

**ASSESSMENT OF TIMBER RESOURCES AND LOGGING HISTORY OF THE
VALLES CALDERA NATIONAL PRESERVE**

by

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ABSTRACT

The purpose of this research is to describe the history of timber harvest in the 89,000 acre Valles Caldera National Preserve in the Jemez Mountains of northern New Mexico.

Logging was arguably the most extensive and ecologically significant twentieth century human modification to forests now enclosed by the Preserve. This research synthesizes various forms of harvest records, timber cruise data, airphotos, maps, and other forestry data to create a cohesive and spatially explicit narrative of logging history. There were three distinct eras of harvest between 1935 and 2000. From 1935 to 1962 easily accessible, lower elevation ponderosa pine and mixed conifer stands were heavily harvested. Clear-cutting took place at most elevations and affected nearly all stand types from 1963 to 1972. After a brief moratorium, harvesting resumed in 1980 and continued until the 2000 creation of the Preserve. We created GIS coverages of each harvesting era (including 1980-1991 and 1992-2000 coverages for the most recent era). Comparison of timber data from 1978 and 1998 demonstrates a broad trend of increase in volume and volume per area of all major species in all areas of the Preserve, though relative rates of increase vary spatially and by species. We created a coarse map of potential old-growth areas that generally agrees with other data on unharvested stands. A stand-level inventory of the Preserve is necessary to evaluate current forest characteristics on a scale comparable to the scale of (1) the effects of logging and logging roads on vegetation and other ecosystem components and (2) future forest treatments. Future timber harvests in the form of small diameter thinning holds promise as an appropriate treatment for reducing fuel load and improving ecological and aesthetic value.

CHAPTER 1: INTRODUCTION TO THE THESIS

Explanation of Problem

The legacies of logging have been understudied in some southwestern ecosystems where timber harvest has had significant, long-term consequences for forest resource sustainability. Southwestern forests have experienced considerable modification during the last century as a result of new and more intense land uses such as timber harvest. Historically, public land use policies have encouraged economically profitable resource extraction without also encouraging ecologically-minded long-term sustainability. The legacies of logging history have significant consequences for land managers currently attempting to establish and implement effective management policies.

The Baca Location #1 land grant (Baca) in northern New Mexico's Jemez Mountains was extensively logged during the twentieth century. Logging practices in this landscape may be the most extensive and most ecologically significant human impacts of the twentieth century. The cumulative effects of logging, grazing, fire suppression, and other human actions have created challenges for current management of the Baca as the Valles Caldera National Preserve (VCNP). The Valles Caldera Trust manages the Preserve and is charged with the protection and preservation of the biological, cultural, economic, and aesthetic integrity of the landscape. To protect and preserve resources for the future, understanding past land uses and their impacts is essential. Many questions about the effect of logging on the flora, fauna, hydrology, soils, and ecosystem functioning remain

as yet unanswered in the VCNP. A prerequisite to focused research on these questions is a spatially explicit reconstruction and analysis of the timber harvesting that has occurred on the Preserve. Currently, there is no comprehensive ecologically-oriented synthesis of the numerous and disparate sources of information about the VCNP's logging history.

Research Objectives

The following questions direct this investigation:

1. What is the logging history of the VCNP?
 - a. Where and when did logging occur?
 - b. What type of logging occurred?
2. How has logging changed the structure of forests?
 - a. What is the current status of merchantable timber?
 - b. How have timber volume and species composition changed over time?
3. How might future harvests affect the forests?
 - a. What general recommendations can be derived for future timber management from knowledge of past harvests?
 - b. What specific recommendations can be made about future forest inventory and mapping that would assist forest management?

We address these questions by qualitatively and quantitatively synthesizing multiple historical and field data sources into a spatially explicit reconstruction of logging events.

This history will be valuable to two audiences. First, it will inform VCNP management decisions by providing a historical and spatial perspective on logging occurrence.

Second, it will contribute to future research aimed at understanding the effects of human impacts on the environmental, economic, and social components of the VCNP landscape by describing available data sets and summarizing their uses and limitations.

Thesis Format

This thesis is written in paper format. It includes a brief research description in chaptered sections and a manuscript intended for publication in the Appendix. This chapter introduces the study and its research questions. Chapter 2 reports major findings of the study. The appendix is a self-contained report to the Valles Caldera Trust also intended to submission to an academic journal of applied forestry. John Kupfer is a coauthor on the manuscript and assisted in interpretation of results and manuscript revision.

CHAPTER 2: PRESENT STUDY

The conclusions of this study will provide a spatial perspective on logging events and their effects to resource managers in the VCNP. This research establishes a foundation of spatially explicit information about the logging history of the Valles Caldera National Preserve by doing the following:

- Describing and evaluating available datasets relevant to timber harvest history
- Describing the current status of the timber resources on the Preserve
- Presenting integration and initial analysis of these datasets, identifying patterns and potential ecological impacts
- Providing historical context for management decisions
- Suggesting how this and future research using these datasets can inform management decisions

Description of Data Sets

The data sets used in this investigation are variable in their spatial and temporal extent, resolution, consistency. Their use requires an acknowledgement of their capabilities and limitations. This research explored three unpublished sets of forestry records about the VCNP (Solinsky 1979, Keel 1998, NMSF records) and evaluated them for future use. The two timber reports (Solinsky 1979, Keel 1998) were coarse in their analysis of timber resources and insufficient for stand-level management. Keel (1998)

used a standard timber cruising technique to collect timber data yet failed to sufficiently meet that technique's requirement for sampling depth.

Current Status of Timber

Logging as a discrete ecological disturbance has affected most forest stands in the VCNP. Harvests varied in extent and intensity over both space and time according to the context of technology, economics, and landscape values. The most current timber volume estimate (1988) is 489,049,000 board-feet on 25,390 ha (62,748 ac) of timbered land. Timber volume and timber density vary by species and geographic area.

GIS Logging Database

Digital spatial data layers were created for each era of logging in the VCNP: 1935-1962, 1963-1972, 1980-1991, and 1992-2000 (the last two layers comprise one era, 1980-2000). Completeness and precision vary according to the completeness and precision of the data sets used. This database provides a spatial perspective on logging history and helps to identify areas that have been intensively harvested and areas that have experienced relatively little harvest.

Timber Comparison, 1978-1998

Analysis of two timber reports over a two decade period (Solinsky 1979, Keel 1998) showed changes in timber volume per acre and species composition for seven geographic areas within the VCNP. With a few minor exceptions, both absolute volume and volume

per area increase for every species in each of the seven strata from 1978 to 1998. The relative magnitude of change varies by species. Volumetric increases primarily reflect small diameter tree growth.

Timber Harvest as a Management Tool

Timber harvest has potential as a management tool in the VCNP. One of the most urgent current management needs is for small diameter tree thinning. Decreases in healthy large trees and increases in small trees have lowered ecological and aesthetic value and potentially increased severe fire risk. Thinning projects have already begun in the VCNP to mitigate potential fire risk and improve forest health and quality (Pueblo of Jemez 2001). This research contributes to an understanding to forest history and the influences of logging on stand characteristics.

Old-Growth Stands

Despite widespread harvest of most of the biggest and oldest trees in the Jemez Mountains the VCNP is home to some of the largest remaining old-growth stands in the entire mountain range (Allen 1989, Muldavin and Tonne 2003, Valles Caldera Trust 2003). This research identified potential old-growth areas which generally agree with other research and timber cruise data. Management of old-growth and high value areas required stand level research and treatment.

Logging Roads

Logging roads are a secondary but significant legacy of timber harvests. Thousands of kilometers of logging roads were built in the 1960s to support intensive and higher elevation timber extraction (Allen 1989). These roads are still ubiquitously visible in the VCNP. There are negative ecological effects of logging roads, but existing roads also have value as access routes for future harvesting operations, fire use and control, research activities, and recreation. A few strategic roads should be maintained for these purposes and the remainder should be restored to forest.

Forest Management Implications

The landscape legacies of logging have significant implications for current and future sustainable management of VCNP forests. The VCNP is today a mixture of high value stands and degraded but recovering stands. High value forest stands include some selectively harvested and unharvested stands that have maintained high ecological, economic, and aesthetic value. Heavily logged and clear-cut stands may still be in the early stages of vegetative response but their timber volume and ecological value are increasing. This research addresses the need to understand these legacies by documenting the occurrence of logging on in the VCNP. This analysis supports several management recommendations.

Small diameter thinning targeted at vulnerable locations can be a beneficial treatment for reducing stand density. Such treatment reduces fuel connectivity thereby vulnerability to stand-replacing fire. Once stands are thinned, reintroduction of low severity fire is a viable management option. Thinning dense understories of shade-tolerant trees may also

reduce vulnerability to insect outbreaks. Small diameter thinning should not greatly increase windthrow potential.

Old growth stands are beginning to succumb to the cumulative effects of human action (e.g., fire exclusion which increases competitive stress) and natural events (e.g., insect and drought-induced stress). Additional management in the form of small diameter thinning can mitigate some of these effects and restore resilience and integrity to old growth stands. Ecologically-based silviculture has potential as an applied ecological tool to support the multiple ecological, economic, and social values of the VCNP's mission. However, the effects of logging on the natural systems of the VCNP are, to a large degree, yet to be determined.

Additional knowledge of stand-level forest structure and history is required to assist decision-making. Currently available data sets are too coarse to inform decisions about local treatment options. A new forest inventory would assess stand structure and history and be comparable to other ecological and silvicultural VCNP data sets. Stand-specific treatment prescriptions should be developed based upon this stand inventory database. Subsequent management action should be accompanied by ongoing monitoring and research.

This research synthesizes information about the logging history of the Valles Caldera National Preserve into a single narrative. We describe data sets relevant to the history of logging and its potential ecological effects are described and present the current estimate of the VCNP timber resource. Integration and analysis of these data sets identifies patterns and potential ecological impacts. This work and future research on logging and

its effects will provides an important historical context for management decisions in the VCNP.

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APPENDIX

**ASSESSMENT OF TIMBER RESOURCES AND LOGGING HISTORY OF THE
VALLES CALDERA NATIONAL PRESERVE**

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To Be Submitted to the Valles Caldera Trust

INTRODUCTION

While plant ecologists have long recognized the importance of abiotic conditions—climate, topography, substrate—in structuring vegetation patterns, it is clear that past land uses and disturbance history can also be important determinants of species composition, biodiversity and community pattern, even in landscapes that outwardly appear “natural.” For much of the first half of the twentieth century, the results of both natural and anthropogenic disturbances were largely seen as little more than ephemeral departures from relatively stable climax communities (Clements 1915). Persistent or irreversible changes in plant community structure or composition following disturbances were largely regarded as rare incidents that only occurred following exceptional events or particularly extreme disturbances (e.g., severe erosion following forest removal and poor agricultural practices). Even in many contemporary ecological studies examining landscape-level mosaics of ecosystem patterns, transitions among land use and land cover types are treated as predictable processes governed largely by the rates of disturbance and recovery.

Recent research, however, has helped to reveal the existence of disturbance “legacies” and demonstrated that while contemporary patterns of species and ecosystems are clearly structured by abiotic conditions, they may also bear the marks of past land use and disturbances. For example, natural reforestation of agricultural lands in New England over the past 150 years has created a predominantly forested landscape (Foster 2002). Bellemare et al. (2002), however, documented persistent compositional differences

between the vegetation of primary and post-agricultural secondary forests, indicating that the distribution patterns for many plant species still reflect the open, agricultural environment of the nineteenth century despite the current predominance of forest cover in the study area.

Understanding historical factors controlling forest structure and composition is a major challenge to ecologists, conservationists and land managers. In the Southwest, forests have experienced considerable changes during the last century as a result of land use policies that encouraged economically profitable resource extraction without also encouraging ecologically-minded long-term sustainability. This historical context of change is relevant to the current and future management of valued resources. The initiation of large-scale commercial logging in the Southwest accompanying EuroAmerican settlement is one example of significant land use change that has substantial ramifications for forest management.

Impacts of Tree Harvesting and Associated Roads

Specific effects of tree harvest and associated activities vary widely as a function of the techniques used to harvest (e.g., clear cutting, structural retention logging) and regenerate (e.g., seeding, seed tree retention) an area. Generally, however, logging can generate significant, long-term ecological consequences (Barnes et al 1998). Large-scale timber harvest is a disturbance affecting forest pattern and process from the scale of an individual tree to that of an entire ecosystem. It is novel by virtue of orders of magnitude more extensive and intensive than prehistoric and noncommercial timber harvest—

logging has no natural equivalent. Two of the primary effects of logging are reductions in the structural complexity of stands and alterations of the landscape's natural heterogeneity. Structural complexity pertains to: 1) the variety of stand structural attributes that are present in natural forests in an area (e.g., the stand age and size class structure, presence of standing snags and downed woody debris, variation in canopy gap structure, vertical heterogeneity associated with different canopy layers), and 2) how these features are arranged across a landscape (i.e., spatial heterogeneity).

Harvesting only large diameter merchantable timber—"high grading"—eliminates old growth, reduces structural diversity, eliminates habitat and promotes understory establishment and growth of certain species. Removal of significant quantities of biomass from a forest affects nutrient and water cycling. Targeting of particular timber species affects stand composition, modifies interspecies resource competition, and alters the availability of seed sources for new establishment. These changes in pattern in turn affect the elements and mechanisms of ecological functioning, including vegetation, wildlife, soil, surface and groundwater, microclimate.

In addition to the direct effects of logging, the construction of logging roads has important consequences for landscape configuration. Roads are known to have a wide range of associated effects on biodiversity and ecological processes (e.g., Baker and Knight 2000), including roadside vegetation and animals as well as water, sediment and chemical fluxes (Forman and Alexander 1998, Forman 2003). Trombulak and Frissel (2000) identified seven general ways that roads affect terrestrial and aquatic ecosystems: (1) mortality from road construction, (2) mortality from collision with vehicles, (3)

modification of animal behavior, (4) disruption of the physical environment, (5) alteration of the chemical environment, (6) facilitation of the spread of exotic species, and (7) changes in human use of land and water. A comprehensive examination of logging effects must thus acknowledge the effects of road construction.

Purpose and Objectives

The purpose of this study is to investigate and document logging history in the Valles Caldera National Preserve (VCNP) in northern New Mexico's Jemez Mountains. The VCNP was previously known as the Baca Location #1 land grant (Baca) and is an area of considerable natural, scenic, historic, and cultural value that has a long legacy of human use and modification. Logging practices in this landscape may in fact have caused the most extensive and most ecologically significant vegetation changes of the twentieth century. The cumulative effects of logging, grazing, and fire suppression have created challenges for current management as the Valles Caldera National Preserve (VCNP).

The VCNP's organic act (Valles Caldera Preservation Act, Public Law 206-248, 2000) mandates the protection and preservation of the biological, cultural, economic, and aesthetic integrity of the landscape. To protect and preserve resources for the future, understanding past land uses and their impacts is essential. Many questions about the effect of logging on the flora, fauna, hydrology, soils, and ecosystem functioning remain as yet unanswered in the VCNP.

A prerequisite to focused research on these effects is a spatially explicit reconstruction and analysis of the timber harvesting that has occurred on the Preserve.

Currently, there is no comprehensive ecologically-oriented synthesis of the numerous and disparate sources of information about the VCNP's logging history. This research fills this information gap. The following questions direct this investigation:

1. What is the logging history of the VCNP?
 - a. Where and when did logging occur?
 - b. What type of logging occurred?
2. How has logging changed the structure of forests?
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We address these questions by qualitatively and quantitatively synthesizing multiple historical and field data sources into a spatially explicit reconstruction of logging events. This history will be valuable to two audiences. First, it will inform VCNP management decisions by providing a historical and spatial perspective on logging occurrence. Second, it will contribute to future research aimed at understanding the effects of human impacts on the environmental, economic, and social components of the VCNP landscape

by describing available data sets and summarizing their uses and limitations.

STUDY AREA

Physical Setting

The Jemez Mountains of New Mexico are located at the southern margin of the Southern Rocky Mountains ecoregion (Neeley et al. 2001). The central landform of the Jemez Mountains is the Valles Caldera (Figure 1). This collapsed magma chamber spans approximately 25 km (15.5 mi) and encloses multiple resurgent lava domes that formed after the chamber's collapse *ca.* 1.2 million years ago (Goff et al. 1996). The physical landscape of the dormant caldera is characterized by forested domes and uplands (about three quarters of the land area) separated by grassland *valles* ('valle' is a Spanish term meaning a treeless depression, similar to the English term 'valley'). Elevation varies from 2440 m (7930 ft) at the outflow of the Jemez River's East Fork to 3430 m (11,254 ft) on Redondo Peak, the highest dome in the caldera. Uplands are underlain by volcanic flows and tuff while *valles* contain alluvial deposits (Smith et al. 1970). Forest soils are andisols, alfisols, and inceptisols, while grassland soils are mollisols (Muldavin and Tonne 2003). The caldera interior is a single watershed unit draining out a breach in the caldera wall to the Jemez River's San Diego Canyon, southwest of the VCNP.

Climate

The nearest climate station to the caldera with a reasonably long period of record is in

the town of Los Alamos, 20 km east of and 300 m below the lowest point in the caldera, although climate observations are currently being collected within the caldera (VCT and J. D. Coop, unpublished data). The regional climate is characterized by a summer monsoonal precipitation pattern, with July and August convective monsoon rains contributing nearly 40% of the annual Los Alamos precipitation average of 475 mm (data from the National Climatic Data Center). Because of its higher elevation, annual precipitation is greater in the caldera than at the Los Alamos climate station (as evidenced by vegetation types) and snowfall is much greater, especially on the domes and caldera rim (Allen 1989). Mean Los Alamos temperatures range from -2°C to 20°C (Figure 2), although the actual temperatures in the caldera are appreciably lower than that climate station data indicates (Muldavin and Tonne 2003) and decrease with increasing elevation and proximity to cold air drainages (J. D. Coop, unpublished data).

Vegetation

The Jemez Mountains flora and ecology is typical of the southern Rocky Mountains (Dick-Peddie 1993). Elevation and slope aspect are the primary gradients across which local forest vegetation varies, as is generally the case throughout the Southwest (Brown 1994). Ponderosa pine (*Pinus ponderosa*) is the major forest species in stands below 2740 m (9000 ft) that ring the valleys except on some north-facing slopes where blue spruce (*Picea pungens*) has recently gained importance (Hogan and Allen 1999, Muldavin and Tonne 2003). Mixed conifer forests dominate the caldera. These stands occur below 3050 m (10,000 ft) and contain combinations of ponderosa pine, Douglas-fir (*Pseudotsuga*

menziesii), white fir (*Abies concolor*), quaking aspen (*Populus tremuloides*), and limber pine (*Pinus flexilis*). Spruce-fir forests dominated by Engelmann spruce (*Picea engelmannii*) and corkbark fir (*A. lasiocarpa* var. *arizonica*) occupy the highest elevations and north-facing slopes on the domes above 2740 m (9000 ft). Aspen (*P. tremuloides*) stands occur throughout the forested landscape, mainly in disturbed (logged or burned) areas (Muldavin and Tonne 2003). Soil characteristics, cold air drainage, hydrology, fire, and grazing contribute to the maintenance of the grasslands that span the valleys in the enclosed caldera (Allen 1989, J. D. Coop, unpublished data), although there is evidence of woody species encroachment (especially by *Pinus ponderosa* and *P. pungens*) into these low elevation grasslands. High elevation grasslands that were historically maintained at least in part by fire also occur on upper, south-facing slopes in the mixed conifer and spruce-fir zones (Allen 1989). Specific forest associations and their characteristic flora are described by Muldavin and Tonne (2003).

Ecological Disturbances

Ecological disturbances are natural or anthropogenic events that disrupt vegetation structure and change the nature or availability of limited vital resources—light, nutrients, and water (White and Pickett 1985). Disturbances are relatively discrete events but over time act as processes with a regime of describable characteristics, such as spatial extent, spatial distribution, frequency, and magnitude (Turner et al. 2001). The strength of a disturbance can be judged in terms of the event itself (intensity of a particular event) or in its ecological consequences (severity of disturbance effects) (Sousa 1984). Disturbances

often exhibit spatial variability with respect to intensity, even within an individual disturbance event. Spatial patterns of response or recovery after a disturbance are often closely related to the spatial distribution of event intensity.

Wildfire, herbivory, and logging are principal disturbances influencing vegetation pattern and process in the VCNP. Human action over the last one hundred fifty years has significantly modified prehistoric disturbance regime characteristics and introduced novel disturbances. Fire and native ungulate herbivory are indigenous disturbances while timber harvesting and domesticated animal grazing are novel at the landscape scale. The relevance of other forest disturbances to research on logging is that the legacies of one disturbance may interact with the characteristics of a subsequent disturbance (Madany and West 1983, Keane et al. 2002). Thus, it is important to view logging—its practice and its effects—as a disturbance in its wider ecological context.

Natural Disturbance Regimes in the VCNP

Lightning-caused and anthropogenic wildfire, wild and domesticated animal herbivory, and forest pest outbreaks are important ecological processes influencing the structure and function of forests. Fire is a keystone natural disturbance process whose regimes have been altered by fire exclusion policies throughout the Southwest (Covington and Moore 1994). Fire has been a regular phenomenon in the Jemez Mountains for at least the last 8000 years (Brunner Jass 1999) and prior to EuroAmerican settlement, fire was the dominant large scale disturbance on the forested landscape (Allen 1989). Frequent, low severity surface fires at lower elevation once maintained old, open-

structure pine stands. Fire at higher elevation may have been less frequent but still maintained patchy grasslands on the caldera rim (Allen 1989) and aspen stands where fire burned with higher intensity (Margolis et al. 2001). Swetnam and Baisan (1996) report mean fire intervals for ponderosa pine and mixed conifer fire history sites (ranging from 10 to 100 ha in size) in the Jemez Mountains ranging between 4.54 and 25.17 years. Some of these sites are also reported by Touchan et al (1996) as having mean fire intervals between 5.0 and 18.9 years.

Although Puebloan peoples have populated northern New Mexico for many centuries, their influence on fire occurrence and severity in the Jemez Mountains is perceived to have been localized and minimal (Allen 2002). However, EuroAmerican settlement of the Jemez, beginning in earnest in the late nineteenth century, profoundly altered the regimes of fire and other processes in substantive ways that Puebloan land uses had not. The fire regime changes discussed below are the result of EuroAmerican influence while Puebloan influences are considered part of the pre-EuroAmerican regime.

Numerous forest pests inhabit the forests of the Jemez Mountains. Recent surveys have detected damage by western spruce budworm (affecting Douglas-fir, true firs, and spruce), spruce beetle (spruce), western/roundheaded pine beetle (ponderosa pine), and aspen defoliators (aspen) (USFS 2002). Tree ring records indicate recurrent outbreaks of spruce budworm (Swetnam and Lynch 1993) and tent caterpillar (Margolis et al. 2001). Logging and insect populations can have synergistic effects on one another; for example, untreated logging slash can initiate insect outbreaks or increase their severity.

Other minor disturbances affect VCNP forests but are not expressly discussed here. Documented examples include mistletoe infestations and windthrow (NMSF records). Because of its increased occurrence in association with logging, windthrow is worthy of management consideration and is discussed later in this paper. Some discrete climate fluctuations may also be considered as disturbances. Interdecadal climate oscillation can have significant direct ecological effects (Allen and Breshears 1998, Swetnam and Betancourt 1998) as well as synergistic effects on other disturbances and deserve management consideration but are not discussed here.

Anthropogenic Disturbance Alterations

The combination of the introduction of grazing animals and the active suppression of fire prompted long-term changes in the vegetation mosaic of the VCNP. Domesticated animal grazing accompanied EuroAmerican expansion into the frontier West in the eighteenth and nineteenth centuries. The removal of fuel connectivity through grazing is widely seen as an initial cause of wildfire cessation in fire-adapted ecosystems in the Southwest (Madany and West 1983, Savage and Swetnam 1990, Touchan et al. 1995).

Historical grazing records (Scurlock 1981) indicate that intense sheep grazing began in the late 1800s in the grasslands and forests of the Jemez. This coincides with a sudden cessation of fire scars on trees around 1879 in the caldera (Morino et al. 1998) and by 1893 throughout the Jemez (Touchan et al. 1996). The fire exclusion policy that characterized twentieth century land management perpetuated the grazing-induced fire interruption and accentuated the deviation of forest structure, composition, and function

from their historic range of variability in the Southwest (Covington and Moore 1994, Brown et al. 2000).

During the first decades of the 20th century, the replacement of sheep grazing by less intensive cattle grazing (Scurlock 1981) permitted some tree establishment but still prevented fire spread by limiting herbaceous fuel production. Livestock grazing continues to the present day under the multiple-use mandate of the Valles Caldera Preservation Act (106th Congress 2000). Recent increases in the elk population have severely curbed tree (especially aspen) establishment (Allen 1998, Krantz 2001). This constant pressure of elk herbivory continues to affect both fire spread and post-logging aspen regeneration and is of specific management concern (Valles Caldera Trust 2003).

The effects of logging as an ecological disturbance have not yet been closely studied at a stand or landscape scale in the VCNP.

Logging History

Researchers have acknowledged logging as an important ecological disturbance in the VCNP (Allen 1989, Martin 2003, Muldavin and Tonne 2003) yet much is still to be learned about logging's effects on the pattern and process of this landscape. Three distinct eras of harvest define the logging history of the Baca, each defined by methods and approaches which reflect the technological, political, and economic context of the period, described in detail by Martin (2003). Harvest method, spatial extent, and species composition of harvest are important determinants of the ecological consequences of logging operations, and each of these determinants is uniquely identified in each logging

event. A description of the historical sequence of logging episodes in the caldera will, however, elucidate some broad patterns of logging as an anthropogenic disturbance regime—its timing, spatial occurrence, and fluctuating intensity—and aid in the interpretation of logging effects.

Pre-1935. Small timber firms began commercial logging operations in the Jemez Mountains in the late 1800s (Martin 2003). Limited by access, these operations easily reached ponderosa pine stands around the village of Ponderosa, in the Cañon de San Diego Grant, south of the Baca (Glover 1990). Harvesting within the Baca, if there was any, was relatively insignificant.

1935-1962. The Civilian Conservation Corps built a road through Ponderosa and across the Valle Grande in 1935 that provided access to the caldera for subsequent truck-based logging operations (Glover 1990, Martin 2003). Glover (1990) estimates the pre-1935 timber potential at 400-500 million board-feet and Martin (2003) reports that in a deed dated July, 1935, 42 thousand board-feet¹ had already been harvested.

The New Mexico Timber and Lumber Company (hereafter NMT, later named the New Mexico Timber Company) bought the timber rights to the Baca from the Redondo Development Company in 1935, commenced logging, and oversaw logging operations from then until 1972. From 1935 to 1962, the ponderosa pine stands of the Baca were “high-graded”, with the best ponderosa pine sawlogs greater than twelve inches in diameter being harvested from the lower elevations, save a few seed trees per acre

¹ Martin (2003, p. 86) presumably misinterprets “mbf,” common notation for “thousand board-feet,” as “million board-feet.” Forty-two million board-feet would have been one tenth of the Baca’s timber, not a feasible single season harvest. Martin also miscites chapter reference #6 (Glover 1990) instead of #5 (1935 deed from Redondo Development to Robert Anderson, Jr.).

(Martin 2003). Approximately 10,380 ha (25,641 ac; 38% of forested area) were harvested using light to heavy selection cutting in the southwest corner on the Banco Bonito lava flow, the northern and eastern rims (Garita and north of Valle Toledo), and around the base of Cerro del Medio, Cerros del Abrigo, and Cerros de Trasquilar (USFS 1993). Before chainsaw technology became pervasive crosscut saws were used to fall timber. Logs were skidded by horses to decks where trucks waited to haul the logs to the mill. Toward the end of the era, middle elevation mixed conifer stands were harvested as roads and technology improved.

1963-1972. Improved technology and roads enabled clear-cutting of all species and sizes on approximately 4700 ha (10,589 ac; 16% of forested area) of the Baca from 1963 to 1972 (USFS 1993, Martin 2003). During this era NMT employed jammer logging, a cable logging system where a mechanical cable winch hauls logs directly from the stump to roadside collection points. At the Baca, the trees were then were hauled to the mill by truck and large slash piles were left in place of trees (USFS 1993, Martin 2003). Regulatory changes and a new pulpwood mill in Arizona further aided intensive harvesting during this period. Legal action halted NMT and its intensive logging methods in 1972 (Martin 2003).

Jammer logging was supported by a dense network of thousands of kilometers of new, contour-paralleling roads, sometimes less than 300 ft (90 m) apart, spiraling up the forested domes of the Baca (Figure 3) (Allen 1989). The roads permitted logging of steep and high elevation slopes and contributed to fragmentation of the remaining forest areas. Lack of conservation practices caused severe soil and water quality damage, not to

mention the aesthetic depreciation of the landscape. These unsustainable practices still affect the biological, economic, and aesthetic quality of today's forests (Figure 4).

1980-2000. From 1980 until the sale of the Baca to the US government in 2000, logging proceeded at a more conservative pace, under the guidance of the New Mexico State Forestry Office. Approximately 1100 ha (2,739 ac, 4% of forested area) were harvested between 1980 and 1992 (USFS 1993). Most harvests employed selection cutting and were guided by conservation-minded guidelines established by the State (New Mexico State Forestry 1990). Selection cutting harvests a portion of mature trees, usually the largest and highest quality individuals of the most valuable species. The proportion of trees harvested varies widely. Some patch cutting took place (a patch is a small clearcut). Logging was carried out in many areas of the Baca including the Cerros del Abrigo, Cerro del Medio (much of which had been previously harvested), and the Sierra de los Valles on the eastern caldera rim (USFS 1993).

Administrative History and Status

The Valles Caldera National Preserve is a national experiment in natural resource management. Previously known as the Baca Location or Baca Ranch (and informally referred to as the Valle Grande, after its most prominent feature), the tract had remained largely intact as a single parcel since its granting by the New Mexico Territory as the Baca Location No. 1 to Luis Maria Cabeza de Vaca in 1860 (Martin 2003). The original parcel was 40,181 ha (99,289 ac); the current parcel is approximately 36,000 ha (88,950 ac), or just under 90% of the original land area (Martin 2003). The act of Congress that

converted the privately held Baca into public land (Valles Caldera Preservation Act, Public Law 206-248, 2000) charges the managing body, the Valles Caldera Trust, with a complex responsibility: “to protect and preserve the scientific, scenic, geologic, watershed, fish, wildlife, historic, cultural, and recreational values of the preserve, and to provide for multiple use and sustained yield of renewable resources within the preserve” (Valles Caldera Preservation Act, sec. 104[b], 2000).

Four forest management goals drive the Trust’s decisions according to the Comprehensive Management Framework set forth by the Trust (Valles Caldera Trust 2003):

- Reduce forest vulnerability to stand-replacing fire (particularly pine and some mixed conifer stands).
- Restore natural fire regimes.
- Restore aspen regeneration.
- Protect and restore old-growth stands.

VCNP forests are also likely to remain a source of wood products in the future, as they have been in the past. These forests are a resource of significant economic, social, and natural value. The landscape legacies of past logging as well as the potential for future logging in the VCNP are relevant to these management goals.

Summary

The Valles Caldera is a heterogeneous mosaic of vegetation types that reflects the influences of abiotic factors, namely climate, topography, and substrate, and ecological processes of disturbance, primarily fire, grazing, and logging. The patterns created by

these conditions and events will shape these forests for centuries to come and conversely the forests will shape the regimes of natural and anthropogenic disturbance. The human impact on the VCNP landscape is indelible and logging practices are arguably the most extensive, most severe, and most ecologically significant disturbance of the twentieth century. A spatial perspective on the history and effects of logging is imperative if the multiple ecological, economic, and aesthetic values of the VCNP are to be effectively managed.

DATA

This study integrated an array of spatial and non-spatial information to contribute to a broad understanding of logging in the VCNP. Data sets used in this analysis span the period of interest, 1935-2000 (Figure 5). They differ in content as well as spatial and temporal extent, resolution, and consistency. Each has sources of error and analytical shortcomings. Differences in spatial extent and resolution have consequences for harvest documentation precision. Many of these datasets have not been previously analyzed with current management objectives in mind, so this section serves as an introduction to their scope of inference and potential uses.

Historical Aerial Photography

The Valles Caldera Trust possesses nine sets of unrectified aerial photograph prints (airphotos) covering at least part of the Preserve (Figure 6; Table 1). The earliest set was flown in 1935, before large scale commercial logging began and subsequent sets often

coincided with the onset of distinct logging episodes. Two additional sets of recent digital orthophoto quadrangles (DOQs) are available.

New Mexico State Forestry records

In 1970, the State Forestry Division of the New Mexico Energy, Minerals, and Natural Resources Department was charged with supervising timber harvests on non-municipal, non-federal and non-tribal lands in the state. From 1970 until 2000, when the Baca passed into federal jurisdiction, the New Mexico State Forestry Division retained records on timber operations on the Baca (Table 2). These records (NMSF records) are now held by the Valles Caldera Trust. They contain information on each timber sale in compliance with minimum standards set forth in the Commercial Timber Harvesting Guidelines in the New Mexico Forest Practices Guidelines (current revision is New Mexico State Forestry 2002). There are records for thirteen separate timber sales between 1980 and 2000. No State Forestry records exist for 1970-1980 (legal interruption of logging activity lasted from 1972 until 1980).

Each individual timber sale record should include a harvest method and regeneration plan, periodic commercial harvest field inspection forms accompanied by topographic quadrangles with hand-drawn boundaries of active harvest areas, and letters regarding various stages and permissions of the sale. In actuality, most of these sale records do not contain all of these elements. Maps are incomplete and most show the boundaries of cutblocks (entire areas for which harvest is permitted) rather than the actual harvested areas, which may be significantly smaller (especially since much post-1980 logging was

selective and more patchy in nature than earlier harvesting methods). Regeneration plans, which explain harvest method and composition of harvest, are incomplete or missing for most sales. Estimates of timber harvest volumes are rare and inconsistently reported.

Timber Reports

There are several Baca-era reports that hold specific analytical interest. Two logging reports by Frank and Dean Solinsky, Consulting Foresters (Solinsky 1963, 1979) were commissioned but only the 1979 report is extant (now held by the Valles Caldera Trust). This report and accompanying map integrate a review of the 1963 and other reports, an examination of airphotos, and additional field reconnaissance into a summary of timber on the Baca as of 1978. The field data collection methods Solinsky used to evaluate timber volume are unknown. The report quantitatively describes timber volume (calculated from basal area and height) by species for each of eight geographic strata and for unharvested and harvested areas (Table 3). Species include ponderosa pine, Douglas-fir, spruce, and white fir over ten inches (25 cm) in diameter and aspen over 6 inches (13 cm) in diameter. The report does not present tallies of numbers of trees, nor does it partition the data by tree size.

In the early 1990's interest in the public purchase of the Baca prompted the US Forest Service to contract a survey of the natural and cultural resources of the Ranch (USFS 1993). This report contains general harvest information and summary statistics that are mostly summarized from the Solinsky reports.

In 1998, Keel and Associates Timber Cruising and Appraisals Company were

commissioned to conduct a “timber cruise” or survey of merchantable timber on the property (Keel 1998, now held by Valles Caldera Trust). The cruise measured the species, diameter, and height of 2,889 trees at 922 plots in 24 strata using the Bitterlich variable plot method (Grosenbaugh 1952) (Figure 7, Table 4). A stratum is a geographic unit of measurement and analysis. The strata in this cruise were larger than a typical management compartment, ranging from 647 to 6,527 acres with a mean of 2,615 acres (261 to 2,641 ha with a mean of 1,058 ha). The cruisers recorded pine, Douglas-fir, spruce, white fir, and corkbark fir over nine inches (23 cm) in diameter. The cruisers also (inconsistently) recorded some occurrences of logging (Figure 8). Keel used the National Timber Cruising Program, NATCRS (USFS 1994), to compile merchantable timber summary reports of volume and number of trees, by strata and by species (plot $n = 875$, 740 of which are non-zero). We used cruise tally sheets (used for data collection in the field), the NATCRS output (digital text file), the report text, and topographic quadrangles annotated with plot locations to conduct analyses.

A brief description of the Bitterlich method of timber estimation is provided here for clarity and to benefit researchers who may wish to use this data in the future. The Bitterlich method of “variable radius plot” or “plotless” cruising has been used by American foresters for over half a century (Grosenbaugh 1952). Traditional fixed plot-based methods sample trees proportional to their frequency per fixed unit area. Variable plot methods sample trees proportional to their size. The plot radius is not fixed in size but rather varies with the diameter of each measured tree (a sampling point is still termed a “plot”). A cruiser stands at a point (the equivalent of a plot center) and rotates a fixed-

angle gauge around that point, tallying the number of trees whose diameter at breast height is greater than the angle projected by the sighting device. The critical angle of the sighting device determines its basal area factor (BAF). Multiplying the observed tree number by the BAF equals the basal area per unit area. Through standard equations, basal area is converted to timber volume. Each tree carries equal weight in computing basal area per unit area (Bell and Dilworth 1988).

The Bitterlich method is relatively fast since no plot or tree measurements are necessary, but it is inferior for density calculation (Lindsey et al. 1958), and a single sample point is a poor estimate of stand properties so many points must be aggregated to assess stand characteristics. A single BAF should be used for a given forest (Bell and Dilworth 1988) because alternating BAFs causes bias arising primarily from points with low tree counts (Iles and Wilson 1988). A suitable BAF can be determined by dividing the estimated basal area per acre by the desired tree count. Average minimum tree count per plot should generally exceed four trees; when plots range between four and twelve trees per plot, efficiency and statistical confidence are both maximized (Iles and Wilson 1988).

Rigorous analysis of the 1998 timber cruise data is problematic. The Keel survey employed different BAFs (Table 4) and on average recorded less than four trees per plot (Figure 9, Table 5). Recent logging could account for low tree number on some plots but cannot explain the consistently low tree numbers. In addition, since this data set was acquired by variable plot surveying techniques, it is not directly comparable to the stand structural data in other fixed plot-based field data sets collected in the VCNP. Inferences

derived from its analysis are limited by the data's lack of precision.

Complementary Data

There are two primary sources of complementary data described below that are useful for examining forest community characteristics and logging effects at VCNP: field surveys and supporting digital spatial data.

We conducted field reconnaissance to verify the location of some harvested areas though we did not widely or systematically field-check the logging boundaries digitized from paper maps or airphotos. We were unsuccessful at relocating monuments (wooden stakes and flagging) at Keel timber cruise reference points, presumably because they had decayed, been removed, or had not been precisely located on cruise maps. We did, however, collect plot-based data on forest structure and composition from 70 stands in logged and unlogged areas (Koski et al., in review). These field data also allowed us to spot-check mapped locations of logging activity. Muldavin and Tonne (2003) similarly located more than 200 vegetation plots throughout the VCNP, although specific data collected at each point varied from relatively detailed plot information to GPS-referenced spot checks of dominant vegetation type.

Second, the Valles Caldera Trust provided supporting GIS digital data layers that aided in the creation and contextualization of the logging data sets. These data layers were land ownership, roads, hypsography, hydrology, and remotely sensed vegetation. The road network (Figure 3; Allen 1989, digitized from 1981 airphotos) was particularly useful since many of the VCNP's roads were built expressly to facilitate timber

operations. Having a digital data layer of roads increased the precision of harvest boundary delineation.

METHODS

We calculated summary harvest statistics for each relevant data set. Raw data from Solinsky (1979) and Keel (1998) were translated into spreadsheet format to facilitate these analyses and future use by managers and researchers.

Current Timber Estimates

The 1998 timber cruise data were used as the most current estimate for timber on the VCNP. Timber volume, volume per area, number of trees, and trees per area were calculated by species and by stratum. Presence of the five reported species in timber cruise plots was collated into plot frequencies from NATCRS output.

GIS Logging Database

We created digital spatial data layers relevant to logging history in a GIS database using ArcView™ v3.3 software by digitizing on top of the 1996 DOQ and 1993 DRG base maps and then converting the digitized layers to ArcINFO™ v8.2 coverages. The area of interest extended beyond the VCNP boundary into Santa Clara Pueblo in the northeast. Polygons were partitioned into coverages by era of occurrence: 1935-1962, 1963-1972, 1980-1991, and 1992-2000. Airphotos and State Forestry maps were the two primary data sources for digitizing harvest boundaries.

Five sets of airphotos obtained from the Valles Caldera Trust were scanned for use in digitizing logged areas. A sixth data set of 1998 digital orthophotos was used as a base map and aided in digitization of more recent harvests. Photographs of the same location taken on different dates were compared to identify boundaries of logging activity. The photos were the primary source for logging activity identification during the period 1937-1962 and in many cases it was relatively easy to identify harvest boundaries based on textural contrast between heavily cut and adjacent uncut stands (Figure 10). The boundaries of selection cuts were much more difficult to identify than clear-cut areas (e.g., Figure 11) and were digitized based on all available data sets and the judgment of the digitizer.

The records from New Mexico State Forestry were the primary data set used to identify logging activity from 1970-2000. The maps in this data set have logging boundaries sketched by hand on topographic quadrangles. They have greater temporal precision but less spatial accuracy and precision than airphotos. In many cases only the sale and block boundaries were delineated on NMSF maps. A block is a subunit of a sale; logging operations progressed block by block. In most cases only a portion of each block was harvested but the majority of maps do not indicate the harvested area, just the block boundary (Figure 12). Airphotos were used wherever possible to confirm NMSF logging boundaries, but many boundaries could not be resolved at a finer resolution than the block.

The GIS roads layers were particularly important in digitizing precise harvest boundaries since many of the roads, especially those built in 1963-1972 era, were built

for the express purpose of facilitating logging. Maps and notes from the timber reports as well as field reconnaissance served to enhance the quality of the data. For example, timber cruise data (Keel 1998) sporadically mentioned evidence of past logging, or absence of such evidence, within a plot (Figure 8). The mention of logging at a location that other sources did not identify as a logged area was taken as valid evidence of logging activity. The absence of the mention of logging at a timber cruise plot, however, was not an indication that logging did not occur at or nearby that plot.

Timber Comparison, 1978-1998

Timber volume data is essential for effective implementation of timber management practices. Unfortunately, information about logging operations in the Baca is far from complete. The 1963 Baca timber report (Solinsky 1963), containing old harvested statistics and maps, could not be located. The 1980-2000 New Mexico State Forestry logging records (NMSF records) are not complete enough to precisely identify total harvested volumes during that era. The 1979 timber report (Solinsky 1979) and the 1998 timber cruise (Keel 1998) are relatively thorough, consistent, and complete in their reporting of data. There are, however, concerns regarding bias of these data due to differing sampling methodologies (Solinsky's method is unknown; Keel used the variable plot cruising techniques described in the Data section), small sample size and inadequate geographic coverage (see later discussion).

Comparison of their volumetric data may, however, provide insight into changes in volume, relative species abundance, and stand density over the past twenty years. The

geographic strata boundaries of the two timber reports differ. Consequently, it was necessary to appropriately standardize the data sets before comparison.

We combined the geographically dissimilar strata from each report into seven approximately colinear areas (Figure 13). We aggregated the smaller 1998 strata ($n = 24$) until their boundaries were relatively colinear with the larger 1978 strata ($n = 8$). The comparison strata names are the same as the 1978 names, except for Redondo and Redondo Creek. The 1978 Redondo Creek stratum does not correspond with any of the 1998 strata and is combined with the 1978 Redondo stratum to form the Redondo Complex stratum. The 1978 Redondo Creek stratum was originally part of the Redondo stratum in Solinsky's 1963 report and was separated out only to accommodate the 1973 Geothermal Survey (Pilz et al. 1979). Some boundary inconsistencies were resolved by considering that boundaries on two opposite sides of a grassland are effectively colinear (a grassland possesses no merchantable timber). A few can be explained by changes in the legal boundary of the land unit (USFS 1993), but others could not be avoided given the resolution of the available data.

Some boundary inconsistencies remained, and for these, we combined each indeterminate 1998 stratum with its most closely associated 1978 stratum. The subjective decision of assignment is based upon expert knowledge and field reconnaissance and considers elements including aerial proportion and ecological similarity (using both observed and remotely-sensed vegetation cover). This method is satisfactory because it retains strata as entire units. Using this method, 1998 stratum 1 falls within the 1978 Garita strata, and 1998 stratum 24 and 1978 Dome Road stratum are matched. The

boundary of the 1978 Toledo stratum and 1998 stratum 19 do not exactly coincide, and the 1978 Banco Bonito stratum is not exactly colinear with its complementary contemporary strata, but their boundaries are close enough to accept for the purposes for this analysis.

RESULTS

Logging as a discrete ecological disturbance has affected most forest stands in the VCNP. Harvests varied in extent and intensity over both space and time according to the context of technology, economics, and landscape values. There was extensive high grading of the timber resources during the first logging era, 1935-1962. The practice of clear-cutting removed the large trees but was initially restricted to easily accessible pine and mixed conifer forests. The construction of an extensive road network enabled more widespread logging in all vegetation zones and all areas of the VCNP during the second era, 1963-1972. After an absence of logging for a decade, less intensive, targeted harvests continued during the third era, 1980-2000.

Summary of the Timber Resource

The Keel survey reports the 1998 VCNP timber volume at 489,049,000 board-feet on 25,390 ha (62,748 ac) of timbered land (Table 6) (Keel 1998). (Keel reports the total volume as 486,049,000 board-feet but a summation of partial volumes stratified by species or by stratum verifies a correct calculation of 489,049,000 board-feet. Calculations based upon other output tables provide slightly different results based on

rounding error.) This is the most current estimate of total timber resource on the VCNP. Ponderosa pine and Douglas-fir were the species of principal economic value and hence the most heavily harvested, but all major conifer species have been logged to some extent. Preference was also scaled proportional to size; typically all trees over 8 in (20 cm) were harvested in clear-cuts while selective harvesting favored large, “overmature” trees of greater economic value. Use of small diameter timber was limited to small-scale firewood and Christmas tree collection (NMSF records, USFS 1993). Timber volume and timber density varies by species and strata (Table 6, Table 7).

The major species recorded in the 1998 timber cruise exhibit similar population patterns (Figure 14, Figure 15). Each species except perhaps corkbark fir show unimodal volume distributions, a sharp decline in timber volume with increasing diameter, and a scarcity of volume derived from trees greater than 122 cm (48 inches) in diameter (Figure 14). Similarly, all abundance distributions demonstrate a negative exponential decline in number of trees with size (mathematically similar to the derivative of the volume curves), with few trees greater than 61 cm (24 inches) and very few over 76 cm (30 inches) in diameter (Figure 15).

Logging GIS Layers

Four digital spatial data sets were created and attributed with appropriate metadata. (These layers are held by the Valles Caldera Trust in ArcINFO™ coverage format.) Each layer displays logging activity and severity for that period (Figure 16). No evidence of harvest prior to 1935 was found. From 1935-1962 low elevation ponderosa pine stands

bordering the grasslands endured light to heavy selective cutting, with our mapped locations for this phase of logging concurring with descriptions from Martin (2003) and the USFS (1993). From 1963-1972 clear-cutting occurred over a range of elevations, enabled by a new network of logging roads. There is no visible logging activity from 1973-1979. From 1980-1991 and 1992-2000 selective harvest (ranging from light to heavy) and patch cutting were prevalent throughout the VCNP but on a smaller scale. Absent and imprecise NMSF maps and spatial ambiguity of selective harvests on airphotos leaves the 1980-1991 coverage (and to a lesser extent the 1992-2000 coverage) relatively incomplete (Figure 17). These layers serve as minimum harvest maps since some areas of harvest may not have been identifiable by the methods employed. The 1980-1991 period is particularly suspect, hence its separation from the rest of the third logging era. We used logging evidence from the timber cruise field tally sheets (Figure 8), vegetation plots (Muldavin and Tonne 2003), and field reconnaissance (Koski et al., in review) to check digitized location of logging occurrence. Although harvests in the Santa Clara Pueblo's western corner are shown, they are not included in analyses of VCNP harvest history.

Timber Comparison, 1978-1998

Seven new strata were produced for the purpose of comparing 1978 and 1998 timber volumes on the Baca. The areas of the new strata are relatively colinear (Figure 18) with the greatest discrepancy being for the Garita and Toledo strata (Figure 13). The Garita stratum difference is due to arbitrary boundary delineation; the Toledo stratum difference

is a result of a change in the property boundary.

With a few minor exceptions, both absolute volume (board-feet) and volume per area (board-feet per acre) increased for every species in each of the seven strata (Figure 19, Figure 20). The relative magnitude of change was not consistent between species.

Solinsky stated that Garita, Del Medio, and Toledo (heavily clear-cut) were adequately stocked with young regeneration in 1978; this regeneration soon reached sawtimber size and was counted by Keel in 1998 (Figure 19a,f,g). These strata had between two and six-fold increases in volume. Garita, Redondo Complex, and Del Medio (strata A, C, and F) increased the most in total volume of ponderosa pine. All strata at least doubled their stocking of Douglas-fir. Garita (stratum A) had a six-fold increase in ponderosa pine volume per area while Dome Road (stratum E) had a four-fold increase in Douglas-fir volume per area. White fir increased from absent to or nearly so to having a significant presence in Garita (stratum A) and Banco Bonito (stratum D), two of the lowest strata in elevation.

Banco Bonito (stratum D), a low elevation, generally southerly-sloping plateau, was populated with ponderosa pine forests in 1935. After intensive logging in the first logging era and additional logging in the most recent era, ponderosa pine has failed to increase much in volume, while shade-tolerant white fir (and, to a lesser extent, other conifers such as Douglas-fir) has greatly increased in importance (Figure 19d).

Unlogged Stands

Muldavin and Tonne (2003) described and located stands they believe were not

logged and listed four possible reasons for this:

- difficult slopes, logging not mechanically/economically viable
- immature, non-commercially viable stands
- species composition of low economic value
- aesthetics prevented harvest

Solinsky (1979) considered these to be “non-commercial” areas.

Construction of the GIS logging database provides a spatial perspective on minimum area logged (Figure 21). It generally agrees with Muldavin and Tonne (2003) and with the Keel timber cruise field notations (Figure 22). The uncertainty about the accuracy and precision of the data sources used to digitize the logged areas prevents this research from drawing exact boundaries or identifying exact aerial extent of all unharvested areas.

Some black areas on the map may in fact have been harvested (e.g., the north side of Dead Indian Mountain). There may also be some areas (e.g., zone 6, Willow/South Mountain) where the digitizing precision could not accurately identify internal stands of virgin forest within a selectively logged forest. Some cruise plots with harvest evidence lie within areas identified as potentially unharvested (e.g., zones 8a and 11) by the coarse-scale maps of this research and Muldavin and Tonne. Likewise, there are small patches of trees and individual trees within the minimum estimated harvest polygons that remain from original virgin forest.

Road Network

Logging roads have degraded the ecological and aesthetic qualities of the VCNP landscape. Over 1,000 miles (1,610 km) of roads were built in the Baca between 1963 and 1971 alone (Martin 2003). The same roads that contributed to public outrage and a

lawsuit in the 1960s (Martin 2003) while supporting intensive timber extraction at all elevations are still ubiquitously visible in the VCNP (Figure 4). Records indicate that methods used to encourage plant regeneration on logging roads often failed in the short-term (e.g., Redondo Border, NMSF records).

The landscape fragmentation and resultant negative ecological effects caused by road construction may exceed that of actual harvests in some locations (Tinker et al. 1998). Severity of individual road effects does not vary directly with logging intensity; a kilometer of road built to support a selective harvest would presumably have the same effects as a kilometer of road built to support a clear-cut. From 1963-1972 however, many more roads were built in a more dense arrangement than in other eras.

Other Disturbances

Although the effects of pests and pathogens on VCNP forests have not been intensively studied, it is certain that these disturbance agents have historically played a role in ecosystem functioning and continue to do so today. NMSF records document the locations of some insect and mistletoe infestations, particularly when selective or patch cutting was being used to preclude the spread of these pests (Figure 23).

Records from over half of the 1980-2000 timber sales mention blowdown (windthrown trees) in some capacity (NMSF records). This qualitative evidence suggests that tree mortality by windthrow is accentuated after logging, particularly along ridges and at the edge of clear-cuts (Alexander 1998). NMSF records indicate that even light selective logging in the caldera has increased windthrow potential in the past. Some sale records between 1980 and 2000 included windthrow harvest as part of the harvest plan.

DISCUSSION

Current Timber Estimates

The 1998 estimate of 489 million board-feet is the best estimate for current total timber volume on the VCNP and falls within the range of Glover's (1990) two suggested estimates of pre-1935 Baca timber volumes, 400 and 500 million board-feet. Despite the large uncertainty surrounding Glover's uncorroborated estimates, it is probable that current total timber volume is similar to pre-logging volume.

The cruise data are coarse and are only meaningful when aggregated to the scale of the stratum or Preserve. Since 1998, the major sources of biomass removal—logging, fire, insects, drought—have not significantly affected VCNP forests so it is logical to assume that timber volume has increased during this period. The multiple pathways of vegetation response to past logging in the VCNP have yet to be described, so the direction of change of forest stands is relatively uncertain.

Even if pre-1935 and current volumes are similar, the population structure of timber is certainly different today than in pre-logging times. In many stands, a greater proportion of smaller and more numerous trees populate today's landscape (e.g., Koski et al., in review), and it is likely that species composition is very different today from a century ago. The recent pulse of establishment is due to a combination of post-logging regeneration and increased tree survival in the absence of fire. Logging regeneration includes shade-intolerant species (ponderosa pine, aspen, corkbark fir) established in severely logged stands and shade-tolerant species (Douglas-fir, white fir) established

where less severe logging opened canopy gaps. Understory infilling of shade-tolerant species is a typical product of fire exclusion in fire-adapted conifer forests of the Southwest (Covington and Moore 1994).

Timber Comparison, 1978-1998

Some proportion of the consistent sizable increases in volume detected from 1978 to 1998 may be an artifact of different data collection strategies, but it is logical to assume that the stocking levels of most stands have increased in the last two decades of less extensive selective logging. Favorable warm and wet growing conditions between 1976 and 1990 (Swetnam and Betancourt 1998) could have also contributed to a pulse of young growth reaching the minimum diameter threshold by 1998. We perceive area-normalized statistics and changes in relative species proportions to be less biased than simple comparisons of volume. Even if our stratum aggregation methodology is imprecise, all timber estimations should be generally comparable in assessing volume per area. It should be noted however that variable plot cruising (used in 1998 by Keel) is less reliable in assessing stem density than other sampling methods (Lindsey et al. 1958).

Thinning

Timber harvest has potential as a tool for promoting the multiple values of VCNP forests. One of the most urgent current management needs is for small diameter tree thinning. Thinning can be used to maintain stand health, reduce the probability of severe wildfires (Pollet and Omi 2002), improve timber quality for later harvest, improve the

aesthetics of a stand, and improve habitat (Smith et al. 1997, Nyland 2002). Action should be implemented as stand-specific treatment prescriptions mindful of local forest structure and history. For example, periodic thinning around the Headquarters area may be preferable to other methods of stand structure maintenance. A combination of thinning and prescribed burning or other treatments may be preferred in other locations.

Financial profit from timber utilization is a major economic incentive for logging operations and could support the Congressional mandate of financial self-sufficiency (Valles Caldera Trust 2003). Economic benefit, however, should not supersede but rather complement concern for ecological sustainability. Scott (1998) compared various treatment methods in ponderosa pine forests in Montana (including “revenue production treatment”) and found the “restoration treatment” alternative to be the best balance of ecological, social, and economic gains. Economic value per tree increases with diameter but large diameter tree thinning may be neither ecologically nor economically sustainable if carried to the extreme. Removal of many large, pre-settlement trees may actually increase fire risk (Agee 1997). Even if thinning is restricted to small diameter trees, increased fire severity may occur in the short-term, due largely to fine fuels generated by thinning procedures (Weatherspoon 1996). An effective approach would integrate where possible multiple methods of restoration, such as using prescribed burning or other fuel treatments after a thinning operation to achieve management objectives (Weatherspoon 1996).

A US Forest Service’s Community Forest Restoration Act (CFRA) project in the VCNP is one example of how targeted, stand-specific harvests can support management

objectives. In 2001 the Pueblo of Jemez initiated a three year project under the US Forest Service's Community Forest Restoration Act (CFRA) to thin targeted stands totaling 113 ha including administrative facilities and public access routes "where movement of a catastrophic wildfire could be reasonably curtailed" (Pueblo of Jemez 2001). Targeting locations of high value or high spread potential maximized the efficiency of the work. Selective preservation of individual old, seed, wildlife, and survey trees help improve rather than degrade ecological resilience and integrity. Additional benefits include local employment opportunities and the use of salvaged timber for marketable wood products, increasing its attractiveness as an ecologically, economically, and socially sustainable endeavor (Pueblo of Jemez 2001).

Fuel reduction treatments directly address severe fire hazard by physically removing small diameter fuels that augment fire intensity and provide horizontal and vertical fuel continuity. Logging does not mirror the disturbance effects of frequent, low-severity wildfire. The proper harvesting system can, however, reduce the risk of ignition and spread of catastrophic wildfires as well as restore some of the structural characteristics of a pre-suppression forest.

Past small diameter wood production on the Baca was limited to firewood and Christmas trees (NMSF records, USFS 1993). Expansion into larger markets of small diameter products, such as those encouraged under the CFRA program, could help create an economically self-sufficient mechanism for conducting thinning operations. Using slash from thinning operations to prevent erosion along old logging roads is one example of how these operations could increase ecological sustainability. Aesthetics can be

maintained through thinning by creating more visually desirable stands (Scott 1998), as is planned for History Grove, the old-growth ponderosa pine stand in Valle Grande near the Baca Ranch/VCNP headquarters.

Old-Growth Stands and Preservation Areas

Despite widespread harvest of the biggest and oldest trees throughout the Jemez Mountains, the VCNP is home to some of the largest remaining old-growth stands in the mountain range (Allen 1989, Muldavin and Tonne 2003). One of the forest management goals of the Comprehensive Management Framework is protection and restoration of old-growth stands.

The map of minimum harvest (Figure 21) coarsely identifies areas where old-growth is most likely to occur. This map and the Muldavin and Tonne (2003) map show a substantial level of landscape-scale agreement (Figure 8). They also demonstrate a lack of the fine, stand-scale knowledge necessary for effective timber management. Even if airphoto and NMSF records had been clear and complete enough to show all logging activity, not all uncut stands could be considered old-growth—this designation must be applied with reference to an individual stand's age and disturbance history.

Data limitations notwithstanding, there are still stands of outstanding ecological and social value that outweigh the economic benefit of large-tree harvest and warrant preservation. History Grove, near VCNP Headquarters in Valle Grande is an excellent example of old-growth ponderosa pine forest and should be maintained as such. The Redondo Peak area, recognized for its spiritual, ecological, and aesthetic values (Valles

Caldera Trust 2003), was also identified by Muldavin and Tonne (2003) as an area warranting preservation. It has escaped intensive harvest through its relative inaccessibility and low timber volume.

Old-growth stands, despite their unharvested status, have experienced alteration as a result of disturbance regime changes and currently require active management to maintain their structure and health. Restoration and maintenance of the structural patterns and ecological processes of old-growth forests might even involve small diameter thinning as a management prescription. The sharp negative exponential size distributions of trees displayed in the timber cruise distribution plots illustrate the high proportion of small (i.e., young) trees in all VCNP forests, not just unharvested stands (Figure 15). In old-growth ponderosa pine forests under a natural disturbance regime, we would expect one or more orders of magnitude fewer trees and a shallower size distribution with a longer right-skewed tail indicating the presence of a large proportion of large trees (Covington and Moore 1994). Stand treatments may be applied to restore forest structure to a more desirable state. Any management plan will require consideration not only of the current status of a particular stand, but its spatial context. Neighboring stands that have been harvested may affect uncut stands and the spatial nature of the GIS database will allow managers to consider that when planning restoration actions.

Road Network

Logging roads are a secondary but significant legacy of timber harvests. Allen (1989) reports the total road length in the Jemez Mountains increased from 719 km in 1935 to

8,433 km in 1981. Many of the early roads constructed in the easily-accessible valleys suffer from inadequate surface drainage. Much of the extensive road network constructed in the 1960s to support intensive logging suffers from excessive drainage, creating erosion and surface water quality issues (Valles Caldera Trust 2003). Roads directly affect the landscape patterns, stand structure, and ecological functioning of forests and influence the regimes of disturbance processes. Logging roads may actually cause more and longer-lasting forest fragmentation than the actual clear-cut the roads supported (Tinker et al. 1998).

The existing roads also have benefits, in particular their value as access routes. Roads intended to support past timber harvests could continue to do so in the future. Roads also aid in fire use and control. Roads have already proven their utility for access to grazing livestock, research sites, and recreational opportunities (Valles Caldera Trust 2003). Most of the VCNP's roads, however, are not necessary to support these needs. Strategic roads that can support heavy traffic with minimal maintenance would be beneficial to the VCNP, while most of the dense, spiraling dome roads could be retired. A forthcoming Valles Caldera Road Management Plan should address road maintenance, repair, and removal issues as well as the ecological restoration and damage mitigation of roads that have served their purpose.

Other Disturbances

Changes in composition and structure such as those described in the 1978-1998 comparison have implications not only for future harvests but for ecological disturbance

regimes. Fuel loads and fuel continuity are enhanced by the growth of many short, small diameter trees, enabling more severe wildfire. Spruce budworm, bark beetle, and other pest outbreaks may increase in extent and/or severity where host species are abundant and competition-stressed. Swetnam and Lynch (1993) for example report an increase in spruce budworm synchrony resulting from land use changes. Other factors such as the current southwestern drought accentuate the potential for disturbance regime shifts.

Qualitative evidence suggests windthrow potential increases after logging due to increased wind shear. Post-harvest windthrow is not uncommon in high elevation forests (i.e., spruce and fir) of the southern Rocky Mountains (Alexander 1987). Although it is economically advantageous to harvest windthrown trees, harvest plans should be carefully constructed so as to minimize windthrow potential since the leave trees (uncut mature trees left intact to provide seed sources for subsequent generations) hold long-term ecological and aesthetic value. Complete removal of the forest canopy does not encourage sustainability of forest productivity, economically or ecologically.

Stand Inventory

A stand-level assessment of forest resources is necessary to support forest management. Accurate estimation of tree volume is an indispensable step in timber management planning. As preparation for a timber sale, thinning project, damage appraisal, or restoration action, knowledge of stand characteristics is critical. Size (e.g., diameter, as a proxy for volume or age) and species are the fundamental variables of interest to both foresters and ecologists. Current estimates derived from the timber cruise

are inadequate to address forest management objectives and inadequate to support forest monitoring and concurrent forest research.

A forthcoming vegetation map of VCNP (E. H. Muldavin, unpublished data), vegetation plots established through this research (analyzed in Koski et al., in review), and other forest research (S. Yool, unpublished data) will contribute to stand-level understanding of VCNP forests. With these data sets it will be possible to construct a mosaic of management units. These units of relatively homogeneous forest structure and harvest history (on the order of hundreds of acres in size) would form the basis of future forest management in the VCNP. Existing forest data—perhaps vegetation characteristics, logging history and effects, stand age, fuel types, economic value, and aesthetic concern—would be parsed by unit. Units could then be grouped by treatment prescription and prioritized according to treatment urgency.

CONCLUSIONS

The landscape legacies of logging have significant implications for current and future sustainable management of VCNP forests. The VCNP is today a mixture of high value stands and degraded but recovering stands. High value forest stands include some selectively harvested and unharvested stands that have maintained high ecological, economic, and aesthetic value. Heavily logged and clear-cut stands may still be in the early stages of vegetative response but their timber volume and ecological value are increasing. This research addresses the need to understand these legacies by documenting the occurrence of logging on in the VCNP. This analysis supports several management

recommendations.

Small diameter thinning targeted at vulnerable locations can be a beneficial treatment for reducing stand density. Such treatment reduces fuel connectivity thereby vulnerability to stand-replacing fire. Once stands are thinned, reintroduction of low severity fire is a viable management option. Thinning dense understories of shade-tolerant trees may also reduce vulnerability to insect outbreaks. Small diameter thinning should not greatly increase windthrow potential.

Old growth stands are beginning to succumb to the cumulative effects of human action (e.g., fire exclusion which increases competitive stress) and natural events (e.g., insect and drought-induced stress). Additional management in the form of small diameter thinning can mitigate some of these effects and restore resilience and integrity to old growth stands. Ecologically-based silviculture has potential as an applied ecological tool to support the multiple ecological, economic, and social values of the VCNP's mission. However, the effects of logging on the natural systems of the VCNP are, to a large degree, yet to be determined.

Additional knowledge of stand-level forest structure and history is required to assist decision-making. Currently available data sets are too coarse to inform decisions about local treatment options. A new forest inventory would assess stand structure and history and be comparable to other ecological and silvicultural VCNP data sets. Stand-specific treatment prescriptions should be developed based upon this stand inventory database. Subsequent management action should be accompanied by ongoing monitoring and research.

This research synthesizes information about the logging history of the Valles Caldera National Preserve into a single narrative. We describe data sets relevant to the history of logging and its potential ecological effects are described and present the current estimate of the VCNP timber resource. Integration and analysis of these data sets identifies patterns and potential ecological impacts. This work and future research on logging and its effects will provides an important historical context for management decisions in the VCNP.

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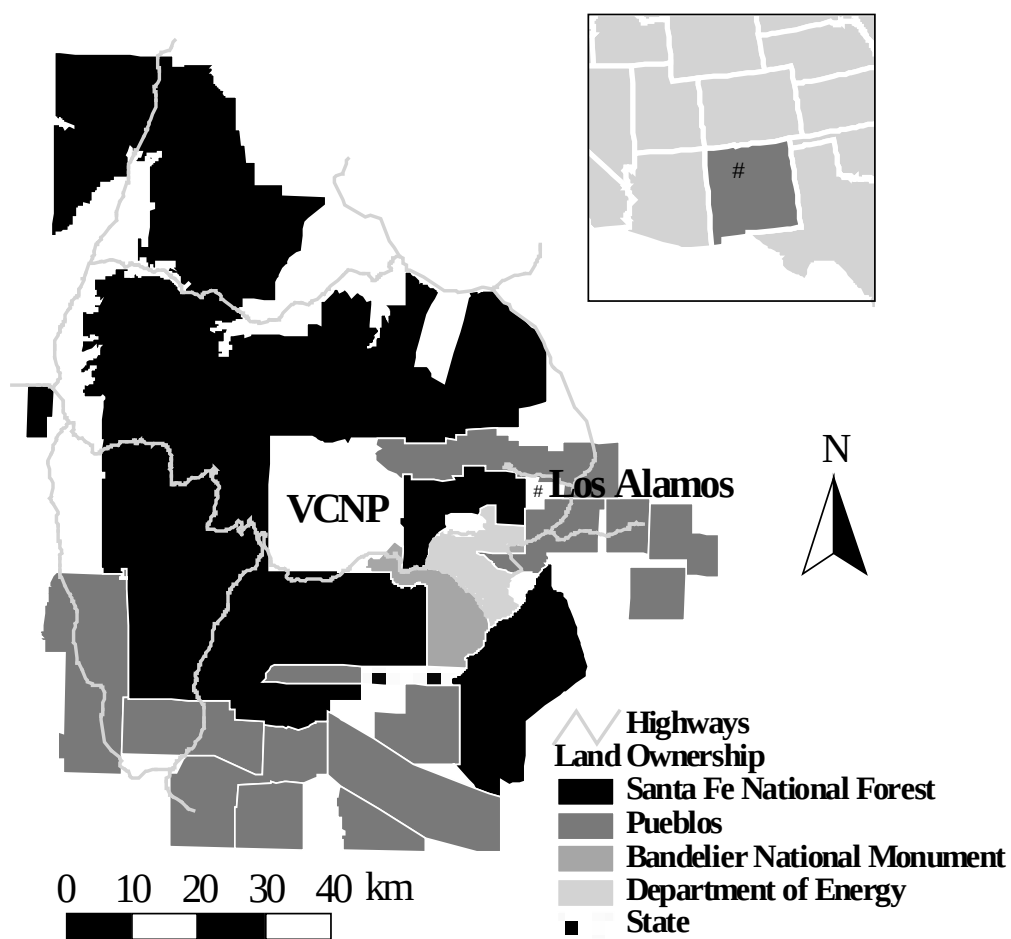


Figure 1: Location of the Valles Caldera National Preserve and major landowners in the Jemez Mountains ecosystem.

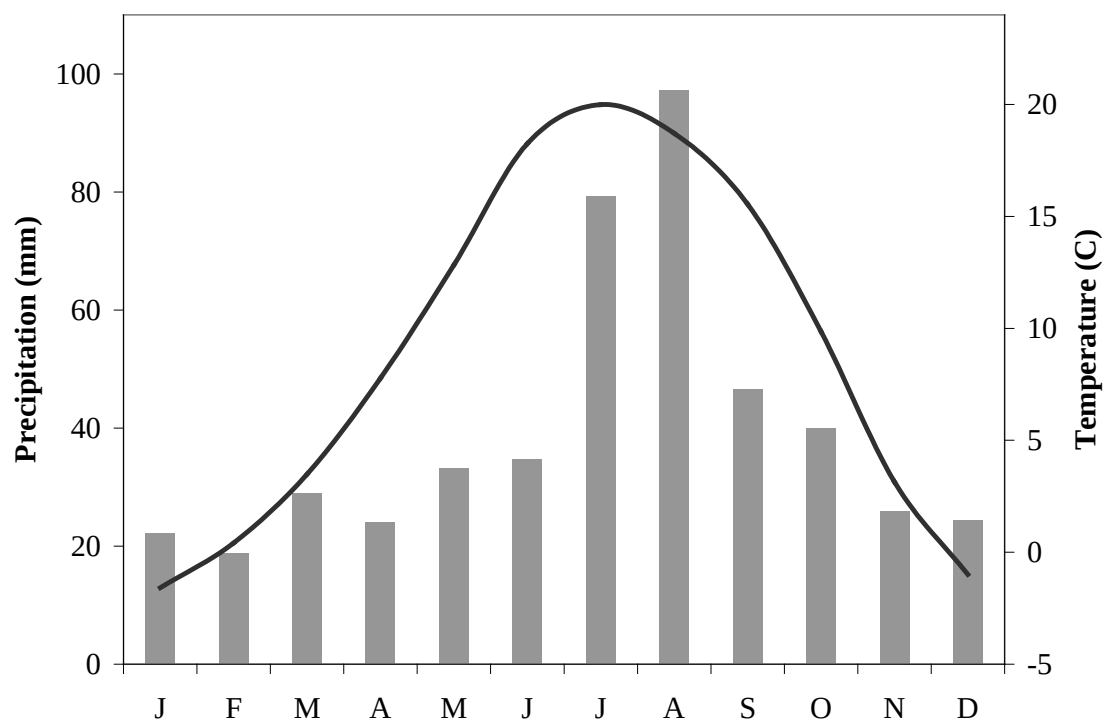


Figure 2: Total monthly precipitation (bars) and average monthly temperature (line) for Los Alamos, New Mexico (station 295084), 1951-2000 (data from the National Climatic Data Center).

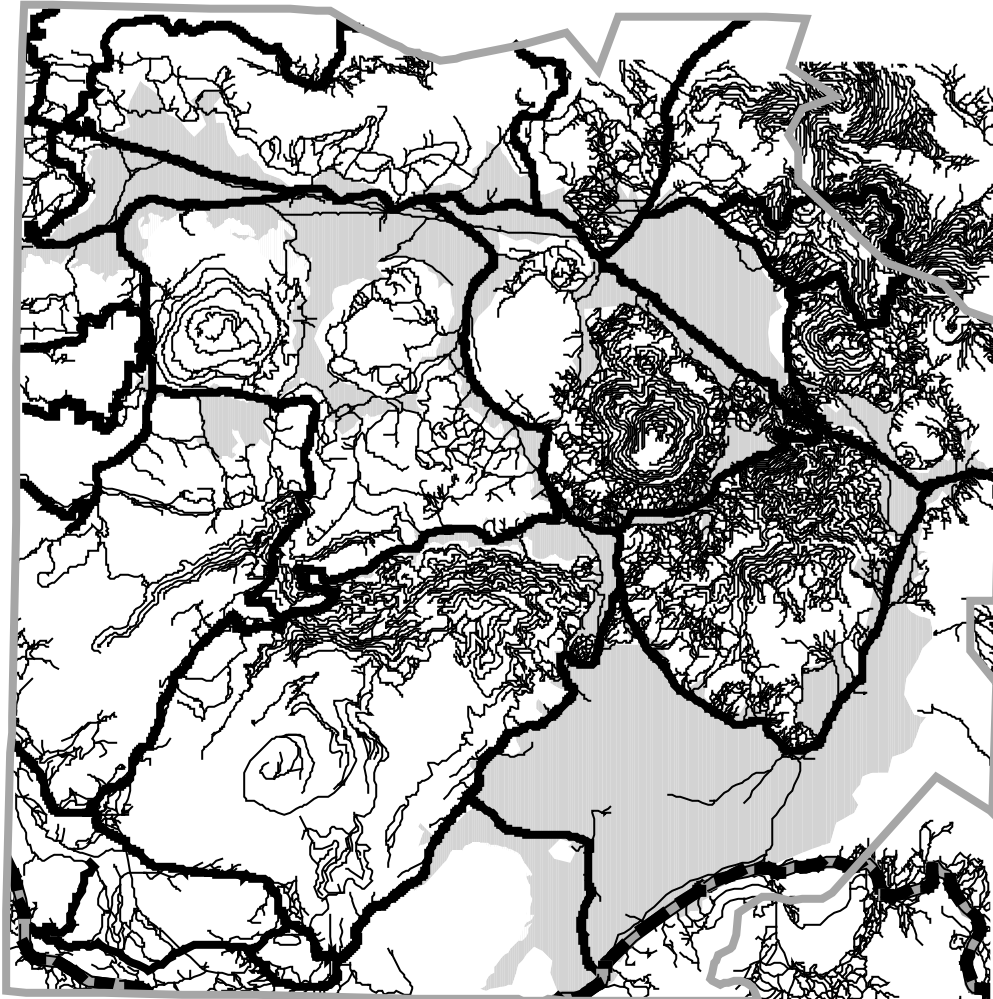


Figure 3: VCNP road network (Allen 1989). Most major roads (thick lines) were built during the first logging era (1935-1962) to facilitate harvest of easily accessible stands near valleys (light gray shading). Most minor roads (thin lines) were built during the second logging period (1963-1972) to facilitate clearcutting.



Figure 4: Logging roads are visible throughout the VCNP.

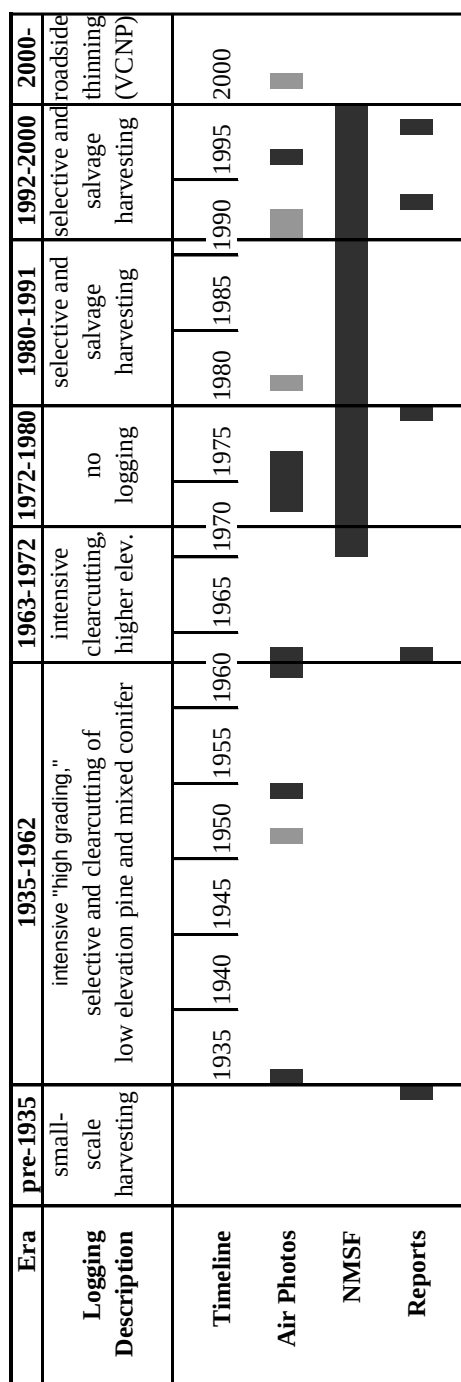


Figure 5: Diagram of data sets relevant to the logging history of the VCNP. Each data set is displayed during its year(s) of observation. Dark shaded data sets were used in this research.

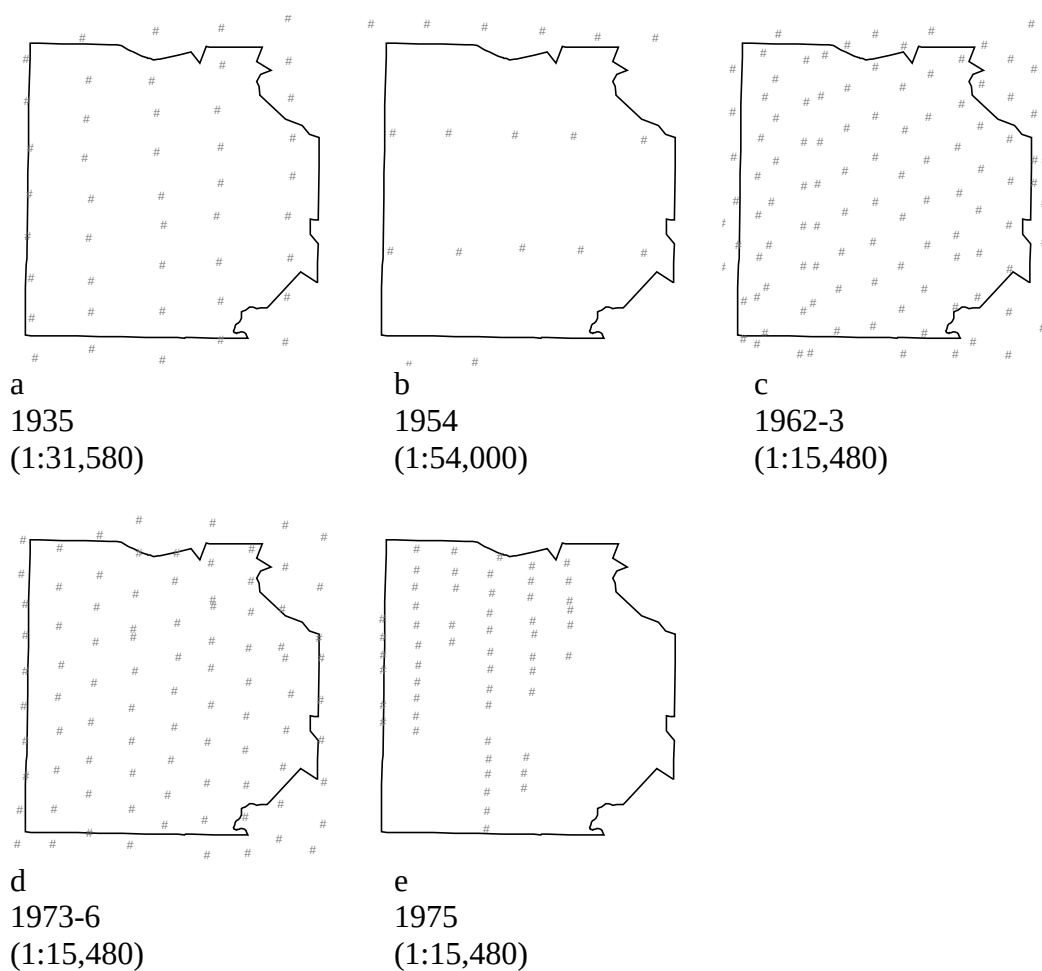


Figure 6a-e: Spatial coverage of the airphotos sets used in this analysis. Points show the geographic centers of photographs used in this research.

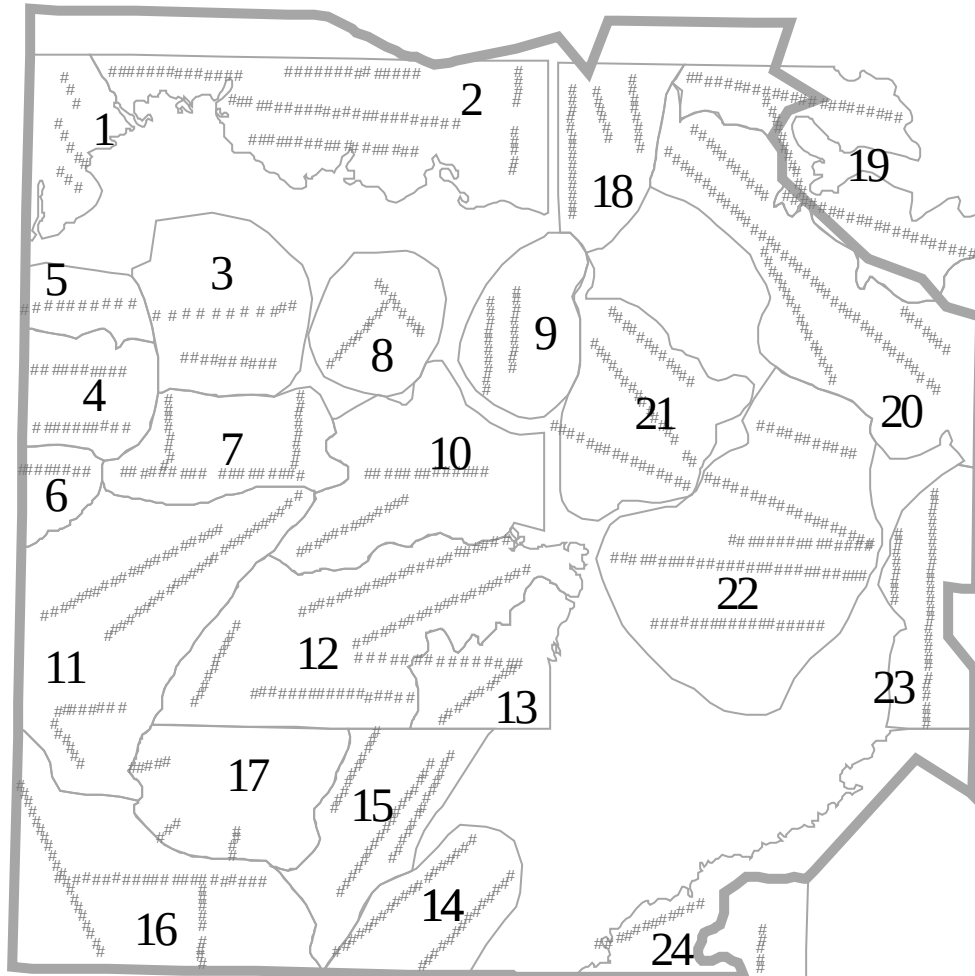


Figure 7: Plot locations from 1998 timber cruise (n = 922) with strata outlined and numbered (Keel 1998).

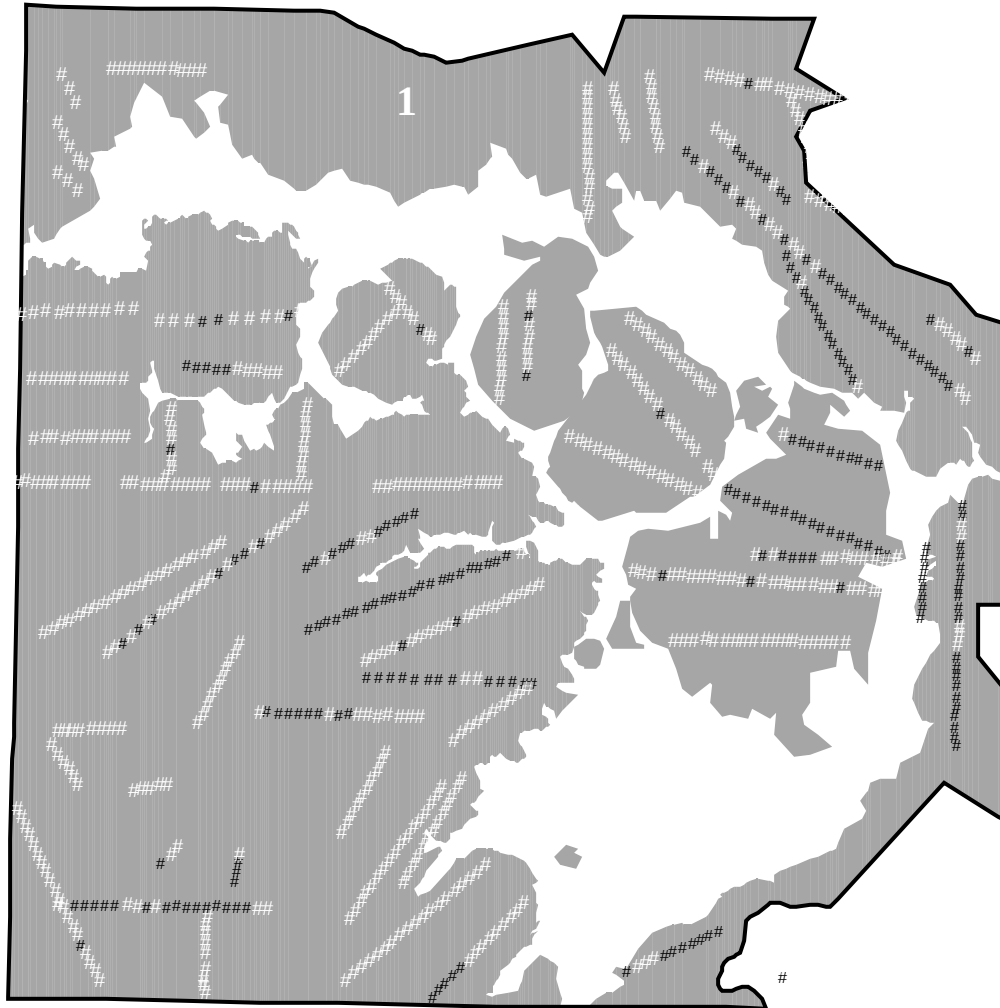


Figure 8: Mention of logging in 1998 timber cruise field tally sheets. Forest is shaded gray. White plots denote plots where no evidence to support or refute past harvest history was given, or where cruisers did not believe prior harvest had taken place. Black plots indicate mention of logging evidence (e.g., stumps).

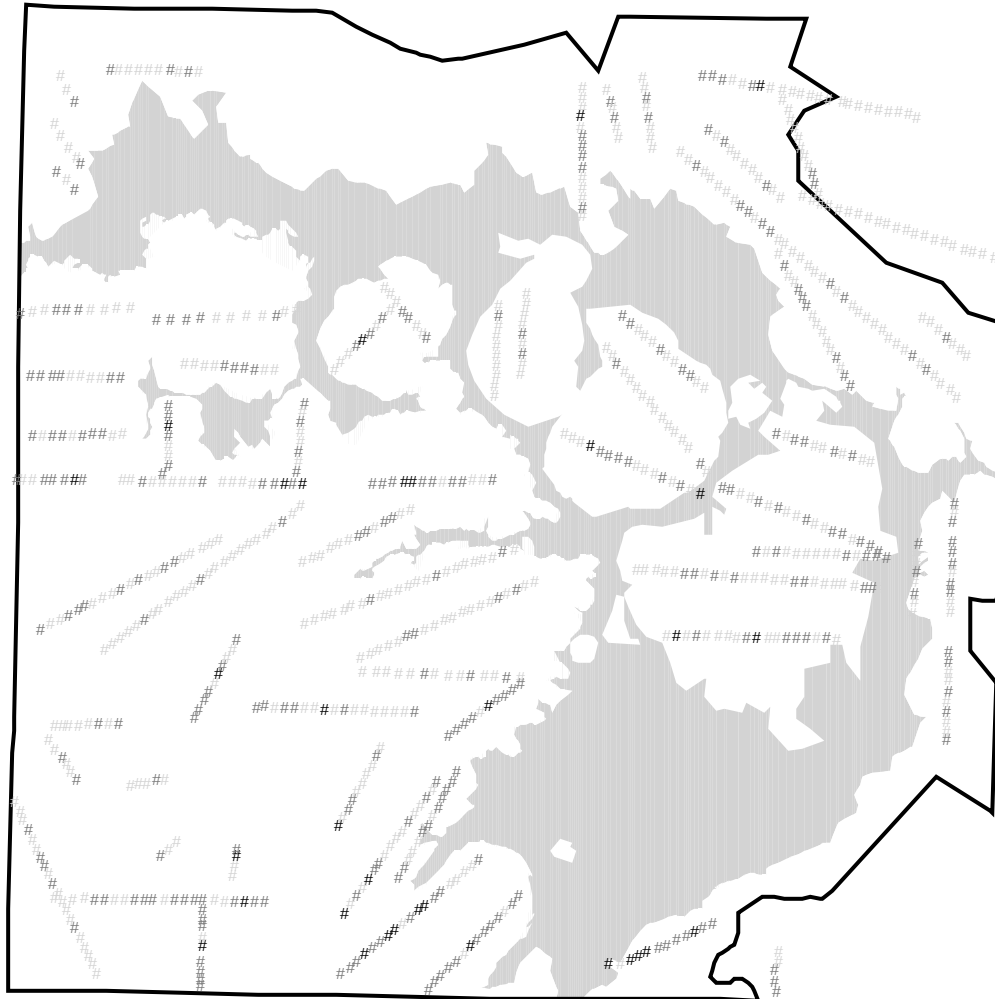


Figure 9: Frequency of trees recorded at each plot (n = 740, 80% of total plots) in the 1998 timber cruise (Keel 1998). Light gray plots recorded 1-3 trees, medium gray plots recorded 4-8 trees, and black plots recorded 9-13 trees. Grasslands are shaded light gray for orientation.

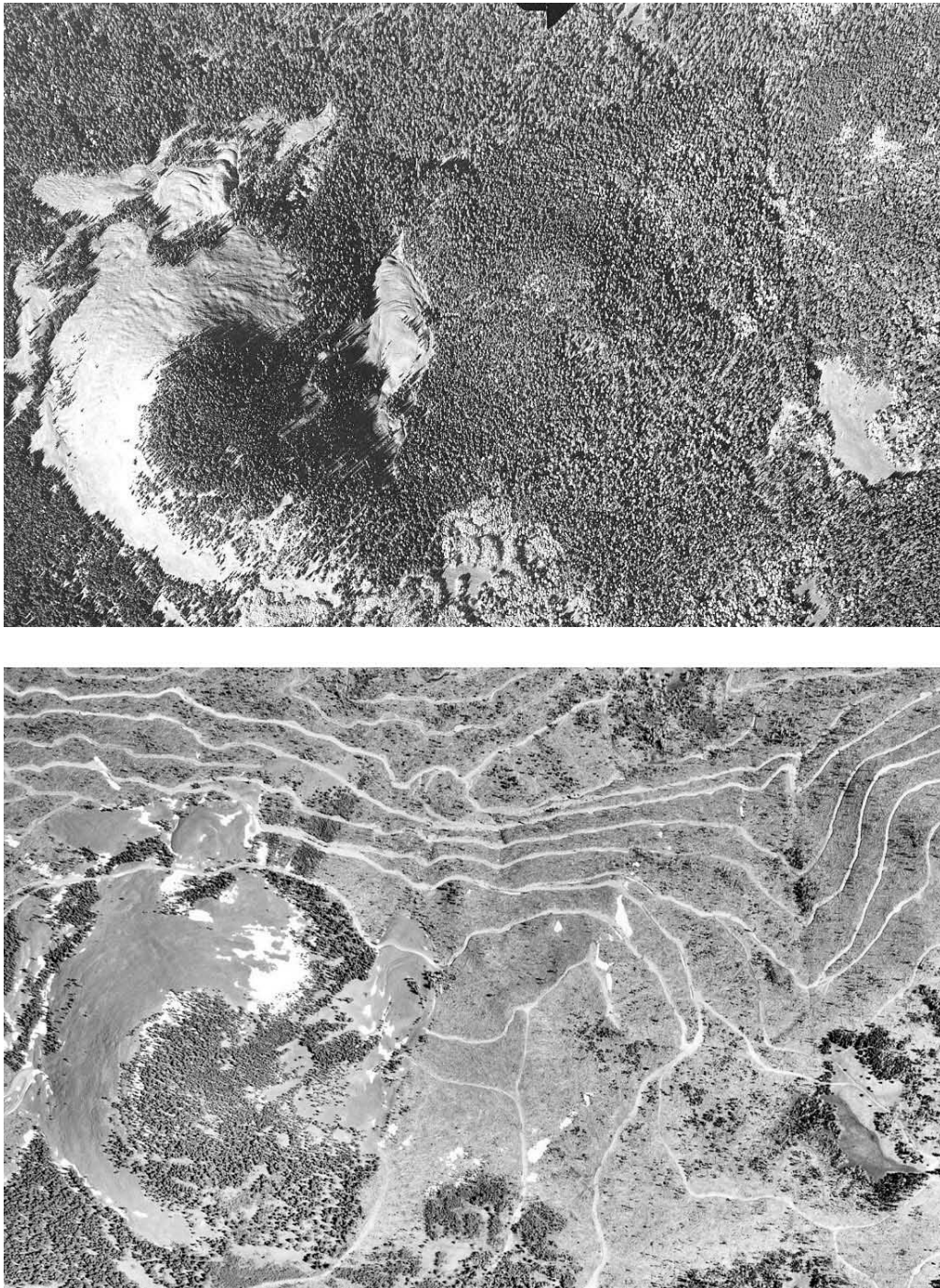


Figure 10a-b: Easily identifiable timber harvest occurred between 1963 (top; photo #11-104) and 1975 (bottom; photo #26-159); Redondito is the dome in the southwest quadrant, photo width is approximately 1.8 km.

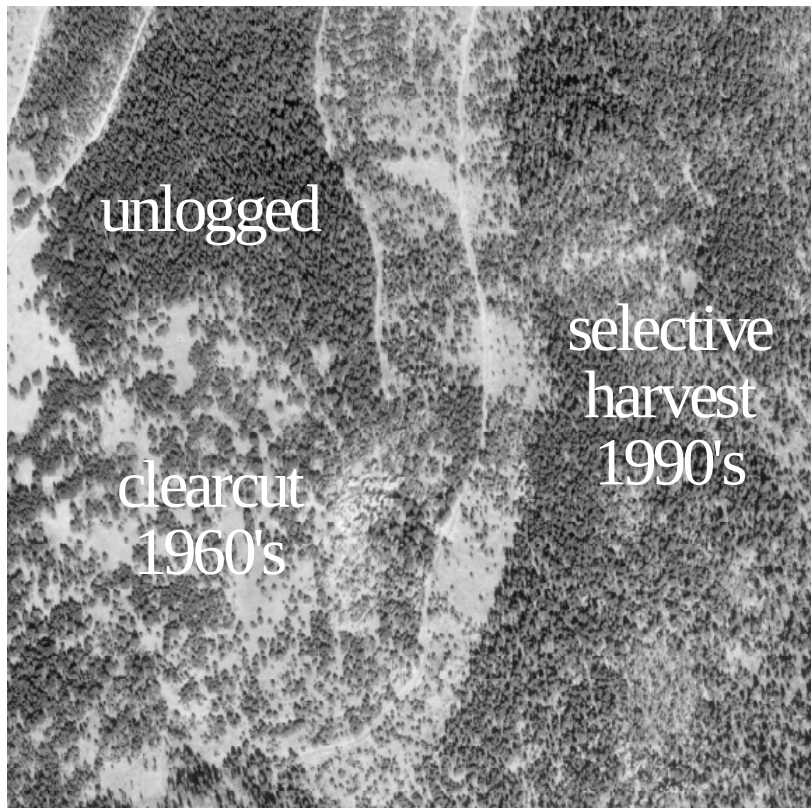


Figure 11: Example of variations in boundary contrasts between stands of differing harvest history. The contrast between unlogged and clearcut areas and even between selectively harvested and clearcut stands was often clearly visible. The contrast between selectively harvested and unharvested stands was often less apparent and sometimes impossible to discern on photographs.

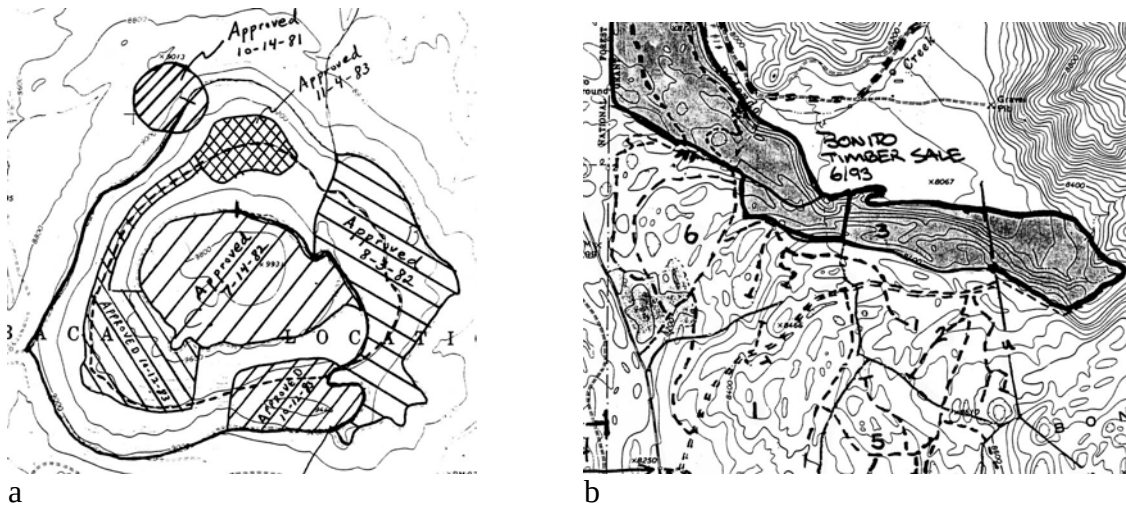


Figure 12a-b: Examples of New Mexico State Forestry records that have (a) well-delineated harvest zones (Dead Indian Mountain timber sale, 1981-3) and (b) poorly-delineated harvest zones showing only sale block boundaries, not actual harvested areas (Bonito timber sale, 1993) (NMSF records).

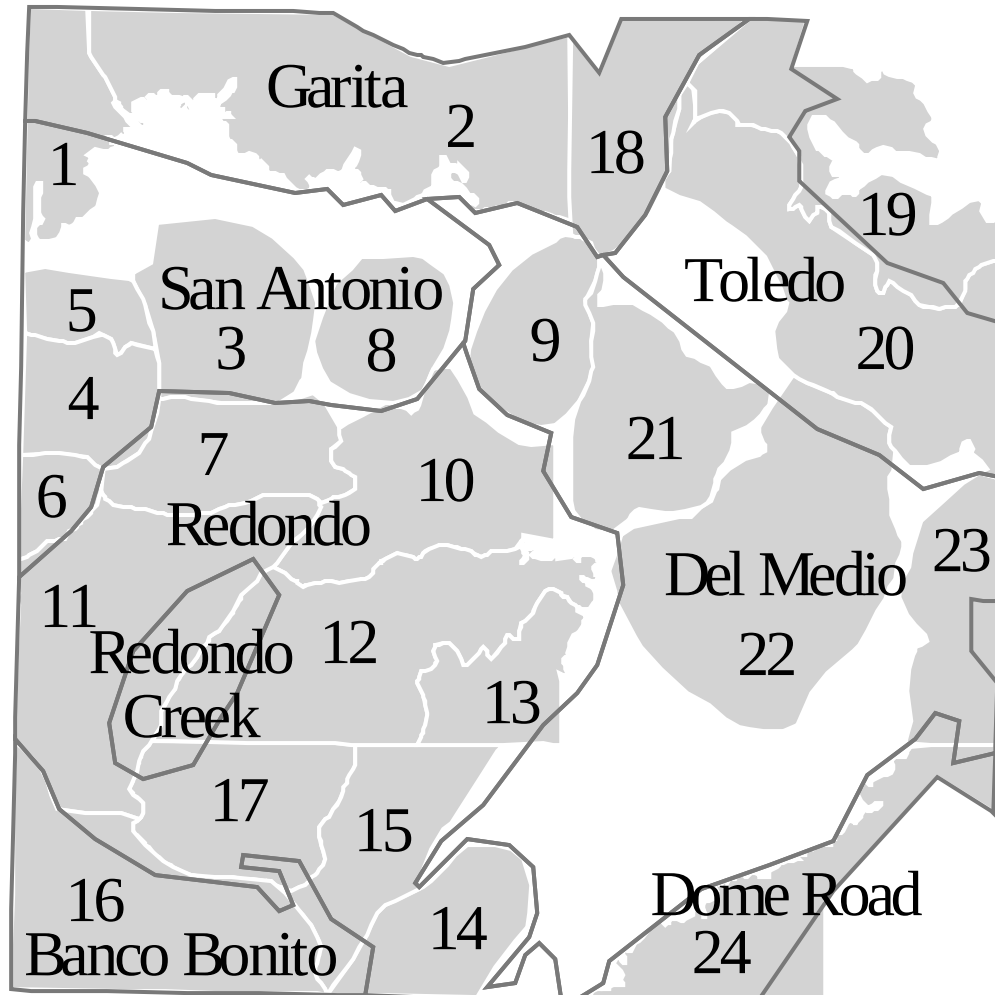
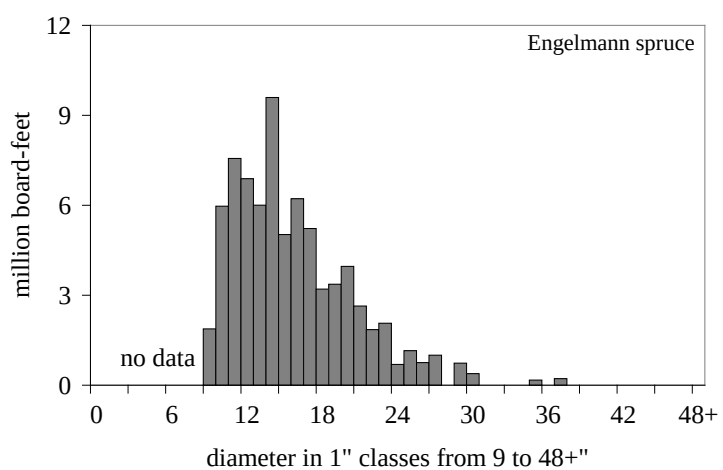
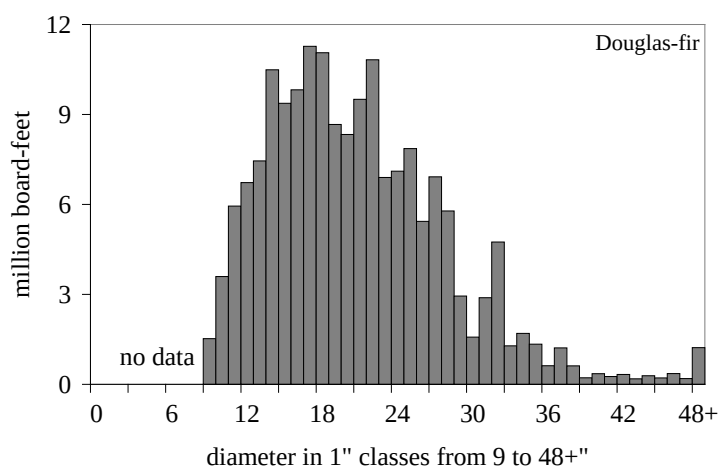
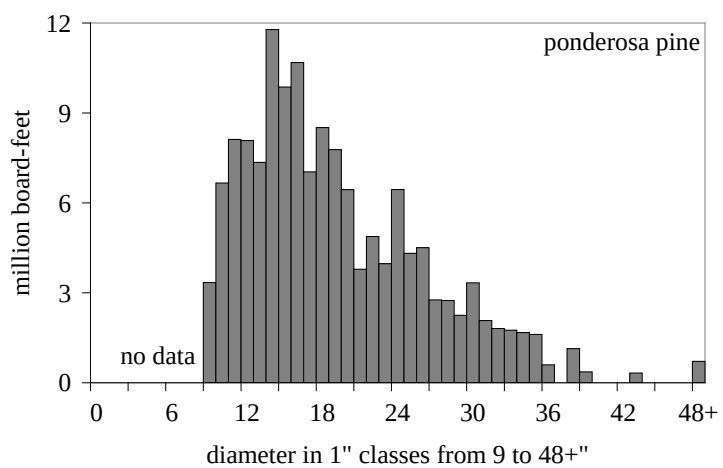


Figure 13: Overlay of 1978 timber strata (named, outlined polygons, Solinsky 1979) and 1998 timber strata (numbered, shaded polygons, Keel 1998). Redefined harvest strata used in the timber comparison used Solinsky's names, with one exception: the comparison combined Redondo and Redondo Creek into the Redondo Complex stratum.



(Figure continued on next page)

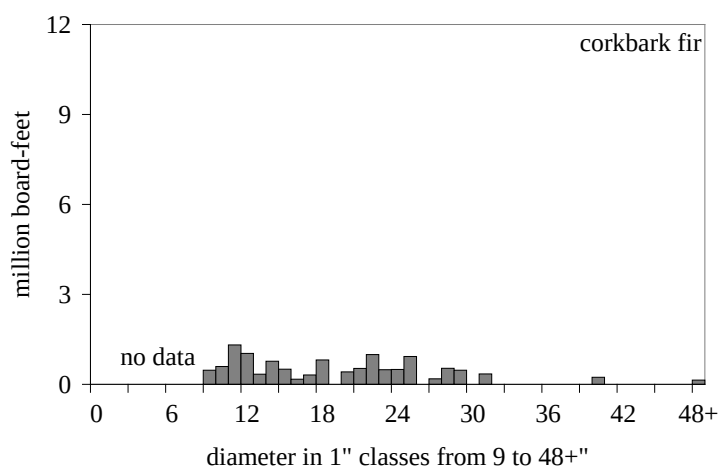
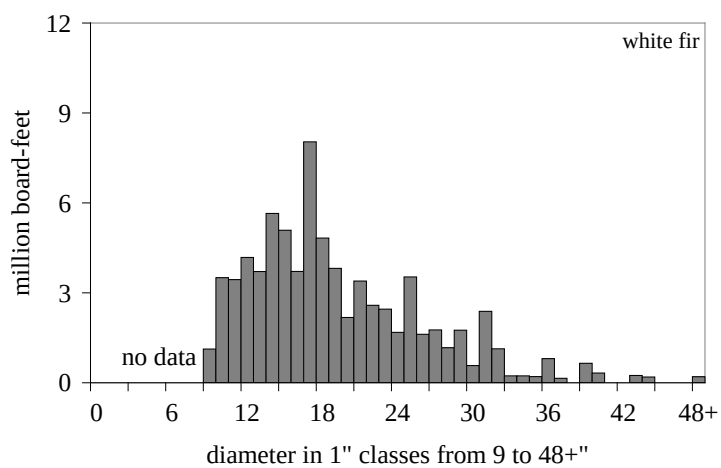
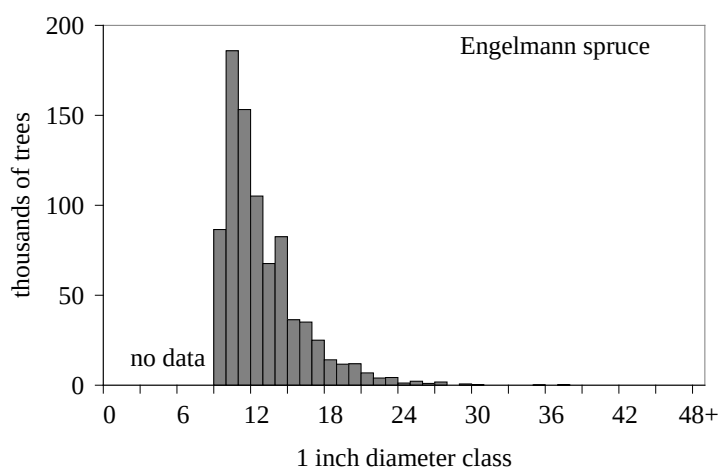
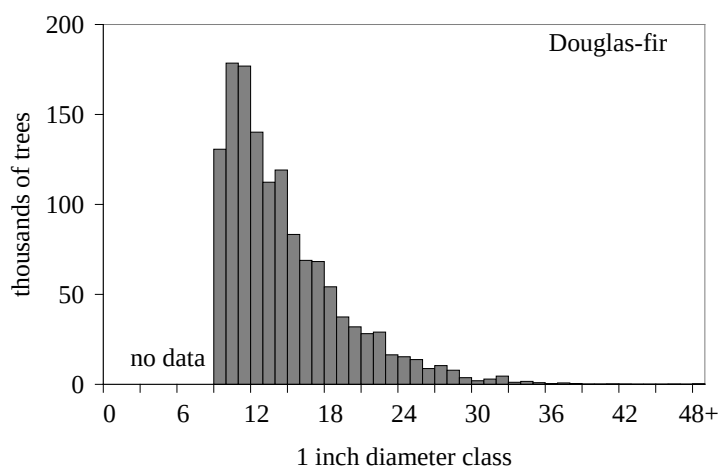
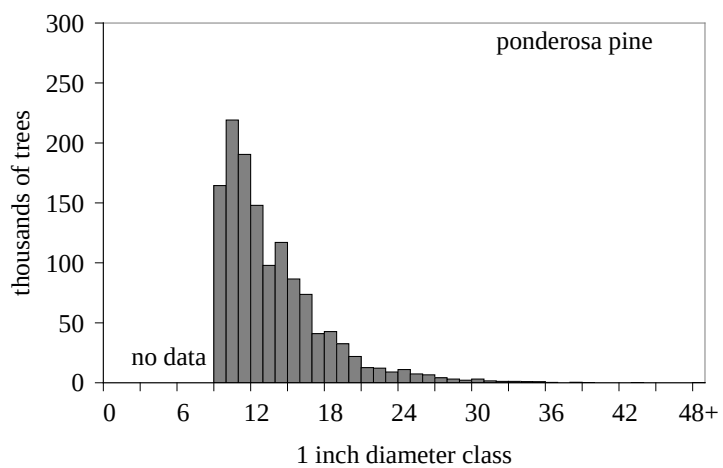


Figure 14a-e: Estimated current (1998) total volume merchantable timber (millions of board-feet) by one-inch diameter classes ranging from 9 inches (23 cm) to 48+ inches (122+ cm) (data from Keel 1998).



(Figure continued on next page)

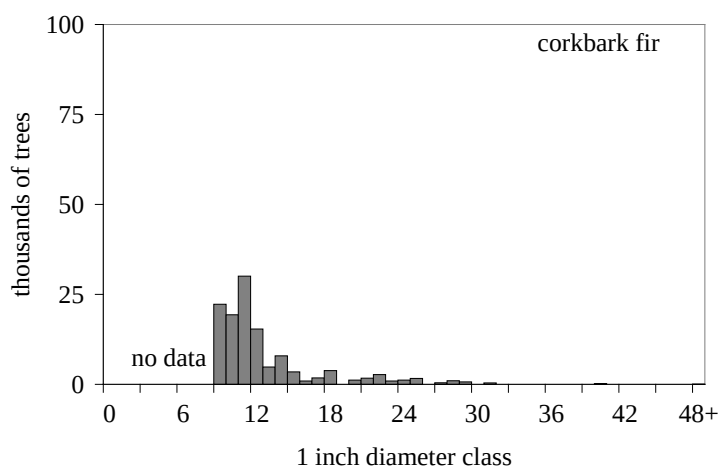
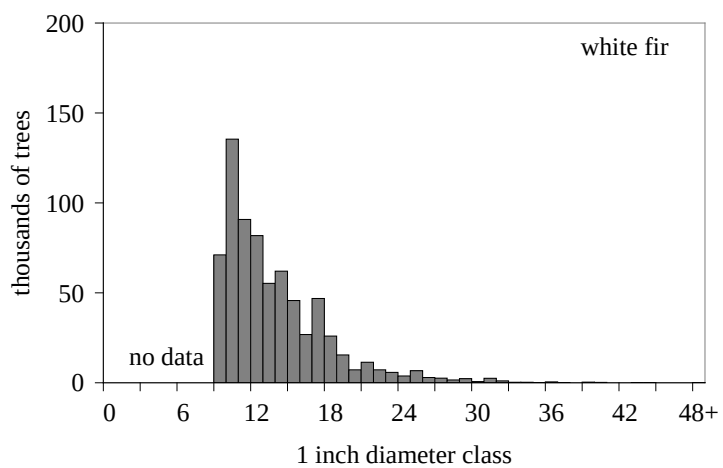


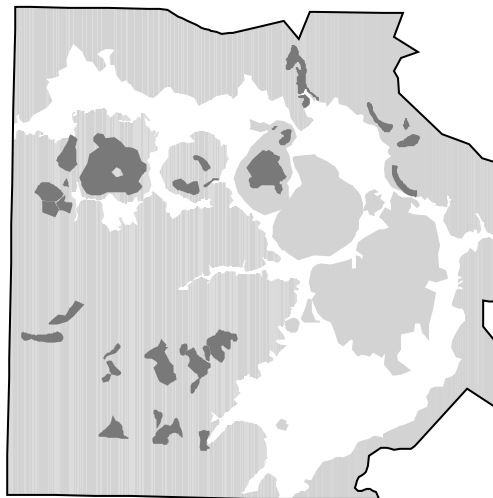
Figure 15a-e: Estimated current (1998) total number of merchantable stems (in thousands; note differing scales) by one-inch diameter classes ranging from 9 inches (23 cm) to 48+ inches (122+ cm) (data from Keel 1998).



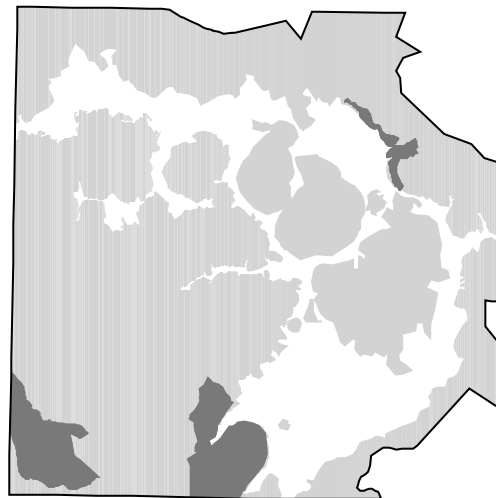
a: 1935-1962



b: 1963-1972



c: 1980-1991



d: 1992-2000

Figure 16a-d: Digitized harvest maps for each of the three major commercial logging eras in the Valles Caldera (the third era, 1980-2000, is divided into two time periods). Dark gray shading indicated minimum harvested area on a light gray background of forest extent. No commercial logging is believed to have taken place between 1972 and 1980.



Figure 17: Illustration of incomplete spatial record of harvest during the era 1980-1991. Harvest blocks within which harvesting was known to have occurred are shaded light gray while actual known harvests within the blocks are shaded dark gray.

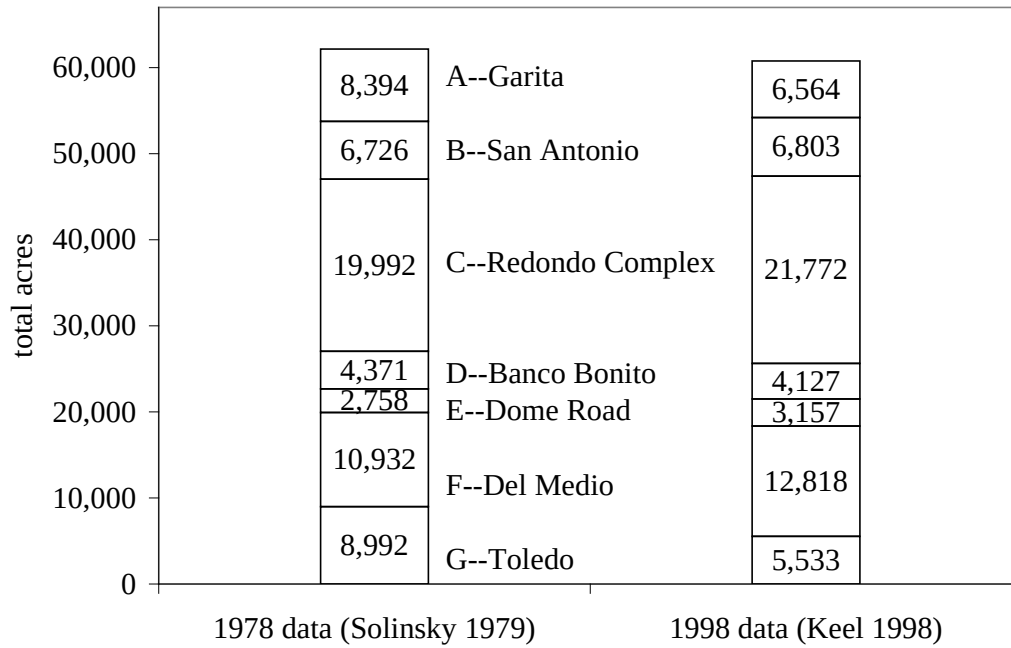
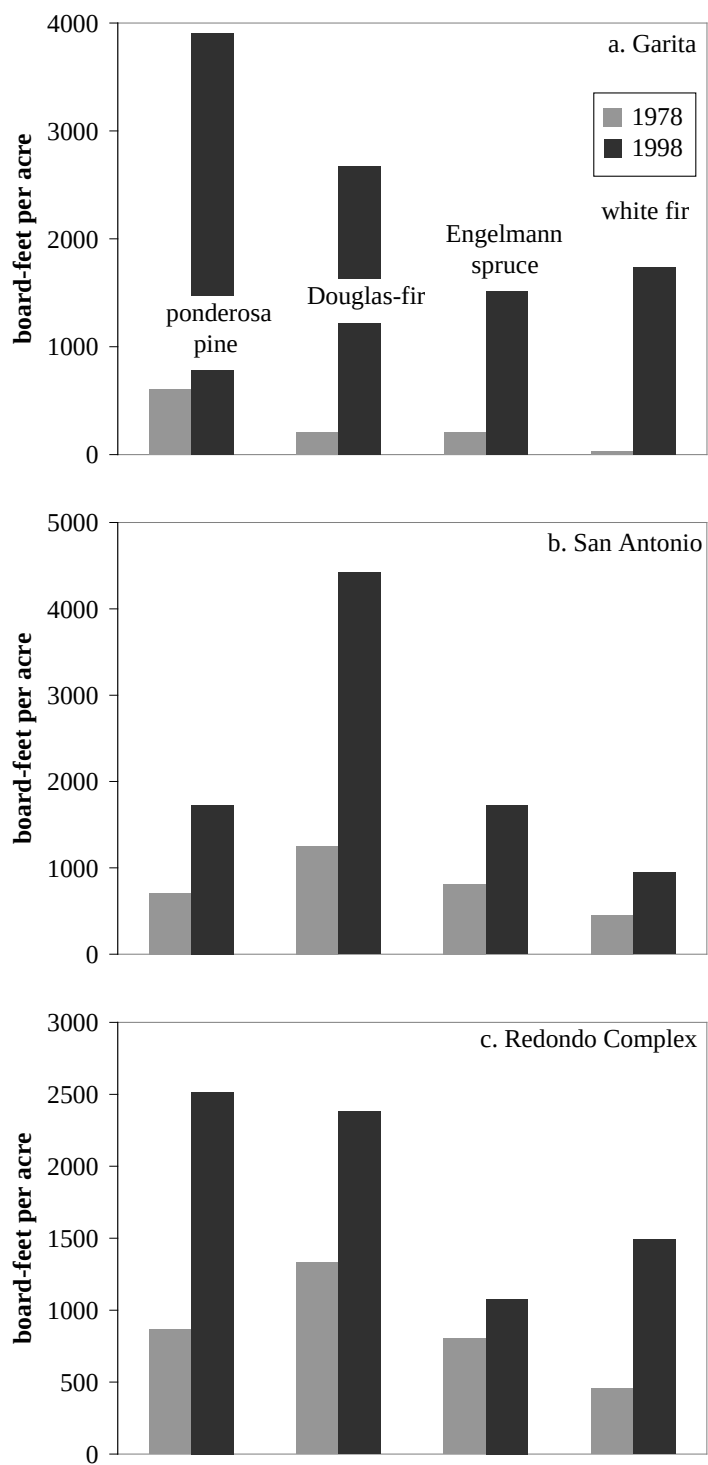
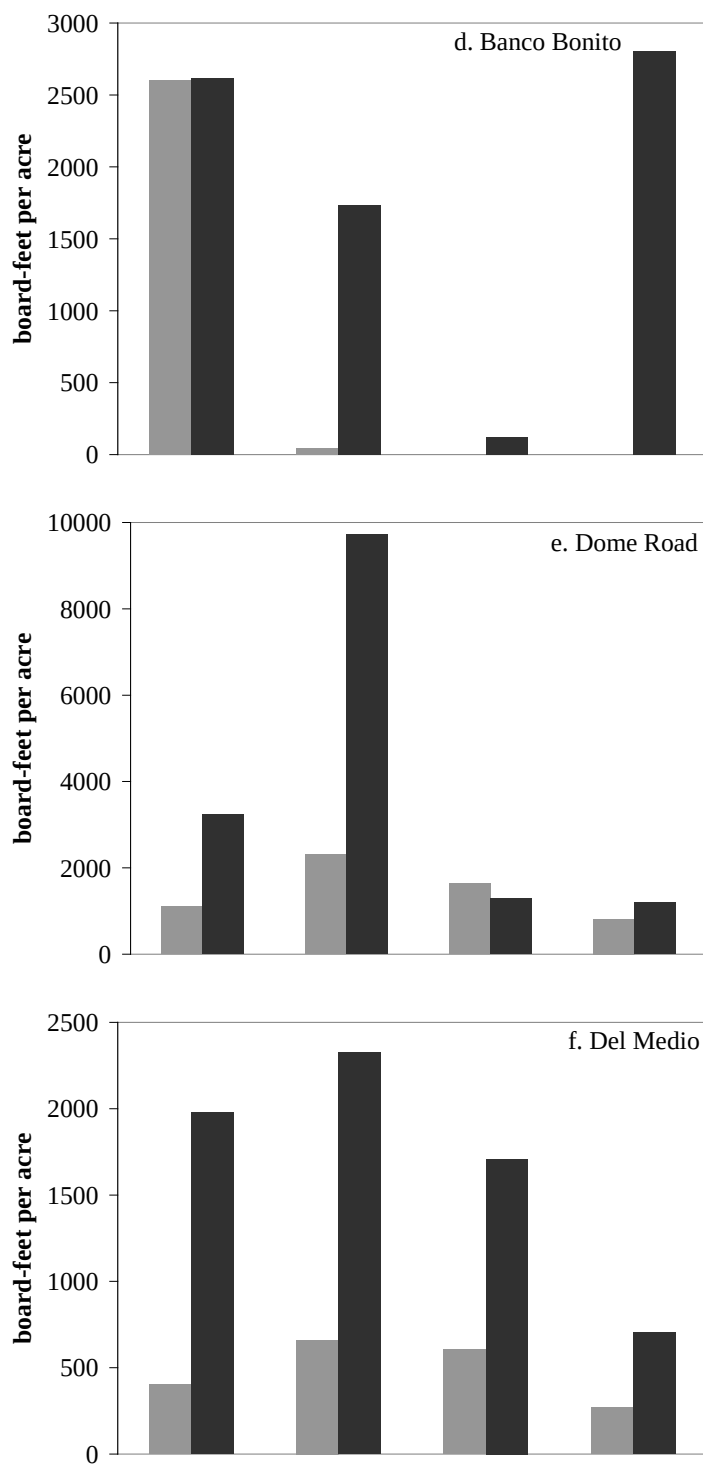


Figure 18: Area comparison between 1978 and 1998 redefined strata (62,165 and 60,774 acres, respectively; data from Solinsky 1979 and Keel 1998).



(Figure continued on next page)



(Figure continued on next page)

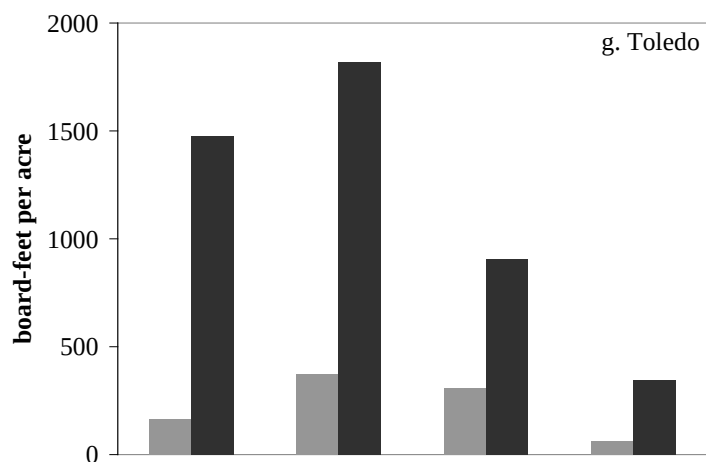
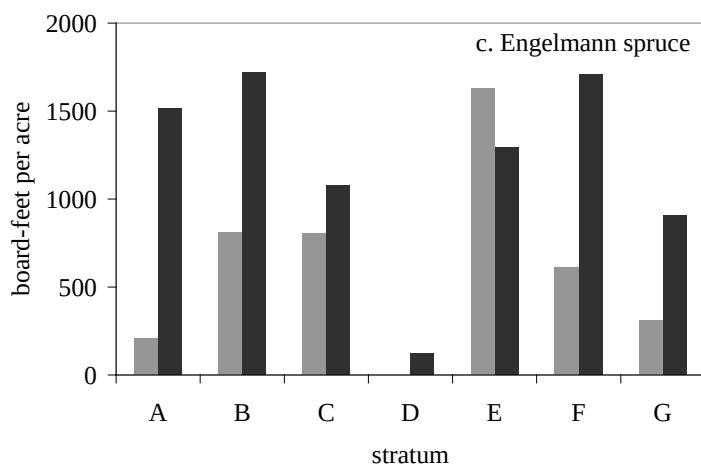
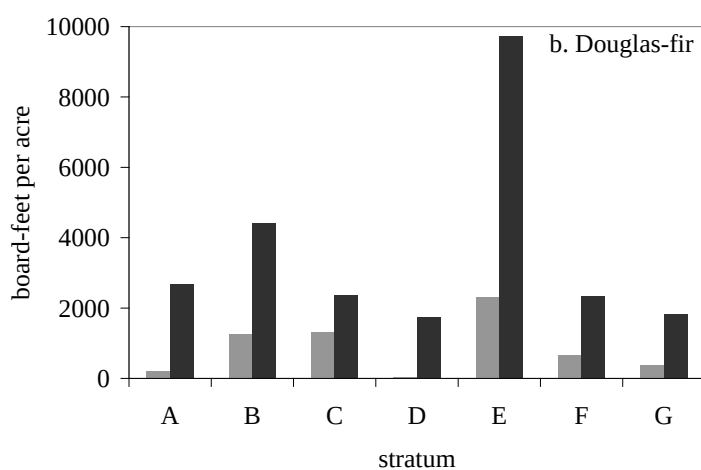
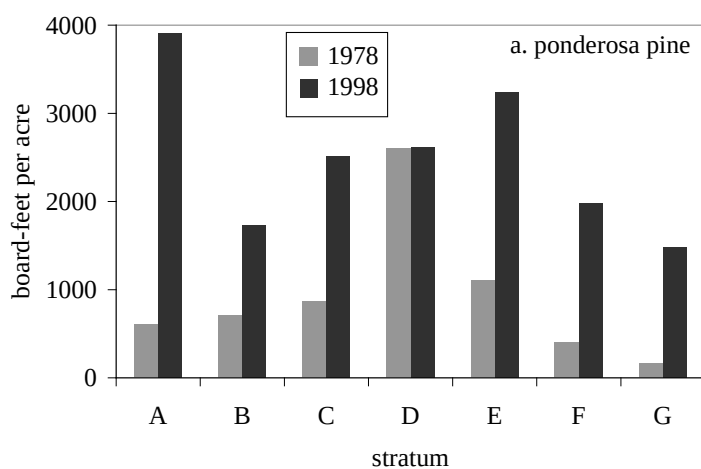


Figure 19a-g: Change in timber volume per area (board-feet per acre) by species (ponderosa pine, Douglas-fir, Engelmann spruce, white fir) between 1978 and 1998 for each redefined stratum (data from Solinsky 1979, Keel 1998).



(Figure continued on next page)

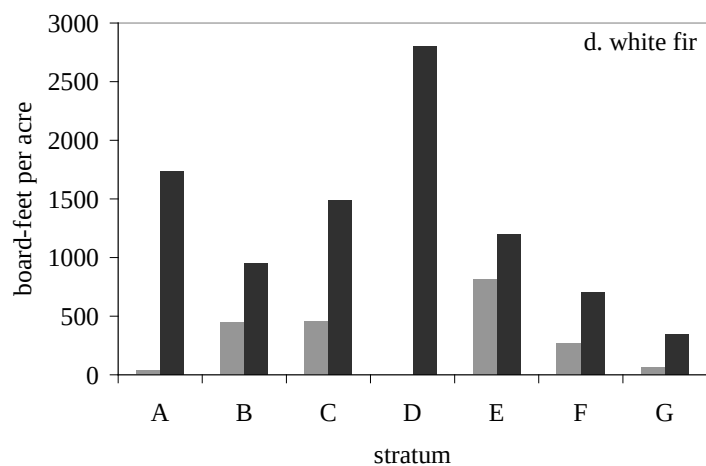


Figure 20a-d: Change in timber volume per area (board-feet per acre) between 1978 (left-hand bars) and 1998 (right-hand bars) for each redefined stratum (data from Solinsky 1979, Keel 1998).

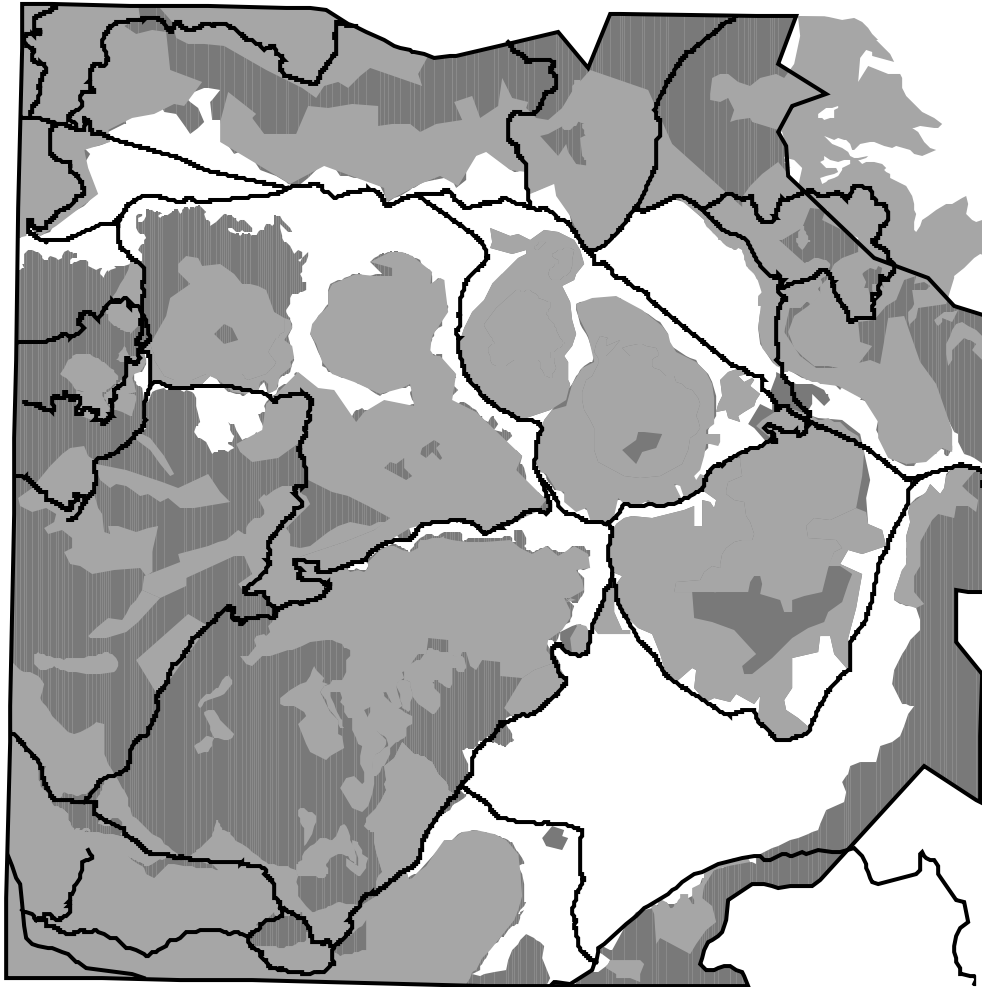


Figure 21: Minimum estimated harvested area (light gray shading) based on digitized polygons of only verified harvested areas. Main roads are shown in black, grassland is white and dark gray shading therefore denotes potentially virgin forest.

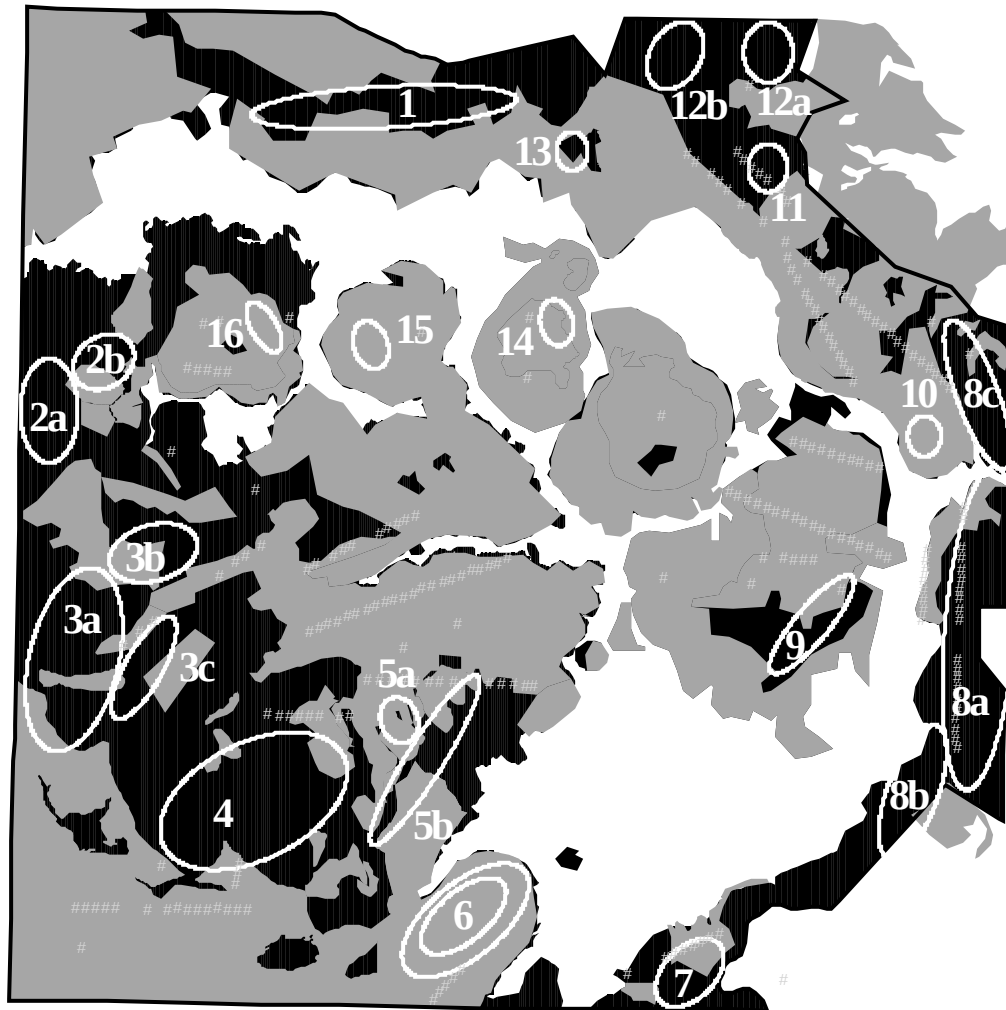


Figure 22: Comparison between potentially unlogged areas. Forested areas shaded medium gray have been explicitly identified in this research as harvested (see Figure 17a-d) and those shaded black are potentially unharvested forest. Numbered ellipses are areas identified as potentially unharvested by Muldavin and Tonne (2003). Light gray circles are timber cruise plots designated as having evidence of prior harvest (Keel 1998).

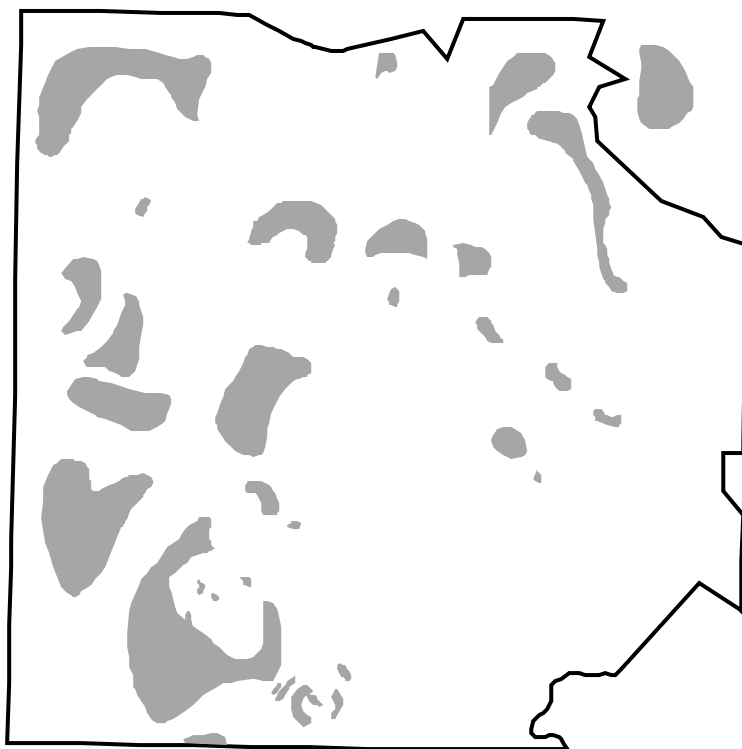


Figure 23: Locations of some insect infestations identified in New Mexico State Forestry records, 1980-2000 (NMSF records).

Table 1: Airphoto sets covering the VCNP. Five print sets and one digital set of airphotos were scanned (300 dpi) and used in this analysis. The methods of interpretation do not require orthorectification. Only every other photograph was scanned in sets which overlap in coverage by 60%.

<u>year</u>	<u>type</u>	<u>scale</u>	<u>used</u>	<u>coverage</u>
1935	grayscale	1:31,680	yes	full
1951	grayscale	1:15,840		partial
1954	grayscale	1:54,000	yes	full
1962-3	grayscale	1:15,480	yes	full
1973-6	grayscale	1:15,480	yes	full
c. 1975	grayscale, color	1:15,480	yes	partial
1981	grayscale	1:24,000		full
c. 1991	color infrared	1:40,000		full
1992	color	1:15,480		partial
DOQ 1996	grayscale	1:12,000	yes	full
DOQ 2001	color	1:12,000		full

Table 2: Timeline of New Mexico State Forestry timber sale records on the Baca, 1980-2000. From 1980 to 2000, New Mexico State Forestry regulated the harvest of timber on the Baca (NMSF records). Records from the following timber sales are extant. Dark shading indicates dates of active harvest; light shading indicates approximate dates of an open timber sale. Incomplete records (indicated in part by question marks surrounding active harvests) limit the accuracy of this table in displaying the full span of each sale.

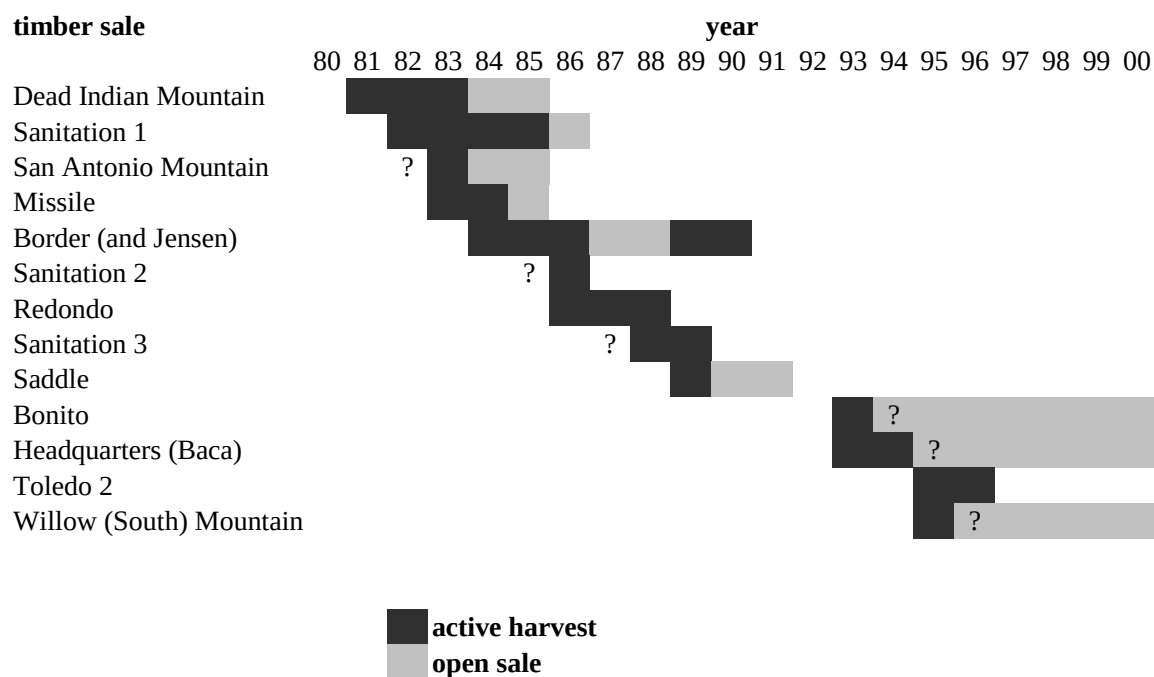


Table 3: Summary of 1978 raw volume data from Solinsky (1979) in thousand board-feet of trees >10 in (>25 cm) (aspen >6 in (>13 cm)).

Timber Type	area		volume (thousand board-feet) by species							
	ha	ac	pond. pine	Doug. fir	spruce	white fir	aspen	total conifer	all	
Redondo										
unharv. conifer	3,259	8,052	11,877	23,775	14,924	8,009	1,580	58,585	60,165	
harvested conifer	3,796	9,381	5,209	1,345	116	744	300	7,414	7,714	
aspen	614	1,518					1,980	0	1,980	
non-commercial	1,433	3,541	0	0	0	0	0	0	0	
grassland	962	2,377	0	0	0	0	0	0	0	
total	10,064	24,869	17,086	25,120	15,040	8,753	3,860	65,999	69,859	
Redondo Creek										
unharv. conifer	181	448	173	1,258	973	249	30	2,653	2,683	
harvested conifer	81	200	36	215	18	54	50	323	373	
aspen	159	393	0	0	0	0	510	0	510	
non-commercial	371	917	0	0	0	0	0	0	0	
grassland	0	0	0	0	0	0	0	0	0	
total	792	1,958	209	1,473	991	303	590	2,976	3,566	
San Antonio										
unharv. conifer	1,508	3,726	3,970	7,936	3,607	2,813	630	18,326	18,956	
harvested conifer	1,008	2,490	807	502	1,847	224	440	3,380	3,820	
aspen	206	510	0	0	0	0	670	0	670	
non-commercial	206	510	0	0	0	0	0	0	0	
grassland	1,129	2,790	0	0	0	0	0	0	0	
total	4,057	10,026	4,777	8,438	5,454	3,037	1,740	21,706	23,446	
Garita										
unharv. conifer	146	360	45	1,491	989	149	70	2,674	2,744	
harvested conifer	2,975	7,352	5,019	225	769	146	200	6,159	6,359	
aspen	276	682	0	0	0	0	890	0	890	
non-commercial	3,397	8,394	5,064	1,716	1,758	295	1,160	8,833	9,993	
grassland	1,157	2,860	0	0	0	0	0	0	0	
total	5,198	12,844	5,064	1,716	1,758	295	1,160	8,833	9,993	
Toledo										
unharv. conifer	380	940	44	2,980	2,190	485	100	5,699	5,799	
harvested conifer	2,677	6,616	1,444	360	576	72	250	2,452	2,702	
aspen	581	1,436	0	0	0	0	1,870	0	1,870	
non-commercial	871	2,153	0	0	0	0	0	0	0	
grassland	1,084	2,679	0	0	0	0	0	0	0	
total	5,594	13,824	1,488	3,340	2,766	557	2,220	8,151	10,371	

(Table 3 continued)

Timber Type	area		volume (thousand board-feet) by species						
	ha	ac	pond. pine	Doug. fir	spruce	white fir	aspen	total	
								conifer	all
Del Medio									
unharv. conifer	694	1,716	1,073	5,418	4,703	1,178	340	12,372	12,712
harvested conifer	3,340	8,253	3,335	1,805	1,945	1,764	630	8,849	9,479
aspen	390	963	0	0	0	0	1,260	0	1,260
non-commercial	390	963	0	0	0	0	0	0	0
grassland	4,992	12,334	0	0	0	0	0	0	0
total	9,805	24,229	4,408	7,223	6,648	2,942	2,230	21,221	23,451
Dome Road									
unharv. conifer	811	2,003	2,013	5,938	4,193	1,806	380	13,950	14,330
harvested conifer	236	584	1,026	415	305	437	100	2,183	2,283
aspen	69	171	0	0	0	0	220	0	220
non-commercial	69	170	0	0	0	0	0	0	0
grassland	36	90	0	0	0	0	0	0	0
total	1,221	3,018	3,039	6,353	4,498	2,243	700	16,133	16,833
Banco Bonito									
unharv. conifer	0	0	0	0	0	0	0	0	0
harvested conifer	1,769	4,371	11,375	195	0	0	0	11,570	11,570
aspen	0	0	0	0	0	0	0	0	0
non-commercial	0	0	0	0	0	0	0	0	0
grassland	61	150	0	0	0	0	0	0	0
total	1,830	4,521	11,375	195	0	0	0	11,570	11,570
BACA TOTAL									
unharv. conifer		17,245	19,195	48,796	31,579	14,689	114,259	3,130	117,389
harvested conifer		39,247	28,251	5,062	5,576	3,441	42,330	1,970	44,300
total conifer		56,492	47,446	53,858	37,155	18,130	156,589	5,100	161,689
aspen		5,673	0	0	0	0	0	7,400	7,400
total timber		62,165	47,446	53,858	37,155	18,130	156,589	12,500	169,089
non-commercial		9,844	0	0	0	0	0	0	0
grassland		23,280	0	0	0	0	0	0	0
total non-timber		33,124	0	0	0	0	0	0	0
Total		95,289	47,446	53,858	37,155	18,130	156,589	12,500	169,089

Table 4: Summary of plot information for 1998 timber cruise (Keel 1998).

stratum	area		plots used	total plots	BAF
	ha	ac			
1	673	1,663	10	10	20
2	1,983	4,901	79	79	20
3	990	2,447	21	21	20
4	546	1,349	20	20	30
5	380	939	10	10	20
6	262	647	8	8	20
7	713	1,761	35	35	20
8	575	1,421	17	17	30
9	460	1,137	19	19	30
10	1,007	2,489	26	26	20
11	2,045	5,053	60	60	30
12	1,832	4,527	75	86	20
13	577	1,427	19	30	20
14	821	2,028	33	33	20
15	980	2,421	43	43	20
16	1,670	4,127	51	52	20
17	836	2,066	12	12	20
18	799	1,974	28	28	30
19	896	2,215	55	55	20
20	1,343	3,318	72	72	30
21	1,325	3,274	45	45	20
22	2,641	6,527	87	108	20
23	761	1,880	33	33	30
24	1,278	3,157	17	20	20
totals	25,394	62,748	875	922	

Table 5: Frequency of tree quantity recorded at plots in the 1998 timber cruise (Keel 1998).

# trees recorded	frequency	percent
0	135	15%
1	115	13%
2	153	17%
3	103	12%
4	119	14%
5	80	9%
6	66	8%
7	41	5%
8	19	2%
9	18	2%
10	12	1%
11	5	1%
12	6	1%
13	3	0%
	875	100%

Table 6: Current (1998) volume (board-feet) by stratum and species (Keel 1998).

stratum	acrage	ponderosa		Engelmann		corkbark		total
		pine	Douglas-fir	white fir	spruce	fir		
1	1,663	1,540,495	970,928	1,623,742	5,046,400	0		9,181,565
2	4,901	12,766,277	13,897,522	9,758,828	4,546,915	120,418		41,089,960
3	2,447	3,312,768	5,767,889	2,917,524	2,735,336	0		14,733,516
4	1,349	3,808,507	11,747,391	0	2,724,164	0		18,280,062
5	939	1,443,097	545,255	507,338	2,717,600	0		5,213,290
6	647	2,809,686	2,330,487	2,035,898	391,718	0		7,567,788
7	1,761	3,038,467	6,400,431	5,231,909	966,027	0		15,636,832
8	1,421	380,827	9,672,499	991,320	3,132,245	0		14,176,891
9	1,137	332,873	2,675,960	816,976	2,206,537	0		6,032,347
10	2,489	9,122,282	1,266,139	4,152,653	2,033,699	0		16,574,773
11	5,053	11,784,386	12,095,255	8,816,882	554,990	429,739		33,681,252
12	4,527	432,851	4,198,455	6,091,922	9,656,092	586,692		20,966,012
13	1,427	3,936,247	6,090,868	1,490,922	844,551	0		12,362,587
14	2,028	11,079,344	8,067,906	244,921	6,572,949	2,739,055		28,704,174
15	2,421	11,432,374	11,622,603	2,053,782	2,821,314	233,036		28,163,108
16	4,127	10,808,270	7,152,929	11,574,625	508,155	2,087,929		32,131,906
17	2,066	3,974,321	2,076,295	4,319,862	0	0		10,370,477
18	1,974	11,312,451	2,665,077	0	336,455	2,238,069		16,552,052
19	2,215	42,254	3,364,200	53,615	2,204,026	636,127		6,300,222
20	3,318	8,134,024	6,692,121	1,843,328	2,799,789	2,572,063		22,041,324
21	3,274	4,907,443	6,733,436	3,006,982	4,980,660	0		19,628,520
22	6,527	6,698,608	8,123,651	4,983,119	14,712,992	438,738		34,957,108
23	1,880	13,409,748	12,271,938	241,161	0	0		25,922,846
24	3,157	10,218,105	30,708,478	3,772,010	4,084,999	0		48,783,592
sum	62,748	146,725,705	177,137,713	76,529,319	76,577,613	12,081,866		489,052,204

Table 7: Current (1998) volume per area (board-feet per acre) by stratum and species (Keel 1998).

stratum	ponderosa pine	Douglas-fir	white fir	Engelmann spruce	corkbark fir	total
1	926	584	976	3,035	0	5,521
2	2,605	2,836	1,991	928	25	8,384
3	1,354	2,357	1,192	1,118	0	6,021
4	2,823	8,708	0	2,019	0	13,551
5	1,537	581	540	2,894	0	5,552
6	4,343	3,602	3,147	605	0	11,697
7	1,725	3,635	2,971	549	0	8,880
8	268	6,807	698	2,204	0	9,977
9	293	2,354	719	1,941	0	5,305
10	3,665	509	1,668	817	0	6,659
11	2,332	2,394	1,745	110	85	6,666
12	96	927	1,346	2,133	130	4,631
13	2,758	4,268	1,045	592	0	8,663
14	5,463	3,978	121	3,241	1,351	14,154
15	4,722	4,801	848	1,165	96	11,633
16	2,619	1,733	2,805	123	506	7,786
17	1,924	1,005	2,091	0	0	5,020
18	5,731	1,350	0	170	1,134	8,385
19	19	1,519	24	995	287	2,844
20	2,451	2,017	556	844	775	6,643
21	1,499	2,057	918	1,521	0	5,995
22	1,026	1,245	763	2,254	67	5,356
23	7,133	6,528	128	0	0	13,789
24	3,237	9,727	1,195	1,294	0	15,453