk 1976b; Chadwick and Yamamoto 1984).

Climate

Although climate of the region has undergone many changes during the intervening 50 million years (Baker 1976; Douglas and Stockton 1975; Pierce 1979; and Richmond, Mullenders, and Coremans 1978), including glacial advances, periods of warming, and changes in erosion rates, the study area was not heavily affected by glacial activity, but did undergo exposure and coverage by sediments. Some of the oldest indicators of past climates in the study area are the petrified trees, leaves, twigs, and pollen found in the volcanic sediments of the Sepulcher Formation. These fossils are approximately 50 million years old, from the Eocene Epoch. The variety of species from tropical to temperate climates (Dorf 1960; Fisk 1976), has led to the theory that the area's paleoenvironment included lowland valleys with a tropical-to-subtropical climate, while the higher elevations had a more temperate climate (Fritz 1987).

Present Climate

The location of this region, far within the interior of the North American continent, well removed from the moderating influence of the oceans, experiences a continental climatic regime of relatively hot summers and cold winters. The climate of the region is additionally

modified by its high elevation, resulting in higher amounts of precipitation and cooler summers. The area is well within the southward path of the polar front, often resulting in large deviations from the monthly temperature average (Trewartha 1981). Additionally the area is exposed to frequent, semi-periodic passages of westerly winter storm systems. The main cause for climatic variation in the region (refer to Table 1) is due to anomalously cold or warm air being advected into the region by displacement of air flow and storm tracks northward or southward (Douglas and Stockton 1975).

Table 1. Monthly Temperature ($^{\circ}\text{C}$) Means and Extremes for Yellowstone National Park Headquarters (Mammoth Hot Springs) at 1,902 m, for 1951-1974 (Dirks and Martner 1982).

Month	Means			Extremes			
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year
JAN	-1.8	-12.3	-7.1	10	1974	-38	1963
FEB	1.2	-10.4	-4.6	13	1958	-34	1962
MAR	3.8	-9.3	-2.7	18	1972	-32	1956
APR	9.3	-3.9	2.7	23	1962	-16	1966
MAY	16.2	0.8	8.5	28	1954	-13	1954
JUN	21.1	4.8	12.9	32	1974	-6	1966
JUL	27.2	7.5	17.4	35	1967	-4	1968
AUG	25.9	7.1	16.5	34	1961	-4	1968
SEP	19.9	2.4	11.2	32	1967	-11	1965
OCT	13.5	-1.8	5.9	26	1968	-17	1971
NOV	4.1	-7.1	-1.4	18	1965	-33	1959
DEC	-0.6	-11.2	-5.9	11	1964	-37	1964

Alternatively warm, often moist air moves up the Columbia-Snake River Valleys pushed by the clockwise circulation around the Great Basin High, producing significant winter precipitation enhanced by the orographic

effect of the region's north-south trending mountain ranges (Bryson and Hare 1974). Because of the prevailing southwesterly flow and the north-south orientation of the Gallatin Range, a rain shadow effect is created and is responsible for the dry conditions found in the Yellowstone River Valley (directly to the east of the Gallatin Range). This flow of air from the southwest is the predominant source of moisture for the region for most of the year. Summer precipitation is dominated first by thunderstorms and showers and secondly by organized frontal activity (Dirks and Martner 1982). In late spring and summer occasional tropical maritime air masses from the Gulf of Mexico make their way into the area from the southeast. The two flow patterns (southwesterly and southeasterly), enhanced by convective heating, then produce thunderstorms and showers characterizing the peak precipitation of the late spring early summer season.

A second precipitation peak occurs from October through March, representing the winter snowpack accumulation. Approximately two-thirds of the mountain precipitation is snowfall. The study area receives on average more than 76 centimeters of water equivalent precipitation on the lower elevations (below 2300 m) and greater than 127 centimeters at the highest elevations (above 2600 m) (Soil Conservation Service 1981). The influence of elevation on monthly precipitation averages, for a high and a lower

elevation location site near the study area, is evident (Table 2). Average annual snowfall is estimated at over 500 centimeters in the lower elevations and over 760 centimeters in the higher elevations (Farnes and Shafer 1972).

Table 2. Monthly and Total Precipitation Averages ($^{\circ}\text{C}$) for Yellowstone National Park Headquarters (Mammoth Hot Springs) at 1,902 m and Rocky Creek Meadows (Soil Conservation Service Snow Course Site) at 2,487 m (Dirks and Martner 1982; Farnes 1987).

Period:	<u>Mammoth</u> 1951-1974	<u>Rock Creek Meadows</u> 1961-1985
JAN	3.58	6.35
FEB	2.13	5.59
MAR	2.72	8.13
APR	3.28	5.59
MAY	4.78	10.41
JUN	5.56	9.40
JUL	2.95	4.32
AUG	3.66	4.06
SEP	3.20	7.87
OCT	2.49	7.62
NOV	2.85	6.10
<u>DEC</u>	<u>3.12</u>	<u>6.86</u>
Yearly	40.31	82.30

Climatic Effects

The effects of climatic-induced processes on the petrified trees include erosion and deposition of surficial materials by runoff and freeze-thaw. These processes result in the exposure of the petrified tree outcrops through the removal of overlying rock and soil. Subsequent deterioration and disintegration of those exposed outcrops is then possible. The various additional effects of climate on erosion include aridity on south-facing slopes resulting in

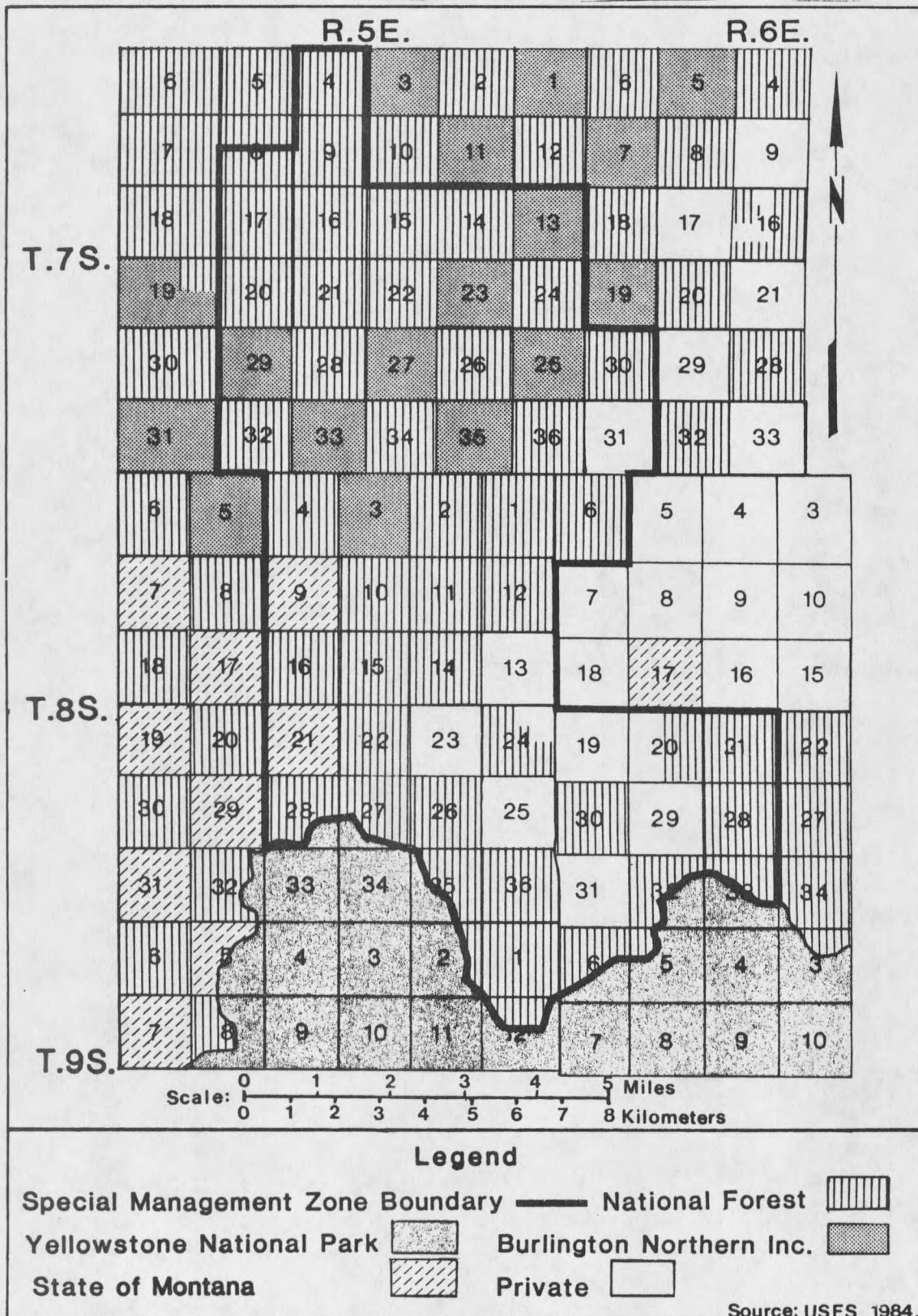
sparse vegetative cover, increased snowmelt runoff, high raindrop impact, and storm shower runoff inducing the downslope movement of soil and rock fragments, cryoturbation processes (active on slopes with little snow accumulation), and bioturbation (burrowing by small mammals under the winter snow cover). These erosion processes impact the petrified wood by both exposing the outcrops and covering the exposed outcrops with fine soil particles. The combination of climate and geology creates a high potential for mass wasting in this area which also impacts the petrified wood resource.

Land Ownership

The study area located within Township 8 South, Range 5 East includes all of the various types of land ownership found in the Special Management Zone (Figure 4). The historical record of how these ownership patterns were developed is important for understanding the problems associated with the management of the petrified wood resource today.

Lands in Township 8 South, Range 5 East (T.8 S., R.5 E.) were acquired by the National Forest system by Presidential Proclamation of 1906. Northern Pacific Railroad was granted half of these lands (18 sections), in a checkerboard pattern, for construction of rail lines under

Figure 4. Special Management Zone Land Ownership Map.



Source: USFS 1984.

a congressional land grant issued in 1864 (Federal Transportation Coordinator 1938).

In 1919 two lots of Section 24 totaling 50 hectares (116 acres) were acquired by a private couple under the Homestead Act of 1862 (U.S. Forest Service 1983). The property had changed ownership several times by 1947 when it was purchased by William Ward. Mr. Ward also purchased sections 13 and 23 from the Northern Pacific Railroad in 1950 and section 25 in 1954 (Security Title 1988). From that time these three sections and the two lots of section 24 have passed in ownership as one parcel. Mr. Ward sold them to B Bar Ranch in 1959. The B Bar Ranch has also changed ownership several times, being owned by various local ranches and holding companies. This property was acquired in 1984 by an out-of-state owner and is presently operated as a working cattle ranch (Gallatin County 1988).

The Federal Government extended the boundaries of Yellowstone National Park northward in 1929, enclosing some lands owned by the Northern Pacific Railroad. The Northern Pacific sold nine full sections and part of one section to the State of Montana in 1945 (Gallatin County 1988). These include sections 7, 9, 17, 19, 21, 29, and 31 in Township 8 South, Range 5 East. This land is now known as the Gallatin Wildlife Management Area and is managed by the State of Montana Department of Fish, Wildlife, and Parks.

Congress has given the U. S. Forest Service authority

to consolidate its holdings by exchanging public for private lands when the exchange furthered the Forest Service's objectives and was in the public interest (Stuart 1976). In the study area the private party was the Burlington Northern, Inc. (BN) (formerly Northern Pacific Railroad) who wanted to consolidate its land holdings for better management, group its holdings in the West Fork of the Gallatin River to develop tree farms, and have better access to its sawmill in Belgrade (Malone 1973).

The first exchange occurred in 1967 without public objection. The U. S. Forest Service and Park Service received 3,866 hectares (9,552 acres) within and adjacent to Yellowstone Park in exchange for 1,638 hectares (4,047 acres) in the West Fork drainage (Navratil and Lassey 1972). This exchange consolidated the federal government ownership within Yellowstone Park boundaries including parts of sections 33 and 35 within Township 8 South, Range 5 East.

The next two exchanges, which were completed in 1972, concerned lands in the West Fork owned by BN that were part of the development plan of the Big Sky Resort. The U. S. Forest Service acquired 8,691 hectares (21,477 acres) in these exchanges in the Tom Miner Basin, the Sawtooth portion of the Gallatin Range, and the Hyalite Creek watershed south of Bozeman including sections 1, 11, and 15 in Township 8 South, Range 5 East (Stuart 1976). An

important aspect of the 1972 exchanges was the provision that allowed BN to sever and retain ownership of the mineral rights and rights to the petrified wood of the lands traded to the Forest Service.

The completion of the two land exchanges in 1972 resulted in the current land ownership pattern (Figure 3). In 1988 Burlington Northern transferred ownership of its land holdings in this area to its subsidiaries. Plum Creek Timber Company received the surface land holdings and Meridian Minerals became owner of the severed mineral and petrified wood rights [these holdings will continue to be referred to as owned by Burlington Northern (BN) in this study]. Two more land exchanges have currently been negotiated between the U.S. Forest Service and BN, but are awaiting Congressional and Presidential approval. These exchanges would consolidate National Forest lands in the SMZ and remove BN ownership in this area except for the mineral rights and petrified wood reservations on previously exchanged Sections. One feature of the proposed exchange is to empower the U.S. Forest Service to trade these types of reservations to completely consolidate the National Forest holdings. The historical development in the Gallatin Petrified Forest land ownership into the present checkerboard pattern by the withdrawal of public lands into the National Forest system and the land grants to the Northern Pacific Railroad (now BN), with subsequent

purchase of blocks of land by the State of Montana and private individuals, has created a difficult situation for consistent and coordinated management efforts needed to preserve the petrified forest.

Land Use

Early uses of the study area, which have continued to the present include timber cutting, grazing, and recreation. The effects include clearcut timbered areas in the study area in the Sunlight Creek and Trail Creek drainages (all on National Forest land). Cattle and sheep grazing became an important landuse in the 1890's in the Gallatin Canyon and on the Yellowstone River side of the Gallatin Range, using the mountain meadows as summer range. Grazing is still allowed on the eastern side of the central divide on U.S. Forest Service land within the study area.

Recreation has also been a long term use. The Buffalo Horn Ranch (now the 320 Ranch), adjacent to the SMZ, started operating as a dude ranch in 1904 in the Gallatin Canyon (Bates 1985).

The Gallatin National Forest lands (10,514 hectares) within the SMZ is administered by three Ranger Districts, Bozeman (26% of the area), Livingston (27%) and Gardiner (47%). The Gallatin Forest Plan (USFS 1988) for the Gallatin National Forest divides the landscape into different Management Areas that have a multiple use prescription. The plan consists of goals, management

practices, standards, and guidelines for those Management Areas. The SMZ has six different Management Areas within its boundaries. Township 8 South, Range 5 East has three Management Areas within its boundaries and portions are administered by the three different Ranger Districts. This division of administrative control and the multiple use planning targets the petrified forest for a variety of activities, making resource protection plans fragmentary and perhaps secondary. Within the study area, west of the central Gallatin divide, the area is managed mostly for grizzly bear and big game habitat, with trails and a few primitive roads. No motorized use is allowed here except snowmobiling after December 1st. Grazing is prohibited. East of the divide the lands are managed for grizzly bear habitat, dispersed recreation, and grazing with motorized use by two and three wheeled vehicles allowed. Portions of sections 1, 6, 12, 18, 24, and 26 are managed for grizzly bear habitat and regulated timber harvest. An improved campground, Tom Miner Campground, is maintained by the U.S. Forest Service at the end of Tom Miner Road and the beginning of Trail Creek Trail (Figure 2).

The Montana State Department of Fish, Wildlife, and Parks manages those lands owned by the state (518 hectares) within the SMZ for wildlife habitat, primarily for elk and grizzly bear. The private land owners develop their own land use directions. The B Bar Ranch and other private

individuals use their lands (2,153 hectares) within the SMZ primarily for cattle grazing. The Burlington Northern lands (2,072 hectares) have had little use with the company waiting for approval of the proposed land trade. If the proposed trade fails to be approved, the company is prepared to begin timber harvesting on its lands (Duke 1988).

METHODS

The procedures described below were used to map the spatial distribution of the petrified forest, to evaluate changes in the forest over time, and to provide management recommendations. First, the results of the previous resource and photographic inventories were closely analyzed to select specimens for further study. Second, a field check was made of those specimens, involving rephotographing, assessing change, and hypothesizing the cause of that change. Third, a qualitative and quantitative assessment of change from the photographic record, compiled from all the surveys conducted, was analyzed in conjunction with various factors, relating to the specimen's location and size. Fourth, based on the conclusions of these investigations, recommendations for change in the management policy for the Gallatin Petrified Forest were developed.

Photographic Survey

All available U. S. Forest Service photographic slides from previous petrified resource surveys were studied in order to evaluate the usefulness of each individual outcrop for this study. Selection of individual specimens for this study was based on: 1) the clarity of the photo and a

record of the specimen being photographed over time, and 2) the suitability of the outcrop for this study as a solid, identifiable portion of a petrified tree that was embedded in the ground or rock so it could not be easily moved and collected. Photos not used were those of pieces of petrified wood that were lying on the ground surface.

A total of 201 specimens were selected for study. Photographic prints were made from the slides for use in the field to aid identification, to assist in an assessment of change, and to locate the proper site and angle from which to rephotograph the specimen. Often more than one photograph per specimen was utilized. These offered different camera perspectives and multiple appearance changes during the period of record.

Field Survey

The field survey of the selected specimens was conducted during the summer and fall of 1988. The specimens were located by using 1:24,000 USFS color and black and white aerial photographs from 1962 and 1971. The locations of the specimen sites had been previously marked by pinholes and labeled on the backs of the photos. Once a specimen was located in the field, a description of the site and area was made. Recorded information included section number, direction and distance from the trail and/or prominent landforms, slope, aspect, nearby

vegetation, elevation, dimensions of the specimen, physical description of the specimen, and an assessment of change as noted from previous photographs. When possible, cause of the change was suggested. Human-related change was determined by evidence of breakage, chipping, hammering, excavation, or other types of disturbance such as the removal of parts of the specimen from the area versus the natural activities of erosion, weathering, and deposition. A copy of the field survey data collection form used is found in Appendix B.

Each specimen was photographed with a standard clipboard positioned with a field sheet attached illustrating the specimen number and current year. Care was taken to replicate the scale and angle of the previous photographs and to capture any relevant features (ie. indications of change) of the specimen. A 35mm single-reflex camera with Ektachrome (ASA 200) and Kodacolor (ASA 64) film were used.

Remote Sensing Analysis

Using results from the field survey, ground training sites for remote sensing analysis were established. These sites were used as sample sites to test the possibility of locating additional petrified forest areas based on photographic appearance. The reflectance signatures of the sites of the petrified forest outcrops were determined

utilizing the Montana State University's Department of Earth Sciences' Eye Com II Image Processor. These reflectance signatures were identified on 1981 aerial photographs (scale 1:24,000) and 1984 color infrared photographs (scale 1:45,000) of the study area.

An area north of the study area was then analyzed according to the identified reflectance signatures from the ground training sites, and partitioned into categories of low, moderate, and best likelihood of containing petrified wood outcrops. An area north of Ramshorn Peak, which contained all categories, was field checked for petrified wood outcrops to determine accuracy of this analysis.

Change Assessment

Qualitative change analyses of the specimens over time was initially done by field observation along with careful visual examination of the photographic record. To add to this subjective and rather general assessment, photographs that were replicative, that had a clipboard (22.6 cm by 29.8 cm or 38.6 cm) for scale, and that showed a clear outline of the specimen were selected for a quantitative analysis of change. The outer edge of each specimen on the photographs was outlined on the Eye Comm II Image Processor screen image and a two-dimensional area measurement was taken of the surface inside the outlined border. Only a two-dimensional area was possible to measure with this

method, ignoring the volumetric aspect of change. Therefore, the amount of change has been potentially misrepresented. The scale of the various photographs resulted in an additional potential source of measurable error, especially when the placement of the clipboards was at an angle to the camera, or the various photographs were taken with the clipboards at differing distances from the specimen. Additionally, distinguishing the boundaries of the specimens was often difficult due to intervening vegetation, poor placement of the clipboard, or similarity in appearance of the specimen's edge and background material. Where significant measurement error was found in comparison to the field observations of change, those specimens were eliminated from further analysis.

Data Analysis

The numerical value of change (loss and gain) of area for each specimen (in total amount, amount per year, total percentage, and percentage per year) was then compared statistically with elevation, elevation change from trailhead, elevation change per 1000 meters from trailhead, distance from trailhead, distance from trail, initial areal measurement (area measured on earliest photograph) of specimen (size), and slope of site. These locational factors were chosen to determine if an explanation for change could be developed. It was suspected that the amount of change to a specimen, potentially caused by human

activity, might be related to the distance someone would have to hike to access the specimen, how much elevation change in the hike was needed, or perhaps how large or small the specimen was.

The measured area change values were transformed into amount and percentage per year of record to eliminate the statistical bias created by the varied time periods of recorded change for different outcrops. This variation occurred because the initial surveys of the area were conducted in different years.

All specimens were impacted by natural processes of change. The human-impacted specimens had the additive effect of human activity as determined by evidence of breakage, chipping, hammering, excavation, or other types of disturbance such as removal of parts of the specimen from the area versus the natural activities of erosion, weathering, and deposition.

The comparison of change and locational factors was accomplished by using scatter plot graphs. Simple and multiple regressions tested the statistical significance of these comparisons, using the difference from zero of the best fit line's slope. Tests were conducted first using all the data and second with the two largest specimens in the human-impacted sample removed. These were removed because they had extremely large area measurement values, skewing the data of the entire sample (this was especially

true for the data set showing the amount loss per year). Single factor regression tests were conducted, first, to determine the independent factors (location factors) that had statistically significant associations with the dependent factors (measured change) in all the sample sets. Secondly, for the human-impacted sample sets, the significant individual associations and those that were close to being significant were analyzed by multiple regression tests to determine the relationship among these factors.

RESULTS AND DISCUSSION

Field Survey

Of the 201 outcrops initially selected for this study 175 were located in the field, rephotographed, and assessed for change. This number represents an 87 percent success rate in locating the original specimens. This success compares favorably to the 30 to 65 percent success rates from previous surveys. This difference is, in part, attributed to the procedure of making prints of the earlier photographic slides and taking them into the field to aid in identification. The information given for location of the sites of the specimens by a pinhole on an aerial photograph was useful, but varied depending on the care taken in originally positioning the hole. It was not satisfactory as the sole indicator of location and, therefore, there is a need for an explanatory text and a map of the location of the specimens for future studies.

Field Observations

The first observation made when entering the Gallatin Petrified Forest was that there was a lack of available information for the visitor concerning the location of the petrified trees and the permit collection policy and

regulations. A sign located at the turnoff to Tom Miner Basin from U.S. Highway 191, which parallels the Yellowstone River between Livingston and Gardiner, announces the Gallatin Petrified Forest. The sign states that collection permits are required, and then directs inquiries to the Forest Service Ranger District. The Forest Service Ranger District offices are located in Bozeman (approximately 96 km north of the turnoff), Livingston (approximately 43 km north of the turnoff), Gardiner (approximately 30 km south of the turnoff), and West Yellowstone (approximately 117 km south through Yellowstone National Park). These are the only locations where collection permits are available. These offices are open during regular business hours Monday through Friday and are not open weekends. Records of numbers of sales of collection permits by the U.S. Forest Service since 1981 indicate the apparent ineffectiveness of this situation (Table 3).

Table 3. Yearly Sales of Petrified Wood Collection Permits

<u>Year:</u>	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>	<u>1986</u>	<u>1987</u>	<u>1988</u>	<u>1989</u>
Permits Sold	74	68	44	51	74	33	53	49	58
Average =	58/year.								

Source: McBride 1989.

Visitor numbers, in contrast, are estimated to be approximately 500,000 recreation visitor days a year in the Gardiner Ranger district portion of the SMZ alone (McBride 1990). The yearly variation in sales of collection permits

may be attributed to the variation in the length of the summer season when the area is free of snow.

At the trailhead to Trail Creek Trail, located at Tom Miner Campground, which is approximately 19 km on a rough, unpaved road from the highway turnoff, a sign announces that one is entering the Gallatin Petrified Forest Special Management Zone. The sign also informs the reader that a petrified wood collection permit is required on National Forest lands and asks the visitor to see the regulations. These regulations (Appendix A) concern allowed collection activities and define which petrified wood outcrops are protected. These regulations are provided to the purchasers of a collection permit. Nowhere on the site are these regulations available or explained to the visitor.

Shards and weathered fragments of petrified wood observed and available to collectors were abundant within the petrified forest. Agatized petrified wood appeared to be restricted to higher elevations and was apparent in the fragments of many disturbed specimens. Crystals mentioned by earlier observers (including Van Dyne, the first volunteer to inventory a portion of the SMZ), were found in only two of the specimens observed during this field survey. These were quartz crystals. No amethyst crystals were observed.

Areas where signs of human disturbance were most common were the ridges north of and adjacent to Tom Miner

Campground (on private land), areas along Sunlight Creek Trail (also private land), and along the trail to Ramshorn Peak summit (National Forest land) (Figures 2 and 3). Interestingly, on all of the private lands within the SMZ, collection of petrified wood is theoretically prohibited. Although prohibition of collection had little or no impact on collection activities in these areas, it is important to realize the lack of information as to collection regulations and areas closed to collection, and the difficulty in knowing one's location on the ground all contribute to making this distinction less important.

One subjective impression formed during the field study was that most of the collection and disturbance of the petrified wood outcrops appears to have occurred where the outcrop was visible and easily accessible from the established trails and pathways. These trails may be more frequently traveled by the casual visitor who may not be aware of the collection regulations. Also the impacts to outcrops that are less accessible from the trails may have been made by collectors who were searching for outcrops containing agate or crystals. It is suspected that these collectors may have been aware of the regulations concerning collection, but were unwilling to abide by them. Knowledge of the location of the property boundaries while hiking in the SMZ again, is difficult and also requires careful study of a topographic map. The small scale of the

map furnished with the U.S. Forest Service collection permit provides little guidance to the collector as to his or her location and therefore the permissibility of collection.

Visual Assessment of Change

Slightly more than half of the 175 located specimens were observed in the field to have had undergone some loss of mass from natural and/or human causes (Table 4 and Appendix C). These losses range from minor breakage and fragmentation of the outcrop to significant removal of parts of the outcrop, physical disintegration, and complete excavation.

Table 4. Visual Change Assessment Results

	<u>Number of Specimens</u>	<u>Percent Field Checked</u>
Total Specimens	175	100
<u>Specimens with No Change:</u>	58	33
<u>Losses of Mass:</u>		
Total # with loss	90	51
Natural causes	48	27
Human causes	42	24
<u>Increases of Mass:</u>	27	15

Evidence of more extensive collection activity prior to 1973 was observed in the form of numerous excavated pits with vegetation recovery noted and numerous fragmented outcrops mentioned in the field notes and photographed by

the volunteers who conducted the previous resource surveys. Although collection activities by visitors has continued to result in losses to the petrified wood resource since implementation the SMZ collection regulations in 1973, it was apparent that the degree of impact was reduced by these regulations.

Forty-two of the field checked specimens exhibited human-induced change (24 percent of the total specimens field checked). Seventy-five specimens (43 percent of the total number of specimens field checked) were determined to have undergone change from natural causes and 58 specimens (33 percent of the specimens field checked) showed no signs of change. The surprisingly large number of specimens that showed no signs of loss and those that showed increases of mass by natural causes supports the hypothesis that new petrified wood outcrops and material are continually being exposed by natural weathering and erosional processes. The lower number of human-caused losses compared to natural losses, suggests that removal by erosional and weathering processes accounts for a significant reduction of the petrified outcrops.

The U.S. Forest Service SMZ regulation number 5 (1973) (Appendix A) states: "Petrified trees occurring in natural growth position are to be protected from all collection activities and visitor disturbance". This description of position is vague enough to be open to number of

interpretations. Fifteen (36% of the total) specimens that were observed to have been impacted by human activity, should have been protected by this regulation. The remaining 37 specimens (64% of total) were available for collection under this interpretation (Appendix C).

Photographic Analysis

Sixty-seven specimens had a photographic record that permitted accurate laboratory measurements of change over time (Table 5 and Appendix E). Although more than two-thirds of these specimens showed a loss in area over time, 67% were impacted by natural causes while 33% were by human-activity. Because natural processes are quite active at these sites, human-induced changes are assessed as additive and, therefore, quite damaging. The 16 measured specimens that increased in area due to erosion of the surrounding ground surface (27% of total specimens measured) provides the impression that the resource is gaining in visibility. It must be remembered, however, that this resource is limited in depth below the ground, and continued erosion and exposure will eventually cease once the specimen is entirely uncovered.

Table 5. Specimens with Measured Areal Change by both Natural- and Human-induced Processes (negative values are area loss and positive values are area gain).

	Number of Specimens	Percent of Type of Change	Range of Measured Change Total Percent	Change Amount/Yr (sq. mm)
<u>Naturally-changed</u>				
<u>Specimens</u>	45	100	-94 to +68	-207,457 to +18,175
Losses	29	64	-94 to -2	-207,145 to -255
Increases	16	36	+1 to +68	+159 to +18,175
<u>Human-changed</u>				
<u>Specimens</u>	22	100	-100 to -1	-61,857 to -3,000
Losses	22	100	-100 to -1	-61,857 to -3,000
Increases	0	0	-	-

Statistical Comparisons

The range of values, means, and standard deviations of the measured change of the specimens and the explanatory factors (Table 6) illustrates the wide variety of types of specimens, the numerous different sites within which the specimens were found, and the inconsistent amounts of material change. The measured amount of change (total amount of change and amount of change per year) in square millimeters demonstrate the larger range of change caused by natural processes than by human activities both in terms of gains and losses. The difference in means between natural- and human-impacted samples for both percentage of

Table 6. Summary of Location and Measured Change Data

<u>Factor (units)</u>	<u>Range</u>	<u>Mean</u>	<u>Standard Deviation</u>
Measured Change:			
<u>Total Amount (sq. mm)</u>			
Natural Change	-1,452,200 to 151,200	-75,198.8	260,319.2
Human-Impacted	-433,000 to -3,000	-92,735.6	117,004.8
<u>Amount per Year (sq. mm/yr)</u>			
Natural Change	-207,457 to 18,175	-9,758.9	35,800.5
Human-Impacted	-61,857 to -231	-12,065.1	16,165.0
<u>Total Percentage (Percent)</u>			
Natural Change	-94 to 68	-8.7	30.9
Human-Impacted	-100 to -1	-30.1	26.6
<u>Percentage per Year (%/yr)</u>			
Natural Change	-13.4 to 5.2	-1.0	3.3
Human-Impacted	-12.5 to -0.1	-3.5	3.0
Location Data:			
<u>Elevation (meters)</u>			
Natural Change	2,320 to 3,053	2,660.8	227.2
Human-Impacted	2,347 to 3,047	2,660.3	245.2
<u>Elevation Change from Trailhead (meters)</u>			
Natural Change	52 to 889	448.5	225.8
Human-Impacted	82 to 883	445.8	277.0
<u>Elevation Change per 1000 meters from Trailhead (meters)</u>			
Natural Change	41.6 to 433.3	137.0	85.4
Human-Impacted	49.8 to 428.6	133.5	95.5
<u>Distance from Trailhead (meters)</u>			
Natural Change	442 to 10,272	4,837.2	3,490.5
Human-Impacted	335 to 10,271	5,460.2	4,203.1
<u>Distance from Main Trail (meters)</u>			
Natural Change	1 to 1,908	688.7	629.0
Human-Impacted	8 to 1,939	491.5	522.0
<u>Slope of Site (degrees)</u>			
Natural Change	5 to 46	29.3	7.6
Human-Impacted	0 to 41	28.4	9.6
<u>Initial Areal Measurement of Specimen (sq. mm)</u>			
Natural Change	16,200 to 3,570,000	545,835.6	872,975.7
Human-Impacted	34,260 to 2,980,000	406,889.8	626,830.7

measured change (total percentage and percent per year) is not significant due to the fact that all human-impacted specimens experienced losses in area compared to a sizeable portion of the natural changed sample which showed increases in area. This accounts for the difference in the means.

The locational factors based on elevation (elevation, elevation change from the trailhead, and elevation change per 1000 m of trail) and the slope factor appear to not induce large differences in whether the changes are caused by natural- or human-related activities. The change in specimens as related to the distance from a main trail appears to support the hypothesis that this might influence human activity. In this case, the mean and standard deviation for the human-impacted sample was considerably smaller than those for the natural-changed sample. The distance from the trailhead, however, shows an opposite effect (the greater the distance, the more the change). A possible explanation is that this reflects the activities of the collector searching for agatized specimens at greater distances up the trails.

The statistical regression analyses, using the measured change (total amount, total percentage, and percentage change per year) as the dependent variable and the exploratory factors as the independent variables, were not statistically significant. The amount of change per year

tested against all of the elevation-based factors and the distance from a main trail also is statistically insignificant. The tests that showed statistically significant results were those of the amount of change per year plotted against three individual factors: initial areal measurement of the specimen (to be referred to as initial area), slope of the site of the specimen, and the distance of the specimen from the trailhead. These significant factors and their statistical relationship to amount of measured change per year will be discussed in the following text (Table 7). The graphs for the remaining factors are presented in Appendix F and the statistical test results for all the locational factors versus amount of change per year are presented in Appendix G.

The graphs of amount of change per year plotted against area (Figures 5 and 6) for the natural changed sample (to be referred to as the natural sample) and the human-impacted sample with two outliers removed (to be referred to as the human sample) have best fit lines that display distinct slopes. These slopes indicate a possible association between the amount of change occurring annually and the original or initial area (size) of the specimens measured. The statistically significant T-test (p-value of 0.0009) suggests that the changes caused by natural processes are strongly associated with the size of the specimen. The graph of the human sample displays a steeper

Table 7. Regression Analysis Results Summary

Dependent Variable: Amount of Change per Year

Single-factor regressions:

<u>Sample</u> Independent Variable(s):	T-test values	F-test values	(p-value)
<u>Natural Change</u>			
Initial Area:	-3.564	12.701	(0.0009)
Slope:	-2.510	6.301	(0.0159)
Distance from Trailhead:	0.058	0.003	(0.9542)
<u>Human-Impacted (All)</u>			
Initial Area:	-7.343	53.915	(0.0001)
Slope:	-1.466	2.148	(0.1583)
Distance from Trailhead:	0.987	0.973	(0.3356)
<u>Human-Impacted (Outliers removed)</u>			
Initial Area:	-2.891	8.359	(0.0097)
Slope:	-0.681	0.464	(0.5044)
Distance from Trailhead:	2.012	4.049	(0.0594)
Multiple-factor regressions:			
<u>Human-Impacted (All)</u>			
Distance from Trailhead:	0.469		(0.6444)
Initial Area:	-6.981		(0.0001)
Combination		26.016	(0.0001)
<u>Human-Impacted (Outliers removed)</u>			
Distance from Trailhead:	2.102		(0.0507)
Initial Area:	-2.934		(0.0093)
Combination		7.183	(0.0055)

slope for the best fit line than the natural sample, but had a lower statistically significant correlation (p-value = 0.0097). These graphs, and the change in p-values, suggest that human activity is causing losses to the relatively smaller specimens (area under 100,000 sq. mm) and is more severe than changes by natural processes. The hypothesis that the larger specimens sustain greater losses

Figure 5. Graph of Amount of Change per Year versus Initial Areal Measurement for the Natural Sample (p-value = 0.0009).

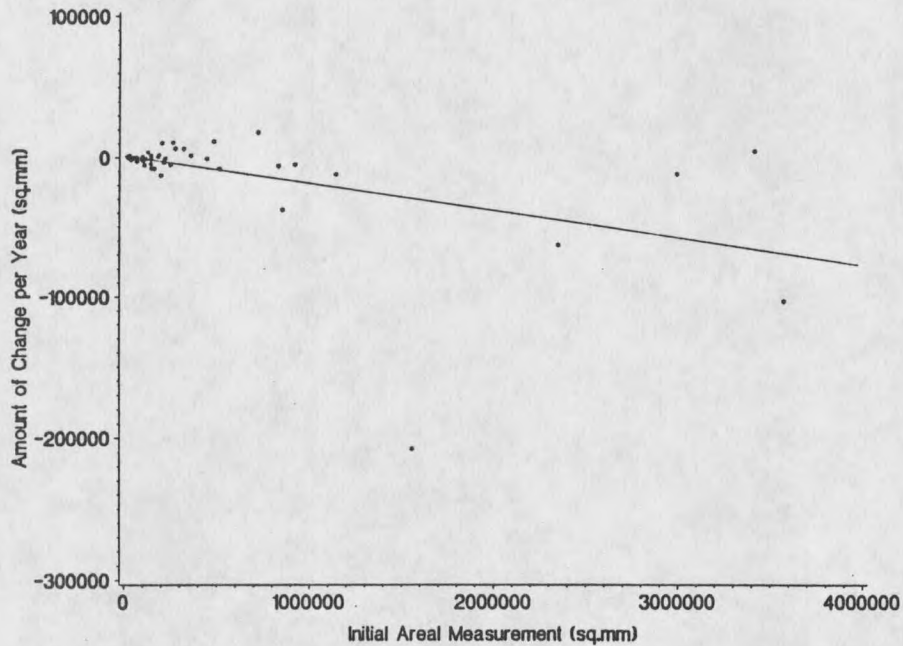
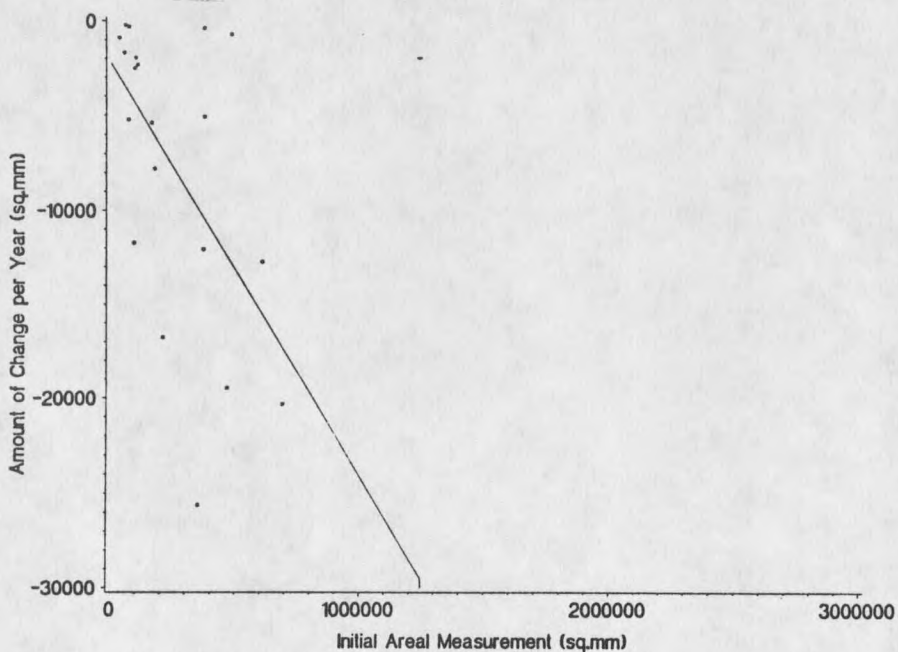


Figure 6. Graph of Amount of Change per Year versus Initial Areal Measurement for the Human Sample (p-value = 0.0097).



in area (size) is valid, but the confidence level is reduced where the impact occurs from human activity.

The graphs of amount of change per year plotted against slope (Figures 7 and 8) show two different distribution patterns for the natural and human samples, but they have similar line slopes. The regression analyses showed a statistically significant association for these factors for the natural sample (p-value = 0.0159), but not for the human-impacted sample (p-values = 0.5044). This result suggests that the association between slope and amount of natural change per year is obscured by human-induced change. In other words, a greater or steeper slope for the site of the outcrop appears to accelerate weathering, erosion, and specimen loss, but people seem to stay predominantly on the more gentle slopes rather than travel to collect from outcrops on the more difficult (steeper) slopes.

The plotted graphs of amount of change per year against distance from trailhead (Figures 9 and 10) present two very dissimilar patterns. The natural sample results indicate a random relationship for change and distance from the trailhead, confirmed by the regression T-test results (p-value = 0.9542). In contrast, the human sample graph has a distribution pattern with two distinct groupings. One group of specimens is apparently impacted at a relatively short distance from the trailhead and the second group is

Figure 7. Graph of Amount of Change per Year versus Slope for the Natural Sample (p-value = 0.0159).

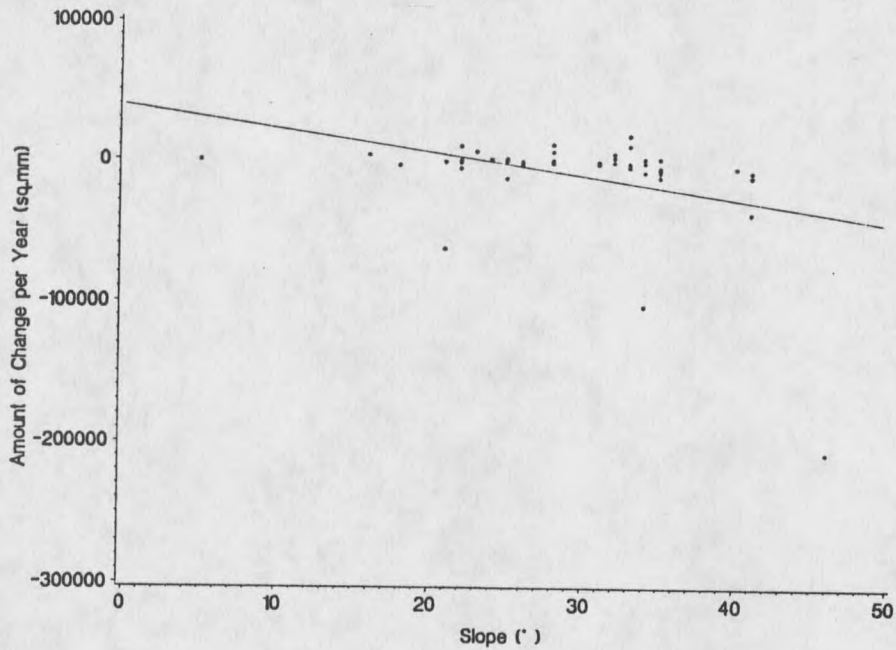


Figure 8. Graph of Amount of Change per Year versus Slope for the Human Sample (p-value = 0.5044).

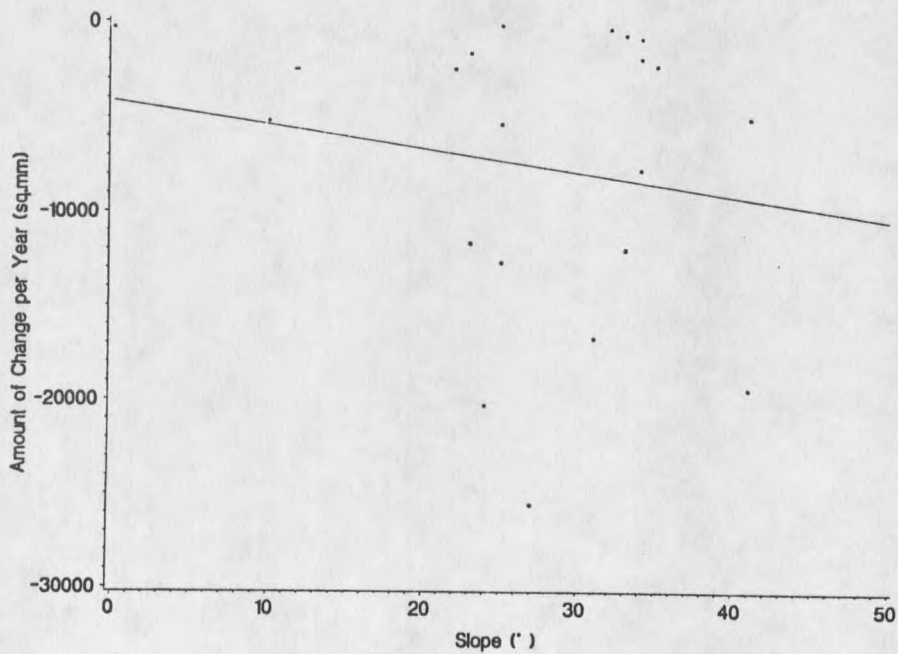


Figure 9. Graph of Amount of Change per Year versus Distance from Trailhead for the Natural Sample (p-value = 0.9542).

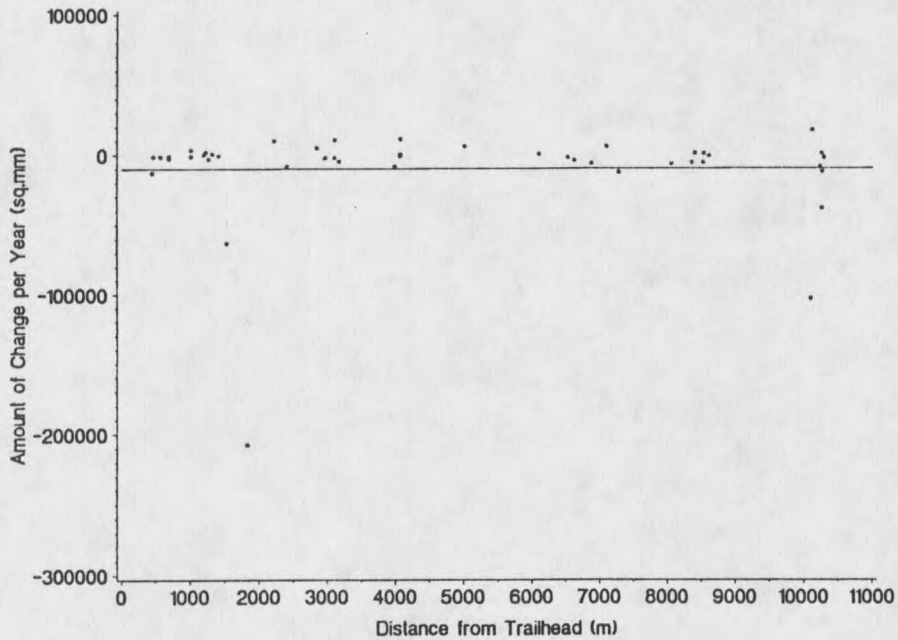
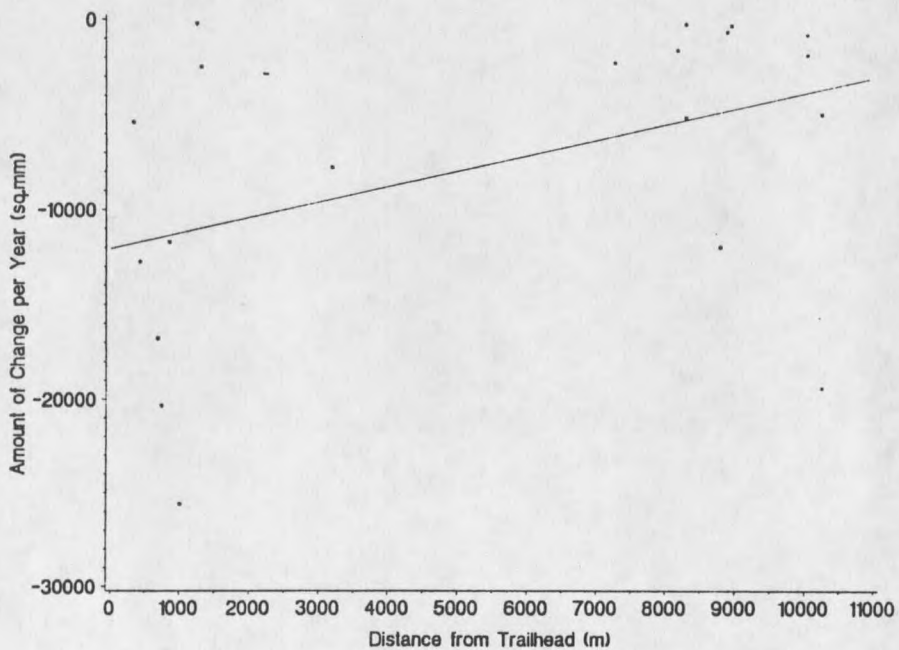


Figure 10. Graph of Amount of Change per Year versus Distance from Trailhead for the Human Sample (p-value = 0.0594).



less impacted, but the impact occurs at a distance from the trailhead. I believe that this pattern is indicative of two distinct types of collecting activities. The group of outcrops that is more impacted at a short distance from the trailhead is probably the result of the collection of petrified wood "souvenirs" by the casual visitor. This type of visitor may be uninformed about the collection permit regulations and is attracted to the petrified wood that very closely resembles "normal" wood (i.e. has rings, bark, etc.). This type of disturbance of the petrified wood outcrops appears to have occurred where the outcrop was visible and easily accessible from the established trails and pathways. These trails may be more frequently traveled by the casual visitor. The less impacted group of outcrops, which are located much farther from the trailhead, endures changes from collectors who search out agatized wood or crystal. These specimens are generally found at higher elevations and in less frequented areas. It is suspected that these collectors were aware of the regulations concerning collection, but were unwilling to abide by them. The regression analysis T-test for these two variables (amount of change per year and distance from trailhead) in the human sample has a p-value of 0.0594. Although this value is short of the 95% confidence level for statistical significance, it is close enough to justify more testing to evaluate the association of these

variables. When the relationship of amount of change per year with area and distance from trailhead was analyzed in a multiple regression, the T-tests results indicated that both independent variables are statistically significant (area, p-value = 0.0093; distance from trailhead, p-value = 0.0507). The combination of these two variables evaluated in the F-test is also statistically significant (p value = 0.0055). The two factors have opposing impacts, but both contribute to the explanation of the amount of change per year in the measured areas of the specimens. So, the hypothesis that human collection activities are influenced by the location of petrified outcrops has been shown to be valid in the case of the distance the specimen is located from a trailhead. Also, the association between loss of mass and size of the outcrop continues to be valid for the human-impacted outcrops, with the human impacts additive to the natural processes of change.

Remote Sensing Analysis

To determine the reflectance values that were representative of the areas where petrified wood outcrops were located, all of the reflectance values of the total study area were first determined. The ranges of reflectance values that best represented the areas of known petrified forest outcrops on a 0 to 255 reflectance scale (0=black,

255=white) were at the higher (i.e. lighter) end of the range (Table 8).

Table 8. Likelihood of the Presence of Petrified Wood and Reflectance Values on Aerial Photographs. (based on a range of 0 - 255).

<u>Likelihood</u>	<u>Reflectance Value Range</u>
Low	149 - 169
Moderate	170 - 189
Best	190 - 255

This reflectance pattern was found on both the normal color aerial photographs (1:24,000 scale) and the high altitude color infrared aerial photographs (1:45,000 scale). Through the ground truthing survey, I did find numerous outcrops in areas categorized as high likelihood areas and no outcrops in the low or moderate likelihood areas. It was concluded, however, that the effort expended in using the remotely sensed reflectance values to locate petrified tree outcrops was more than what was gained. I believe that an analysis of the types of terrain where outcrops would most likely be found would be less time consuming and at least as profitable.

CONCLUSIONS

The results of this study have demonstrated that there are continuing decreases in the petrified wood resource in the Special Management Zone of the Gallatin National Forest due to both natural- and human-related activities. The human-related losses are less than the natural losses, but they are additive. The larger the outcrop and the greater the slope of the site, the more losses by natural processes. These natural processes also, however, are continually exposing, through soil erosion, more of the petrified wood resource. The influence of slope of the location of the petrified outcrops, shown by naturally-caused change, is partially obscured by human impacts, whereas the association of size and loss is valid for both natural- and human-impacted specimens. Human-related activities cause more loss to those outcrops which are close to the main trailheads and that loss decreases to some extent as one moves away from the trailhead. Agatized petrified wood and crystal formations seem, however, to induce more exploratory losses by collectors. It is suggested that there are two types of collectors. One type of collector searches for agatized petrified wood or crystals found at locations farther from trailheads, but causes less amount of loss than the casual collector (the second type of

collector) who may be uninformed concerning the collection regulation and collects out of curiosity or collects petrified wood that resembles live wood for its "souvenir" value. The damages to outcrops by human-related activities may be, in part, a result of lack of knowledge on part of the public of the restrictions concerning collection and the vagueness of the definition of which outcrops are prohibited from collection activities. It is probable that a total prohibition of collection of petrified wood in the SMZ of the Gallatin National Forest would not be totally enforceable due to the remote location and the size of the management zone. Unenforced prohibition of collection may not provide any additional protection unless the would-be collector abides by the prohibition because the reasons are well explained. Yellowstone National Park, which has such a collection prohibition, has reported difficulties in preventing damage to petrified wood outcrops by visitors. The Park areas located along the boundary of this study area showed similar specimen impacts as found on the National Forest lands. Areas within the SMZ where collection is prohibited (private lands) have experienced the same degree of impact as areas open to collection, but knowledge of the rules was not available to the collector.

Recommendations and Rationales

Based on the results of this study, the following management recommendations are made to the Gallatin

National Forest:

1. The regulations restricting collection of petrified wood have been somewhat successful in reducing the amount of exploitation of this resource, at least in comparison to what occurred prior to 1973. Compliance to the regulations of collection is not complete. Destruction to some specimens by human activity is continuing to occur, but many of the outcrops experiencing impacts are open to collection under present regulations. It is recommended that the "hobbyist" collection policy by permit be continued only if certain changes are made. This recommendation is based on the assumption that complete prohibition of collection is not enforceable. More official presence of Forest Service personnel may encourage compliance with collection regulations or a collection prohibition, but total enforcement is not possible in the entire SMZ.

2. The present definition of a "protected outcrop" (one not to be collected or disturbed) as one being in a "natural growth position" is too vague and undefinable to the collector. The definition should be broadened and clarified to include the many unique specimens and large logs found in the petrified forest. Certain stumps that were not upright (in a "natural growth position"), but which contained quantities of agate or crystal growth, were found to be the major target of collectors. For example, a

branch-end embedded in a cliff with the center containing crystals could be, according to the current definitions, interpreted as available for collection. One such type of specimen found during this study had survived intact, but there were signs of many other excavated branch ends nearby. Earlier writers frequently mentioned petrified outcrops with numerous crystals, but now outcrops of that type are extremely rare. This is a substantial loss of a valuable resource. The reduction in the variety of the petrified resource is perhaps the greatest impact of visitor collection on the Gallatin Petrified Forest, both now and before implementation of the collection restrictions. There are also many outcrops that are diagonally standing or horizontally embedded in the ground that are unique or outstanding specimens of the petrified forest (i.e. they are very large, uniquely colored or shaped, filled with agate or crystals, etc.). Perhaps these should be preserved for viewing by the public. Therefore, a new definition of a protected outcrop should be considered. For example, all petrified wood outcrops that are embedded in or attached in any way to a rock outcrop, cliff, or the ground surface are protected and all collection activities and visitor disturbances of these outcrops are prohibited.

3. At the present, collection regulations are only available when a permit is purchased at a USFS District

office. It is believed that a significant portion of human impact on petrified specimens is from the uninformed visitor. The only notice concerning the SMZ is at the Tom Miner Campground trailhead. This notifies the visitor that he or she is entering the Gallatin Petrified Forest and that collection is allowed with a permit. To improve this situation the regulations should be posted at all trailheads entering the SMZ, including those trails from Yellowstone National Park (YNP). This is especially important in the southern part of the SMZ where there is considerable visitor traffic originating from Tom Miner Campground, on Sunlight Creek Trail, on trails out of the Buffalo Horn drainage, from YNP, and from access points to the north (i.e. Ramshorn Peak area) (Figures 2 and 3).

4. Collection permits need to be more available. They are presently sold only at USFS District offices on weekdays during business hours. Most visits to Tom Miner campground, for example, are on weekends. Permit sales have averaged 56 per year since 1981 (see Table 3) however there are probably many more people than that who collect petrified wood in this area. To increase the permit availability (and therefore dispersal of information concerning the resource values, the allowable collections, etc.) it is recommended that the U.S. Forest Service sell permits on site at Tom Miner Campground, possibly via a self-service type of arrangement.

5. Because members of the public who drive into Tom Miner Campground to view the petrified forest have no idea where to go to find specimens or, perhaps, are incapable of a strenuous hike to search for them, the USFS has expressed interest in developing an interpretative trail. Based on the field examinations made in this study, a recommended site for an interpretative trail (Figure 2) begins where Trail Creek Trail enters section 14 (Township 8 South, Range 5 East). The proposed trail would climb a low ridge to the northwest. The trail could be switchbacked to allow for easy access. The trail would then lead west, below the volcanic conglomerate cliffs to the westernmost cliff of the ridge. This cliff face has numerous easily viewed petrified wood outcrops embedded in its surface. Following the base of this outcrop, the proposed trail would come to an open slope (where the trail would have to be cut into the slope and switchbacked), and then would continue to the ridgetop. Trail erosion may be a problem (but there are presently visitor trails located in the area undergoing erosion so a properly constructed trail would not be an added stress). At this point, a very large petrified tree outcrop would be visible across this slope, and more outcrops embedded in the cliff above would be visible. The proposed trail would lead onto the ridgetop where three more petrified tree stumps are found approximately 20 meters to the south. The trail then could follow the

fairly flat and gentle grade of the ridgetop to the north where numerous upright stumps and other unique specimens are grouped. The possibilities for continuing the trail around the ridge to the west above Dry Creek and back down to Trail Creek Trail for a completed loop are many and depend on the desired extent of an interpretative trail. Also, some areas of the proposed extension are steep and trail construction and maintenance may be difficult. If this trail is constructed and people are encouraged to visit this area, it is critical that the area traversed by the trail be closed to collection activities to preserve the specimens for viewing. Enforcement of this prohibition would require patrolling by a Forest Service official, but could be encouraged by educational signs explaining the reasons for the prohibition and the scientific value of the petrified resource located in this area. Public education provided by this proposed interpretative trail could encourage compliance with collection restrictions in the entire SMZ if the value of the resource is adequately explained and stressed.

6. It is recommended that a USFS employee be based in the Tom Miner Campground. Tasks for this employee could include selling permits, enforcement of collection regulations, providing informational talks and tours of the interpretative trail, and, possibly, campground hosting. It is believed that at a minimum, the occasional presence

of a USFS employee would help compliance with collection regulations.

7. Because of the checkerboard pattern of land ownership it is difficult to know one's precise location on the ground in relation to section lines and ownership. This information is needed because collection activities are prohibited on private lands within the SMZ (Burlington Northern subsidiaries and B Bar Ranch) and on those National Forest lands where BN holds reservations on the petrified resource. To aid the collector the USFS could do two things: 1) post signs designating private lands along main trails and campground areas and/or, 2) provide a larger, more detailed map of allowable collection sites with the collection permit.

8. Also, the expansion of resource inventories (already begun) would increase our knowledge of the extent and abundance of the petrified forest for future management considerations. Continued monitoring of the surveyed outcrops is recommended to provide a continuous record concerning collection patterns and possible changes in those patterns that may occur due to policy changes. Also future volunteers should be provided with photographic prints of specimens that are to be resurveyed and rephotographed. This will aid in locating the specimens and in obtaining accurate, replicate photographs.

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APPENDICES

APPENDIX A

SPECIAL MANAGEMENT ZONE REGULATIONS

Special Management Zone Regulations

1. "Hobbyist" type collection of petrified wood is allowed on designated National Forest lands within the Gallatin Petrified Forest Special Management Zone provided that individual is covered by a valid collection permit.

"Hobbyist" type collection is defined as: collection of petrified wood for personal use and not involving the sale of any naturally occurring or processed specimens.

2. "Commercial" type collection is prohibited on National Forest lands within the SMZ.

"Commercial" type collection is defined as: collection of petrified wood involving the sale of naturally occurring or processed specimens.

3. Collection under an approved permit is authorized for the calender year in which the permit is approved. The cost of a permit is \$5.00 per person or family and \$10.00 for a group permit.

4. Collection weight limits: For the collection of petrified wood on National Forest lands covered by the mandatory permit, there is a daily limit for any one person of 25 pounds plus one sample but not to exceed 100 pounds in any one calender year.

5. Protection of Standing Petrified Trees: Petrified trees occurring in natural growth position are to be

protected from all collection activities and visitor disturbance.

6. Excavation or Digging Regulations: Exploratory excavation is not permitted. Specimens must be at least partially exposed by natural erosional processes. The use of explosives, jackhammers, drills, bulldozers, or other mechanical excavating devices will not be permitted on National Forest lands covered by the collection permit. Naturally weathered fragments may be collected at the base of standing specimens providing that the fragments are in no way attached to the protected specimens. When collection activities cause disturbance of soil, vegetation, or litter, the collector shall return the site to such a state so as to prevent erosion due to his activities.

7. Vehicle Use Regulations: Four or more wheeled or crawler type vehicles are restricted from National Forest lands within the SMZ except for the access road to the Tom Miner Campground and approximately 1.8 miles of the Sunlight Creek road system, which provide parking areas and end-of-road for visitors. Oversnow vehicles are permitted within the SMZ, but such use will be confined to times when snowcover is deep enough to protect the resources. Two and three wheeled trail vehicles are permitted on designated roads and trails. Pack and saddle stock are permitted. The use of

helicopters for collection or transportation of petrified wood is prohibited.

8. Burlington Northern does not permit collection of petrified wood on their private lands or on those National Forest lands where they hold reservations on the petrified resource.

9. Collection of petrified wood on state or private lands is by permission only and subject to their regulations and collection requirements.

From: Gallatin Petrified Forest Special Management Zone permit and regulations (USFS 1973).

APPENDIX B

SAMPLE FORM

FIELD DATA FOR PETRIFIED FOREST STUDY

Date _____ Site ID number _____
 Picture # _____ Roll # _____
 Location: Section _____

Aspect _____ Slope _____

Proximity to trail: _____

Vegetation Type _____

Description of specimen:

Stump	_____	Upright	_____	Elevation	_____	SIZE:	
Log	_____	Horizontal	_____			Height	_____
Log End	_____	Diagonal	_____			Width	_____
Branch	_____					Length	_____
						Diameter	_____

Physical Description:

Description of Change:

Observer _____

APPENDIX C

FIELD SURVEY DATA TABLES

Table 9. Petrified Forest Sites Field Checked

SITE #	LOCATED	CHANGE	NATURAL/ HUMAN	MEASURED CHANGE	PERCENT OF CHANGE
1-4	X	NO	-	NO	-
1-9	X	NO	-	NO	-
1-10	X	NO	-	NO	-
1-11	X	YES	NAT	YES	+14
1-13	NO	-	-	-	-
1-14	X	YES	NAT	YES	+14
1-15	X	YES	HUM	YES	-15
1-16	X	YES	NAT	YES	-10
1-18	NO	-	-	-	-
1-23	X	NO	-	NO	-
1-25	NO	-	-	-	-
1-26	NO	-	-	-	-
1-27	X	NO	-	NO	-
1-28	X	YES	NAT	YES	-85
1-31A	NO	-	-	-	-
1-32	NO	-	-	-	-
1-34	NO	-	-	-	-
1-35A	X	YES	NAT	YES	+4
1-35B	X	NO	-	-	-
1-35C	X	NO	-	-	-
1-35D	X	NO	-	-	-
1-36	X	NO	-	-	-
1-37A	X	YES	NAT	NO	-
1-37B	X	YES	NAT	YES	+48
1-38	X	YES	HUM	YES	-21
1-39A	X	YES	NAT	YES	-39
1-39B	X	YES	NAT	NO	-
1-41	X	NO	-	NO	-
1-42	X	YES	NAT	YES	-19
1-43	X	YES	HUM	YES	-36
1-44	X	NO	-	NO	-
1-45A	X	YES	HUM	NO	-
1-45B	X	YES	HUM	YES	-100
1-46A	X	YES	NAT	NO	-
1-46B	X	YES	NAT	YES	+6
1-46C	X	YES	NAT	YES	-20
1-46D	X	YES	HUM	NO	-
1-46E	X	YES	HUM	YES	-64
1-47	X	YES	NAT	YES	-50
1-48A	X	YES	HUM	NO	-
1-48B	X	YES	HUM	NO	-
A1-48(1)	X	YES	HUM	NO	-
A1-48(2)	X	YES	HUM	NO	-
1-49A	X	YES	HUM	YES	-24
1-49B	X	YES	NAT	NO	-
1-50	X	NO	-	NO	-
1-51	X	YES	HUM	YES	-44
1-53	X	YES	HUM	NO	-

Table 9 (CONTINUED).

SITE #	LOCATED	CHANGE	NATURAL/ HUMAN	MEASURED CHANGE	PERCENT OF CHANGE
1-55	X	YES	HUM	NO	-
1-56A	X	YES	HUM	NO	-
1-56B	X	YES	NAT	NO	-
1-57	X	YES	NAT	YES	-40
1-58	X	YES	NAT	YES	-2
1-59	X	YES	NAT	NO	-
1-60	X	NO	-	NO	-
1-61A	X	YES	NAT	YES	+31
1-61B	X	YES	NAT	YES	+3
1-62	X	YES	NAT	YES	+19
1-63	X	YES	HUM	NO	-
1-64	X	YES	NAT	YES	+10
1-65	X	YES	NAT	YES	-51
1-67A	X	YES	HUM	NO	-
1-67B	X	YES	NAT	YES	-42
1-68	X	YES	HUM	NO	-
1-69	X	YES	NAT	YES	-23
1-70A	X	YES	NAT	YES	+26
1-70B	X	NO	-	NO	-
1-70C	X	NO	-	NO	-
1-71	X	YES	NAT	NO	-
1-72A	X	YES	NAT	YES	-14
1-72B	X	NO	-	NO	-
1-72C	X	YES	HUM	YES	-28
1-73A	NO	-	-	-	-
1-73B	X	YES	NAT	NO	-
1-74B	X	NO	-	NO	-
1-75	X	NO	-	NO	-
1-76A	X	YES	NAT	YES	-10
1-76B	X	NO	-	NO	-
1-77	NO	-	-	-	-
1-78A	X	NO	-	NO	-
1-78B	X	YES	HUM	NO	-
1-78C	X	YES	HUM	NO	-
1-79	X	YES	NAT	NO	-
1-80	X	NO	-	NO	-
1-81A	X	YES	NAT	NO	-
1-81B	X	YES	HUM	YES	-40
1-82A	X	YES	HUM	YES	-6
1-82B	X	YES	HUM	YES	-96
1-82C	X	NO	-	NO	-
1-83	X	YES	NAT	NO	-
1-84	X	YES	NAT	YES	-28
1-85	X	NO	-	NO	-
1-86A	X	YES	NAT	YES	+68
1-86B	X	YES	NAT	NO	-
1-87A	X	YES	NAT	NO	-
1-87B	X	NO	-	NO	-
1-87C	X	YES	NAT	NO	-

Table 9 (CONTINUED).

SITE #	LOCATED	CHANGE	NATURAL/ HUMAN	MEASURED CHANGE	PERCENT OF CHANGE
1-88	X	NO	-	NO	-
1-89A	X	YES	NAT	YES	-7
1-89B	X	YES	NAT	YES	+13
1-90	X	NO	-	NO	-
1-91B	X	YES	NAT	NO	-
1-91C	X	YES	NAT	YES	-5
1-91D	X	NO	-	NO	-
1-92	X	YES	NAT	NO	-
A-1	X	NO	-	NO	-
M-1	X	YES	NAT	NO	-
M-2	NO	-	-	-	-
2-1	X	YES	NAT	NO	-
2-2	X	YES	NAT	NO	-
2-3	X	NO	-	NO	-
2-4	X	YES	NAT	YES	-42
2-5A	X	YES	HUM	YES	-5
2-5C	X	YES	NAT	YES	-3
2-5D	X	NO	-	NO	-
2-5E	X	YES	HUM	YES	-33
2-6A	X	YES	NAT	NO	-
2-6B	X	YES	NAT	YES	+3
2-6C	X	NO	-	NO	-
2-6D	X	YES	NAT	YES	-35
2-7A	X	NO	-	NO	-
2-7B	X	YES	HUM	YES	-29
2-7C	X	NO	-	NO	-
2-7D	X	YES	NAT	YES	-13
2-8A	X	YES	NAT	NO	-
2-8B	X	YES	HUM	YES	-26
2-8D	X	YES	HUM	NO	-
2-11A	X	YES	HUM	NO	-
2-11B	X	YES	HUM	YES	-1
2-12	X	YES	HUM	YES	-1
2-13	X	YES	HUM	NO	-
2-14	X	YES	NAT	NO	-
2-15	X	NO	-	NO	-
2-16	X	NO	-	NO	-
2-17C	NO	-	-	-	-
2-18	NO	-	-	-	-
2-19A	NO	-	-	-	-
2-19B	NO	-	-	-	-
2-24A	X	YES	HUM	YES	-21
2-24B	X	YES	HUM	YES	-16
2-24C	X	YES	HUM	NO	-
2-24D	X	YES	NAT	NO	-
2-25	X	NO	-	NO	-
2-26A	X	YES	NAT	YES	-23
2-26B	X	YES	NAT	YES	+20

Table 9 (CONTINUED).

SITE #	LOCATED	CHANGE	NATURAL/ HUMAN	MEASURED CHANGE	PERCENT OF CHANGE
2-D-1	NO	-	-	-	-
2-D-4	X	YES	NAT	YES	-96
2-D-8	X	NO	-	NO	-
2-D-12	X	YES	NAT	YES	-6
2-D-13	X	YES	HUM	YES	-15
2-D-14	NO	-	-	-	-
2-D-15	X	YES	NAT	NO	-
2-D-16	X	YES	HUM	NO	-
2-D-17	NO	-	-	-	-
2-D-18	X	NO	-	NO	-
2-D-21	X	YES	NAT	NO	-
2-D-22A	X	NO	-	NO	-
2-D-22B	X	NO	-	NO	-
2-D-23	X	NO	-	NO	-
2-D-25	X	NO	-	NO	-
2-D-26	X	YES	HUM	YES	-15
2-D-27	NO	-	-	-	-
2-D-28	NO	-	-	-	-
2-D-29	NO	-	-	-	-
2-D-30	X	YES	HUM	YES	-31
2-D-31	X	YES	NAT	YES	-22
2-D-32	X	YES	NAT	YES	-7
2-D-33	X	YES	NAT	YES	+29
2-D-34	X	NO	-	NO	-
2-D-35	X	NO	-	NO	-
2-D-36	X	NO	-	NO	-
2-D-37	X	YES	NAT	NO	-
2-D-38	X	YES	NAT	NO	-
2-D-39	X	NO	-	NO	-
2-D-40	X	YES	NAT	YES	-7
2-D-41	X	YES	NAT	YES	+1
2-D-42	NO	-	-	-	-
2-D-43	NO	-	-	-	-
2-D-44	X	YES	NAT	NO	-
2-D-45	NO	-	-	-	-
2-D-46	X	YES	NAT	NO	-
2-D-47	X	NO	-	NO	-
2-D-48	X	NO	-	NO	-
2-D-49	X	NO	-	NO	-
2-D-51	X	NO	-	NO	-
2-D-52A	X	YES	HUM	NO	-
2-D-52B	X	NO	-	NO	-
2-D-53	X	NO	-	NO	-
2-D-54	X	NO	-	NO	-
2-D-55	X	NO	-	NO	-
2-D-56	X	NO	-	NO	-
2-D-57	X	YES	NAT	YES	+36
2-D-58A	X	NO	-	NO	-
2-D-58B	X	YES	NAT	YES	-11

Table 9 (CONTINUED).

SITE #	LOCATED	CHANGE	NATURAL/ HUMAN	MEASURED CHANGE	PERCENT OF CHANGE
2-D-59	X	YES	NAT	NO	-
2-D-60	X	NO	-	NO	-
2-D-61	X	YES	NAT	YES	-19
2-U-8	X	NO	-	NO	-
2-U-9	X	NO	-	NO	-
2-U-11	NO	-	-	-	-
2-U-15	NO	-	-	-	-
TOTALS:			HUM=42		
<u>201</u>	<u>175</u>	<u>YES=117</u>	<u>NAT=75</u>	<u>YES=66</u>	
100%	<u>87%</u>	67%		38%	
	100%	<u>NO=58</u>	H=24%	<u>NO=109</u>	
		33%	N=43%	62%	

Table 10. Human-Impacted Specimens Protected by USFS Petrified Wood Collection Regulations

<u>Site #</u>	<u>Protected</u>	<u>Site #</u>	<u>Protected</u>
1-15	yes	2-5A	no
1-38	yes	2-5E	no
1-43	no	2-7B	no
1-45A	no	2-8B	no
1-45B	no	2-8D	no
1-46D	no	2-11A	yes (part)
1-46E	no	2-11B	no
1-48A	no	2-12	yes
1-48B	no	2-13	yes
A1-48(1)	no	2-24A	yes
A1-48(2)	no	2-24B	no
1-49A	no	2-24C	no
1-51	no		
1-53	no	2-D-13	no
1-55	no	2-D-16	yes
1-56A	no	2-D-26	yes
1-63	no	2-D-30	yes
1-67A	no	2-D-52A	yes
1-68	yes		
1-72A	yes	Total	= 42
1-78B	no	Protected	= 15 (36%)
1-78C	no	Not Protected	= 27 (64%)
1-81B	yes		
1-82A	yes		
1-82B	yes		

APPENDIX D

MEASURED DATA FACTORS ABBREVIATIONS

Table 11. Measured Change and Locational Factors
Abbreviations

Measured Change	
Total Amount of Change	AMOUNT
Amount of Change per Year	AMTYR
Total Percentage of Change	PERCENTAGE
Percentage of Change per Year	PCTYR

Locational Factors	
Initial Areal Measurement	AREA
Slope of Specimen Site	SLOPE
Distance from Main Trail	DISTTR
Distance from Trailhead	DISTTH
Elevation of Specimen Site	ELEV
Elevation Change from Trailhead	ELEVCH1
Elevation Change per 1000 m of Trail	ELEVCH2

APPENDIX E

MEASURED SPECIMENS DATA TABLE

Table 12. Natural Change Sample Measurement Data.

S I T E	A M O U N T	P E R C E N T	A M T Y R	P C E N T Y R V	E L E V E N H I	D I S T A N C E	E L E V E N H I	D I S T A N C E	S A L I N I T Y		
1-11	17900	14	3580	2.8	2409	265	1006	263.4	1006	126300	16
1-14	27400	14	2108	1.1	2451	307	1219	251.9	1219	187700	32
1-16	-23050	-10	-2881	-1.3	2451	307	1260	243.7	1260	68070	26
1-28	-166730	-85	-12825	-6.5	2320	176	442	398.2	442	197100	25
1-35A	2060	4	159	0.3	2387	243	1189	204.4	1189	54100	22
1-37B	7830	48	602	3.7	2368	224	1310	171.0	1310	16200	24
1-39A	-7770	-38	-598	-2.9	2419	275	1403	196.0	732	20470	26
1-42	-8050	-19	-1006	-2.4	2454	177	1005	176.1	152	443900	21
1-46B	-7200	-6	-900	-0.8	2414	137	685	200.0	244	113500	31
1-46C	-20240	-20	-2530	-2.5	2411	134	685	207.8	244	100900	31
1-47	-18190	-50	-1399	-3.9	2329	52	560	92.9	91	36350	28
1-57	-64590	-40	-8074	-5.0	2702	425	3974	107.0	12	161700	35
1-58	-4300	-2	-538	-0.3	2713	436	4053	107.6	45	221600	25
1-61A	151200	31	11630	2.4	2710	433	4061	106.6	8	482000	28
1-61B	4650	3	581	0.4	2711	434	4063	106.8	10	180950	28
1-62	52600	19	6575	2.4	2710	433	5002	86.6	12	275300	28
1-64	9460	10	728	0.8	2828	551	6087	90.5	4	97440	24
1-65	-19380	-51	-1491	-3.9	2868	591	6511	90.8	1	38030	22
1-67B	-45016	-42	-5627	-5.3	2870	589	6861	85.9	1	108200	22
1-69	-48300	-23	-3715	-1.8	2871	590	6607	89.3	6	212200	18
1-70A	82400	26	6339	2.0	2899	588	7085	83.0	12	320300	23
1-72A	-156900	-14	-12069	-1.1	2745	468	7265	64.4	192	1139000	35
1-76A	-79700	-10	-6131	-0.8	2743	466	8042	58.0	969	829900	35
1-84	-68620	-28	-5279	-2.2	2669	392	8344	47.0	1271	248200	40
1-86A	19030	68	1464	5.2	2673	396	8387	47.2	1314	27860	25
1-89A	-66000	-7	-5077	-0.5	2685	408	8507	48.0	1434	918900	35
1-89B	18300	13	1408	1.0	2685	408	8518	47.9	1445	143500	35
1-91C	-3320	-5	-255	-0.4	2635	358	8595	41.6	1522	66790	5
2-4	-62000	-42	-7750	-5.3	3053	889	10211	87.1	305	146300	41
2-5C	-92200	-3	-11525	-0.4	3048	884	10243	86.3	337	2987500	41
2-6B	11400	3	1425	0.4	3050	886	10234	86.6	328	358600	34
2-6D	-302000	-35	-37750	-4.4	3048	884	10244	86.3	338	852100	41
2-7D	-12430	-13	-1554	-1.6	3048	884	10272	86.1	366	93640	34
2-26A	-823600	-23	-102950	-2.9	2999	835	10089	82.8	183	3570000	34
2-26B	145400	20	18175	2.5	3005	841	10098	83.3	192	719200	33
2-D-4	-1452200	-94	-207457	-13.4	2347	183	1829	100.1	579	1556000	46
2-D-12	-8600	-6	-1229	-0.9	2362	198	457	433.3	457	144700	32
2-D-31	-31790	-22	-4541	-3.1	2673	509	3158	161.2	1908	141800	33
2-D-32	-13700	-7	-1957	-1.0	2664	500	3097	161.5	1847	212200	33
2-D-33	75700	29	10814	4.1	2664	500	3097	161.5	1847	262600	33
2-D-40	-13700	-7	-1957	-1.0	2562	498	2957	168.4	1707	212200	28
2-D-41	36000	1	5143	0.1	2537	373	2835	131.6	1585	3408000	32
2-D-57	72200	36	10314	5.1	2505	341	2210	154.3	960	203300	22
2-D-58B	-56900	-11	-8129	-1.6	2530	366	2393	153.0	1143	512000	34
2-D-61	-441000	-19	-63000	-2.7	2513	349	1524	229.0	762	2346000	21

Table 13. Human-Impacted Sample Measurement Data
 (* = outlier).

S I T E	A M O U N T	P E R C E N T	A M T Y R	P C E N T Y R V	E L E V E N H 1	D I S T R I B U T I O N 1	E L E V E N H 2	D I S T R I B U T I O N 2	S A L I N I T Y		
1-15	-3000	-5	-231	-0.4	2469	325	1250	260.0	1250	58360	25
1-38	-20010	-21	-2513	-2.6	2429	152	1311	116.9	640	95200	22
1-43	-127950	-36	-25590	-7.2	2429	152	1005	151.2	152	351800	27
1-45B	-93840	-100	-11730	-12.5	2420	143	853	167.6	152	93840	23
1-46E	-134140	-64	-16768	-8.0	2432	155	685	226.3	244	211100	31
1-49A	-162700	-24	-20338	-3.0	2444	167	739	226.0	270	690400	24
1-51	-70260	-44	-5405	-3.4	2359	82	335	244.8	274	164100	25
1-72C	-30426	-28	-2341	-2.2	2743	466	7265	64.1	192	107486	35
1-81B	-21850	-40	-1681	-3.1	2707	430	8170	52.6	1103	54110	23
1-82A	-4090	-6	-315	-0.5	2692	415	8292	50.1	1219	72920	0
1-82B	-67986	-96	-5230	-7.4	2690	413	8294	49.8	1221	71100	10
2-5A	-40700	-11	-5088	-1.4	3045	881	10241	86.0	335	376300	41
2-5E	-155800	-33	-19475	-4.1	3047	883	10243	86.2	337	467000	41
*2-7B	-402000	-29	-50250	-3.6	3044	880	10271	85.7	365	1004000	36
2-8B	-96600	-26	-12075	-3.3	2689	525	8793	59.7	15	373000	33
2-11B	-5800	-1	-725	-0.1	2734	570	8882	64.4	13	484000	33
2-12	-3200	-1	-400	-0.1	2743	579	8938	64.8	8	375900	32
2-24A	-7170	-21	-896	-2.6	2999	835	10028	83.3	69	34260	34
2-24B	-15704	-16	-1963	-2.0	2999	835	10029	83.3	70	100900	34
2-D-13	-89300	-15	-12757	-2.1	2347	183	427	428.6	427	608100	25
*2-D-26	-433000	-15	-61857	-2.1	2387	223	884	93.4	518	2980000	37
2-D-30	-54636	-31	-7805	-4.2	2678	514	3189	191.9	1939	177677	34

APPENDIX F
MEASUREMENT DATA GRAPHS

Figure 11. Graph of Amount of Change per Year versus Distance from Main Trail for the Natural Sample (p-value = 0.5523).

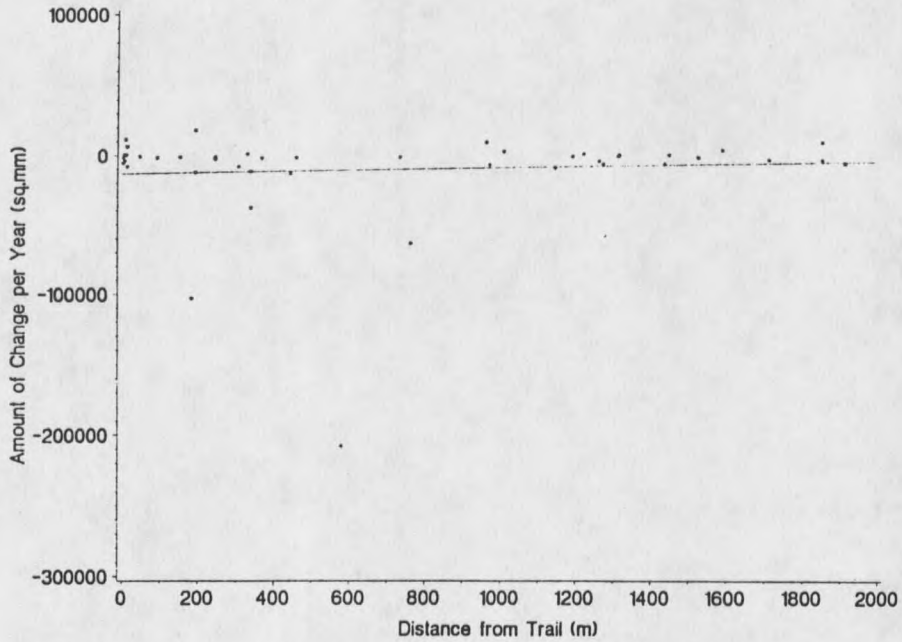


Figure 12. Graph of Amount of Change per Year versus Distance from Main Trail for the Human Sample (p-value = 0.3176).

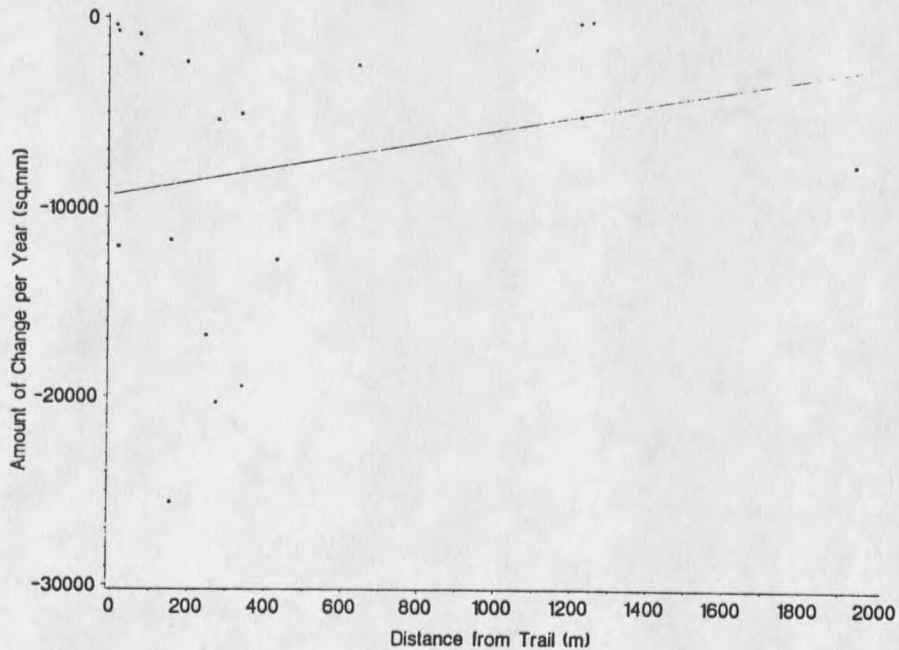


Figure 13. Graph of Amount of Change per Year versus Elevation of Specimen Site for the Natural Sample (p-value = 0.6295).

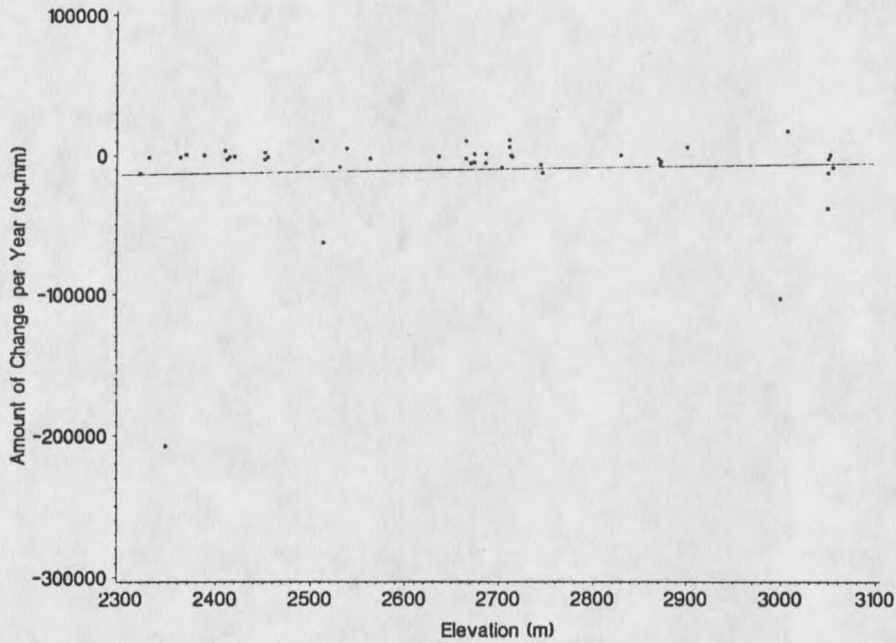


Figure 14. Graph of Amount of Change per Year versus Elevation of the Specimen Site for the Human Sample (p-value = 0.1785).

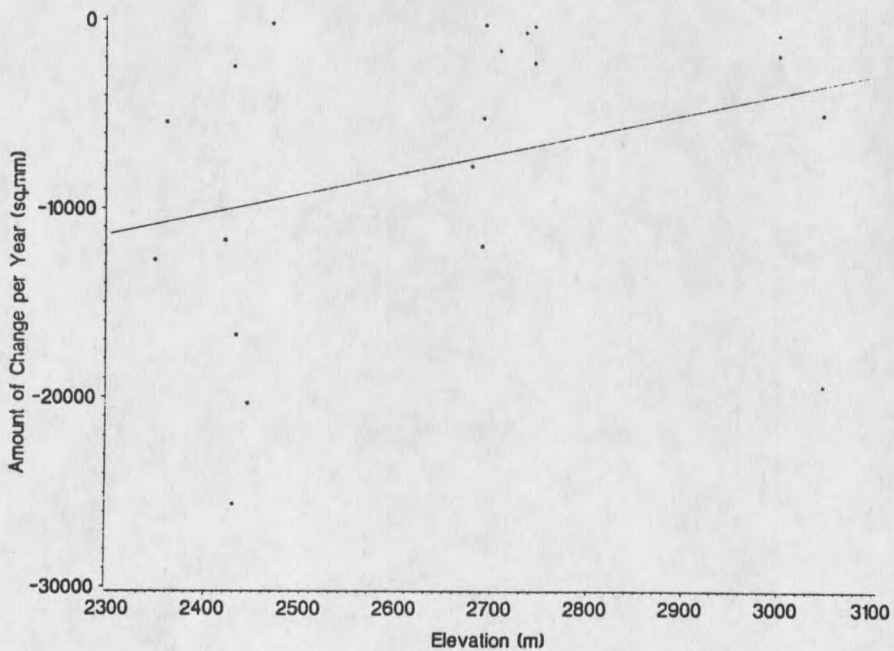


Figure 15. Graph of Amount of Change per Year versus Elevation Change from Trailhead for the Natural Sample (p-value = 0.8905).

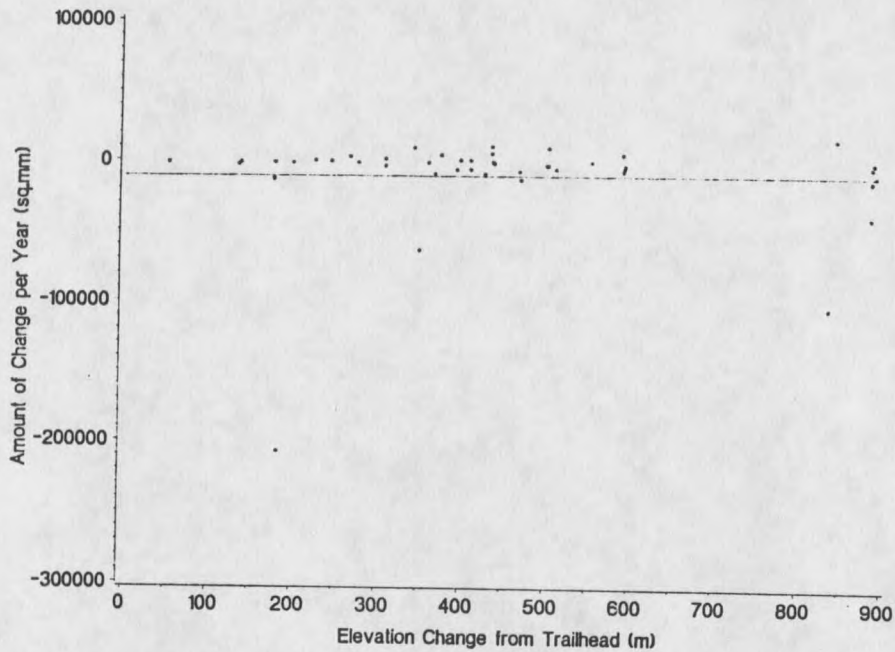


Figure 16. Graph of Amount of Change per Year versus Elevation Change from Trailhead for the Human Sample (p-value = 0.1692).

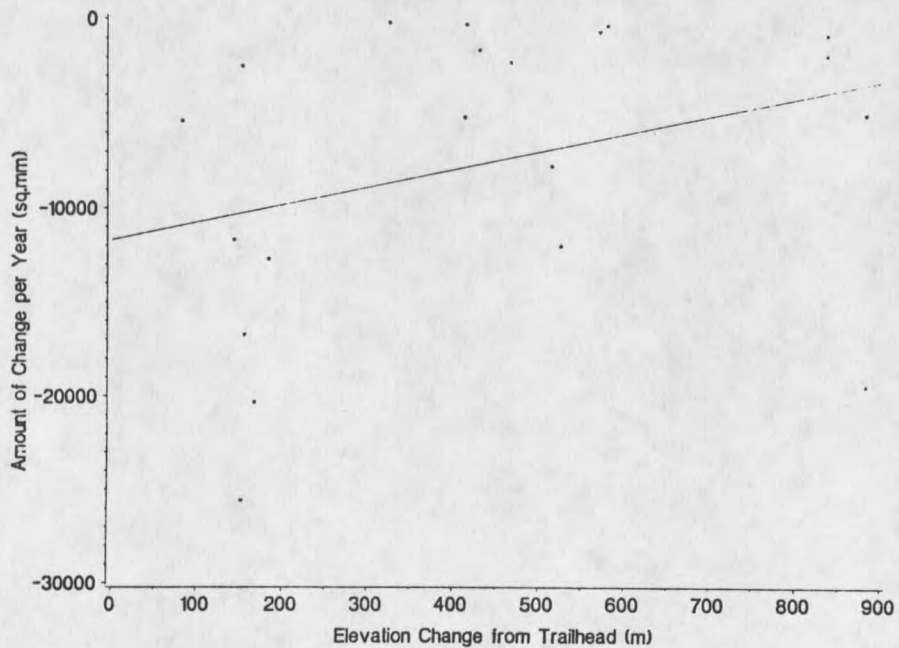


Figure 17. Graph of Amount of Change per Year versus Elevation Change per 1000 m of Trail for the Natural Sample (p-value = 0.7104).

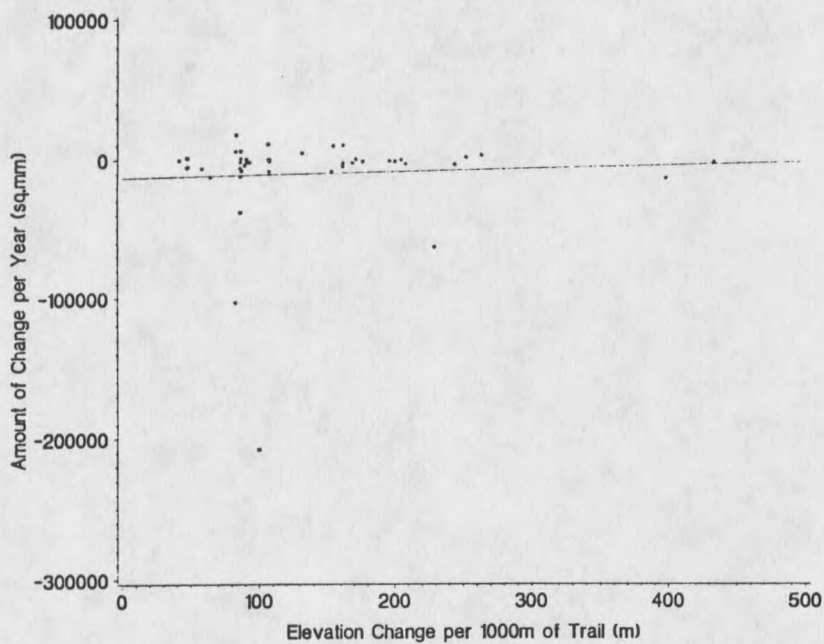
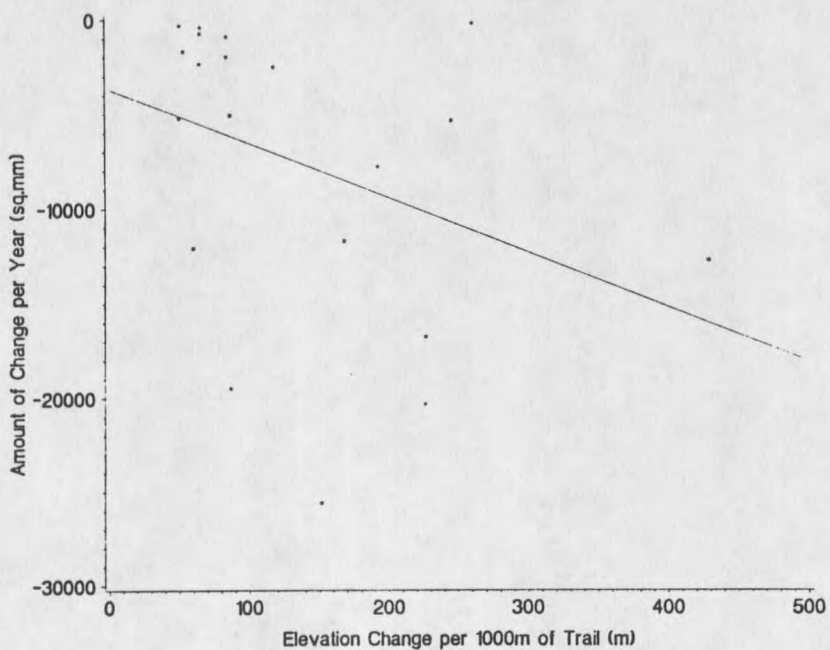


Figure 18. Graph of Amount of Change per Year versus Elevation Change per 1000 m of Trail for the Human Sample (p-value = 0.1132).



APPENDIX G

REGRESSION ANALYSIS TABLES

Table 14. Regression Analysis Results for Amount of Change per Year versus the Locational Factors for the Natural Sample.

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	12858724435	12858724435	12.701	0.0009
ERROR	43	43534913368	1012439846		
C TOTAL	44	56393637803			
ROOT MSE		31818.86	R-SQUARE	0.2280	
DEP MEAN		-9758.87	ADJ R-SQ	0.2101	
C.V.		-326.051			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	930.01551416	5611.98566	0.166	0.8692
AREA	1	-0.0195826	0.005494854	-3.564	0.0009

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	7207907242	7207907242	6.301	0.0159
ERROR	43	49185730561	1143854199		
C TOTAL	44	56393637803			
ROOT MSE		33820.91	R-SQUARE	0.1278	
DEP MEAN		-9758.87	ADJ R-SQ	0.1075	
C.V.		-346.566			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	39303.79479	20184.62951	1.947	0.0581
SLOPE	1	-1676.4	667.81871087	-2.510	0.0159

Table 14 (Continued).

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	4383021.44	4383021.44	0.003	0.9542
ERROR	43	56389254782	1311378018		
C TOTAL	44	56393637803			
ROOT MSE		36212.95	R-SQUARE	0.0001	
DEP MEAN		-9758.87	ADJ R-SQ	-0.0232	
C.V.		-371.077			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-10196.3	9294.04681	-1.097	0.2787
DISTTH	1	0.09042102	1.56403533	0.058	0.9542

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	466611490.29	466611490.29	0.359	0.5523
ERROR	43	55927026313	1300628519		
C TOTAL	44	56393637803			
ROOT MSE		36064.23	R-SQUARE	0.0083	
DEP MEAN		-9758.87	ADJ R-SQ	-0.0148	
C.V.		-369.553			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-13324.2	8020.90402	-1.661	0.1040
DISTTR	1	5.17697554	8.64320940	0.599	0.5523

Table 14 (Continued).

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	307915275.62	307915275.62	0.236	0.6295
ERROR	43	56085722528	1304319129		
C TOTAL	44	56393637803			
ROOT MSE		36115.36	R-SQUARE	0.0055	
DEP MEAN		-9758.87	ADJ R-SQ	-0.0177	
C.V.		-370.077			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-40746.7	64004.24910	-0.637	0.5277
ELEV	1	11.64584839	23.96886373	0.486	0.6295

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	25136793.09	25136793.09	0.019	0.8905
ERROR	43	56368501010	1310895372		
C TOTAL	44	56393637803			
ROOT MSE		36206.29	R-SQUARE	0.0004	
DEP MEAN		-9758.87	ADJ R-SQ	-0.0228	
C.V.		-371.009			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-11260.1	12110.60031	-0.930	0.3577
ELEVCH1	1	3.34720635	24.17194326	0.138	0.8905

Table 14 (Continued).

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	182630385.77	182630385.77	0.140	0.7104
ERROR	43	56211007417	1307232731		
C TOTAL	44	56393637803			
ROOT MSE		36155.67	R-SQUARE	0.0032	
DEP MEAN		-9758.87	ADJ R-SQ	-0.0199	
C.V.		-370.49			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-13027.9	10273.37213	-1.268	0.2116
ELEVCH2	1	23.85770416	63.82908038	0.374	0.7104

Table 15. Regression Analysis Results for Amount of Change per Year versus the Locational Factors for the Human Sample.

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	368832016.96	368832016.96	8.359	0.0097
ERROR	18	794276537.24	44126474.29		
C TOTAL	19	1163108554			
ROOT MSE		6642.776	R-SQUARE	0.3171	
DEP MEAN		-7666.3	ADJ R-SQ	0.2792	
C.V.		-86.649			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-2234.83	2394.94424	-0.933	0.3631
AREA	1	-0.0218678	0.0075638	-2.891	0.0097

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	29236961.36	29236961.36	0.464	0.5044
ERROR	18	1133871593	62992866.27		
C TOTAL	19	1163108554			
ROOT MSE		7936.805	R-SQUARE	0.0251	
DEP MEAN		-7666.3	ADJ R-SQ	-0.0290	
C.V.		-103.528			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-4153.44	5453.19391	-0.762	0.4561
SLOPE	1	-127.277	186.82334503	-0.681	0.5044

Table 15 (Continued).

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	213587539.65	213587539.65	4.049	0.0594
ERROR	18	949521014.55	52751167.47		
C TOTAL	19	1163108554			
ROOT MSE		7263	R-SQUARE	0.1836	
DEP MEAN		-7666.3	ADJ R-SQ	0.1383	
C.V.		-94.7393			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > T
INTERCEP	1	-12070.4	2725.41988	-4.429	0.0003
DISTTH	1	0.80831903	0.40170837	2.012	0.0594

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	64481912.18	64481912.18	1.056	0.3176
ERROR	18	1098626642	61034813.45		
C TOTAL	19	1163108554			
ROOT MSE		7812.478	R-SQUARE	0.0554	
DEP MEAN		-7666.3	ADJ R-SQ	0.0030	
C.V.		-101.907			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR HO: PARAMETER=0	PROB > T
INTERCEP	1	-9335.68	2385.28725	-3.914	0.0010
DISTR	1	3.36229887	3.27119302	1.028	0.3176

Table 15 (Continued).

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	114244302.56	114244302.56	1.961	0.1785
ERROR	18	1048864252	58270236.20		
C TOTAL	19	1163108554			
ROOT MSE		7633.494	R-SQUARE	0.0982	
DEP MEAN		-7666.3	ADJ R-SQ	0.0481	
C.V.		-99.5721			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-35492.6	19946.09063	-1.779	0.0921
ELEV	1	10.48170613	7.48579782	1.400	0.1785

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	118994198.79	118994198.79	2.051	0.1692
ERROR	18	1044114355	58006353.08		
C TOTAL	19	1163108554			
ROOT MSE		7616.19	R-SQUARE	0.1023	
DEP MEAN		-7666.3	ADJ R-SQ	0.0524	
C.V.		-99.3464			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-11721.7	3304.15994	-3.548	0.0023
ELEVCH1	1	9.31743733	6.50536048	1.432	0.1692

Table 15 (Continued).

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	1	155214357.90	155214357.90	2.772	0.1132
ERROR	18	1007894196	55994122.02		
C TOTAL	19	1163108554			
ROOT MSE		7482.922	R-SQUARE	0.1334	
DEP MEAN		-7666.3	ADJ R-SQ	0.0853	
C.V.		-97.608			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-3696.27	2913.00459	-1.269	0.2206
ELEVCH2	1	-28.7934	17.29409891	-1.665	0.1132

DEP VARIABLE: AMTYR

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	532710999.02	266355499.51	7.183	0.0055
ERROR	17	630397555.18	37082209.13		
C TOTAL	19	1163108554			
ROOT MSE		6089.516	R-SQUARE	0.4580	
DEP MEAN		-7666.3	ADJ R-SQ	0.3942	
C.V.		-79.4323			

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > T
INTERCEP	1	-6466.06	2978.46139	-2.171	0.0444
AREA	1	-0.0204384	0.006967086	-2.934	0.0093
DISTTH	1	0.71143374	0.33841970	2.102	0.0507

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