# Assessing the Effects of Management Actions on Soils and Mineral Cycling in Mediterranean Ecosystems[1]

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Abstract: Mediterranean ecosystems can be harvested, undergo type conversion, or be burned. Both wildfires and prescribed burning are important features of these ecosystems. All these activities affect soils and mineral cycling. Managers are concerned with assessing the impacts of different management activities. Soil, physical, chemical, and biological properties are important parts of these assessments. The implications of nutrient loss and availability on short- and long-term site productivity are lacking. Guides are needed by land managers for making assessments of their decisions.

Many land management decisions and activities concerning mediterranean-type ecosystems affect nutrient cycling processes and mechanisms. Recent legislation in the United States has mandated that the impacts of these different activities be assessed. Equally important is recognizing which treatments affecting soils and nutrient cycling may lead to soil-site degradation.

Much of the information necessary to assess these impacts of different management actions appears in research publications and documents which are not readily available to the land manager when making day-to-day decisions. This presentation discusses the possible impacts arising from different management actions and suggests some handbooks needed by land managers. Because fire is an important feature of mediterranean ecosystems, it necessarily makes up a large portion of the discussion.

## THE MEDITERRANEAN ECOSYSTEM AND ITS MANAGEMENT --A BROAD PERSPECTIVE

Although mediterranean ecosystems include forests and grasslands, the most widespread vegetation type is evergreen sclerophyllous shrubs. This shrub type is known as mattoral in Chile, fynbos in Africa, maquis or garrigue in France, heath in Australia, and as chaparral in the United States. In California, chaparral occupies about 4.4 million hectares (Wieslander and Gleason 1954) and in Arizona another 1.2 million hectares (Hibbert and others this symposium)[1].

The soils and parent rock are diverse and vary widely over short distances; almost all geologic types are found in the different mediterranean environments. Soil fertility levels and nutrient pools vary widely both locally and regionally. Data on total nutrient pools of phosphorus and nitrogen shows the soils in Chile and the mediterranean zone of Europe, North Africa, and the Middle East are moderately fertile (Rundel 1978). Australia and South Africa have infertile soils, and California chaparral soils are intermediate in fertility. Little is known about the relationships between total nutrient pools and their availability to different plants.

The diverse vegetation, climate, and soils in the mediterranean ecosystems present a large number of unique management situations. However, space permits discussing only a few general activities and their impacts. Managers can either partially or completely harvest the vegetation. Forests can be logged or thinned; shrub areas can be harvested for biomass, can undergo type conversion, or can be grazed; and grasslands can be grazed or mowed. An important feature of mediterranean ecosystems is fire--both naturally occurring wildfires and prescribed burning. Managers can also either temporarily or permanently change the plant cover. Brush areas can be converted to grass, and forests can be invaded by brush or noncommercial trees after harvesting. Still other ecosystems receive minimum use and remain in nearly natural conditions, although these areas are diminishing and will be more intensively managed as the world population increases.

## ASSESSING THE IMPACT OF MANAGEMENT ACTIONS

The management activities outlined above affect nutrient cycling by interrupting the flow of elements through the ecosystem, altering nutrient availability, or in some cases selectively removing significant portions of the total nutrient pool. Further, these activities also affect the physical, chemical, and biological soil properties.

### Harvesting

Logging and thinning in forests, type conversion and biomass harvesting in evergreen shrub areas,

[1]Presented at the Symposium on Dynamics and Management of Mediterranean-type Ecosystems, June 22-26, 1981, San Diego, California.

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Gen. Tech. Rep. PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982.

and grazing of grasslands directly and indirectly affect mineral cycling. Harvesting not only removes biomass and the nutrients contained in the crop but also can accelerate nutrient losses by erosion and leaching. Harvesting activities may also affect nutrient availability on the site.

Information on the distribution of nutrients in live vegetation (leaves, twigs, stems), litter, and soil provide an important basis for assessing the impact of harvesting because this information can be used to estimate the quantity of nutrients removed from a site. These losses can then be compared with total nutrient pools on a site and serve as the basis for judging whether these losses may have a potential impact on the area. If a substantial portion of the nutrient is removed, there may be a decrease in site productivity unless it is replaced by fertilization or some other way. A recent guide developed by Boyer and Dell (1980) outlined an approach for assessing the impact of logging and slash disposal treatment on forested areas in the Pacific Northwest. Unfortunately, the amounts of nutrients which could be removed without causing site degradation (threshold values) were not established for the different nutrients.

Some general guidance is also available on the potential impact biomass harvesting may have on chaparral sites. Chaparral sites are known to be low in nitrogen and phosphorus (Hellmers and others 1955), thus making these nutrients of the greatest concern to the land manager. Information on the distribution of different nutrients over a wide range of chaparral sites has been presented by Zinke at this symposium. This type of information when combined with the nutrient requirements of plants may provide the basis for classifying chaparral sites according to their nutrient pools and their possible vulnerability to nutrient depletion and site degradation.

## Fire Effects

The physical, chemical, and microbiological properties of soil are all affected by fire. The physical properties most likely affected are soil aggregation and moisture movement (infiltration, water repellency, etc.). Soil chemical properties most readily affected are organic matter; total and available forms of nitrogen, phosphorus, and sulfur; and ion-exchange properties of the soil. The microbiological properties affecting the input, loss, and availability of nutrients may also be significantly affected by fire. These include such properties as organic matter decomposition, nitrogen fixation, and nitrification.

The changes in the soil occurring during a fire seem related to the intensity of the fire (DeBano and others 1979b). Therefore, it is essential to first characterize fire intensity and relate it to soil heating before attempting to finally assess fire effects on soil properties and nutrient cycling.

### Characterizing Fire Intensity

Fire intensity is frequently described in qualitative nonstandard terms as being light, moderate, and intense because it is difficult to predict heat fluxes and time-temperature relationships during a fire (Rothermel and Deeming 1980). Two more exact expressions of fire intensity, based on fire behavior, have been proposed--fireline intensity and heat per unit area. Fireline intensity, which is related to flame length, is best suited for predicting the effect of fire on items in the flame, such as the combustion of branches, leaves, stems, etc. This parameter would be best suited for assessing the impact of fire on nutrients in the standing biomass. Heat per unit area is based on fireline intensity and the rate of spread. This parameter would better describe fire effects in the litter and duff or soil heating. Expressing fire intensity in the above terms for individual prescribed fires is complex and time consuming and, therefore, has not been widely used in the past for assessing fire effects on soils. However, utilizing flame lengths to calculate fireline intensity as outlined by Rothermel and Deeming (1980) may make these intensity indexes easier to determine and more widely used.

The difficulties described above in determining fire intensities has led to the use of more qualitative ways of classifying fire intensity. Most of these methods are based on the appearance of the postburn vegetation and litter. Classification systems have been developed for forests (Boyer and Dell 1980) and chaparral areas (Bentley and Fenner 1958, DeBano and others 1979b). Postfire seedbed appearance has been used to classify fire intensity on chaparral areas in southern California (Wells and others 1979), and these have been related to soil temperatures present during a fire (Bentley and Fenner 1958).

### Relating Soil Heating to Fire Intensity

Once fire intensity has been characterized, it must be related to soil heating before fire-related changes in the soil can be assessed. Unfortunately, fireline intensity and heat per unit area have not yet been related to soil or litter heating although this may be possible by using correlation techniques (Rothermel and Deeming 1980). Developing a relationship between fire intensity and soil heating is further complicated by the litter layer because it both interferes with the transfer of heat downward in the soil and burns, releasing additional heat. These complications have lead to failure when attempts were made to develop useful duff-consumption (Van Wagner 1972) and duff-burnout models (Albini 1975). The litter presents a more formidable problem in forests than in brush areas because the litter layer is generally thicker and moister.

Until the shortcomings of the litter consumption and fire behavior models are solved, it may be necessary to measure, or estimate, soil and litter temperatures and relate them to changes in soil properties. Measured soil temperatures have been used to predict the effects of light, moderate, and intense fires on soil properties in chaparral areas of southern California (DeBano and others 1979b). When soil temperatures cannot be measured it may be necessary to obtain the best estimates possible from the literature or wherever data exists.

## Wildfires Versus Prescribed Fires

When fire related impacts are being assessed in forest and brush areas, it is important to distinguish between prescribed burns and wildfires. Wildfires in both forests and brushlands usually burn intensely because the conditions are conducive to rapid propagation (high temperatures, low humidities, dry fuels). They can consume large areas in a short time while destroying most of the standing vegetation and litter on the soil surface. Fire intensities vary locally throughout an area burned by a wildfire, and some areas burn at moderate or low intensities--or in some cases are unburned. During prescribed burn fires the intensities are usually lower because more marginal burning conditions are selected. During a prescribed burn in brush the flames move through the canopy where they consume variable amounts of live vegetation and most of the dead fuels. Unburned "islands" are common during low to moderate intensity prescribed burns in brush. Prescribed burning in forests is even less severe and is designed to minimize damage to the larger standing trees and consume dead fuels and litter on the soil surface.

## Assessing Fire Effects

Soil Physical Properties--The soil physical properties most likely altered by fire are: soil structure, soil wettability, and clay mineralogy. The destruction of organic matter and soil structure increases bulk density, diminishes aggregate stability, and decreases macro-pore space. When mineral soil is heated to 980°°C clay minerals are irreversibly altered (Ralston and Hatchell 1970). Alteration of organic substances starts at 200°C and 85 percent are destroyed at 300°C (Hosking 1938). Within this temperature range, hydrophobic substances responsible for decreasing soil wettability are vaporized in the surface litter and distill downward in the soil where they condense and form a water repellent layer (DeBano 1981). Temperatures of 250°C are necessary to fix the hydrophobic substance tightly to the soil particles. Above 288°C the hydrophobic substances are destroyed. The loss of soil structure and a decrease in wettability decreases infiltration and accentuates runoff and erosion.

Soil Chemical Properties--Although burning alters several soil chemical properties, the changes of most concern to the land manager are: the organic matter, nitrogen, phosphorus, and perhaps sulfur and potassium contents. Loss of organic matter decreases cation exchange capacity and diminishes the soils' ability to retain the abundant available plant nutrients released on the site during a fire. This is of greatest concern in a coarse textured soil containing small amounts of clay.

Nitrogen is probably the most important plant nutrient affected by fire because it is the nutrient most likely to be limiting (Hellmers and others 1955) and a large amount of the total nitrogen is volatilized and lost during fire (DeBano and Conrad 1978). Fire also affects organic nitrogen mineralization and may make this nutrient readily available to plants (DeBano and others 1979a). As the intensity of burning increases, the amount of nitrogen lost by volatilization increases. At temperatures above 500°C, 100 percent of the nitrogen in plant and litter material is lost (White and others 1973). Between 300° and 400°C, 50 to 75 percent of the nitrogen is lost. Between 200° and 300°C, up to 50 percent of the nitrogen may be lost, and below 200°C no measurable nitrogen is lost. The information on nitrogen losses at different temperatures can be combined with the surface and soil temperatures and used to estimate nitrogen losses at different burning intensities (fig. 1). The amount of nitrogen volatilized from the standing plants (live and dead) also depends on both the intensity of the fire and the completeness of the burn. Even when most of the standing shrub vegetation is consumed, significant amounts of nitrogen can remain in the charred branches and stems remaining after the fire. Nitrogen losses by volatilization during prescribed fires in forested areas is probably less than in chaparral because the soil, litter and duff temperatures are much lower than during brush fires (DeBano and others 1979b).

Sulfur is also volatilized but less is known about it than nitrogen. The importance of sulfur losses will require additional research. One study indicated potassium may be lost during burning (DeBano and Conrad 1978) although this may have a minor consequence because it is probably replaced by weathering of parent material during soil formation.

Many other plant nutrients contained in the organic matter, including phosphorus, are released and made readily available by burning. The abundance of available plant nutrients after fire makes the fertilization of freshly burned areas questionable. Little information is currently available on the length of time these nutrients remain in an available form before being immobilized. Although on-site movements occur, the losses from an entire watershed are not well understood. Most nutrients lost because of erosion are lost in debris rather than in runoff water (DeBano and Conrad 1976).

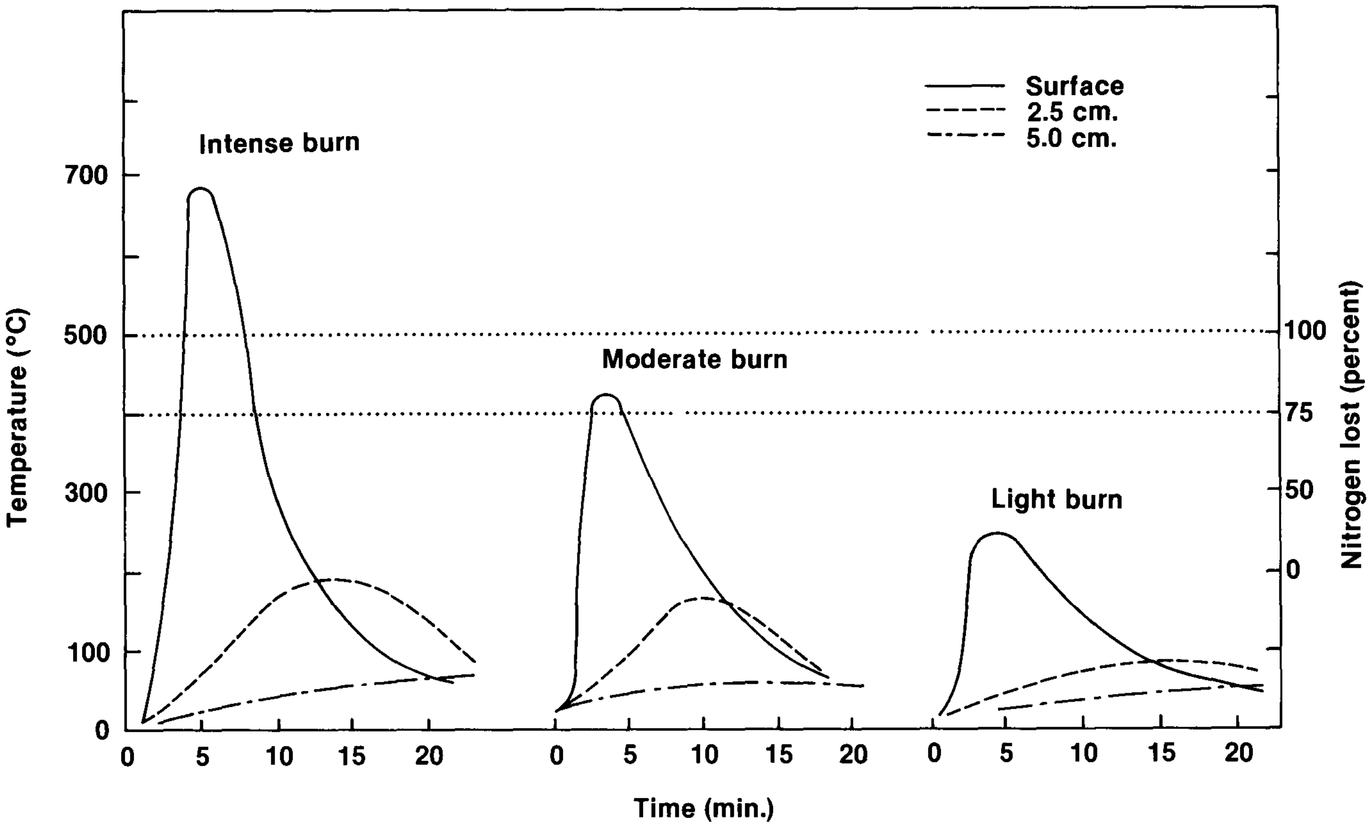


Figure 1--Surface and soil temperatures, and associated losses of nitrogen during: intense, moderate, and light intensity fires in chaparral (DeBano and others 1979).

Soil Microorganisms--Soil heating directly affects microorganisms either by killing them directly or altering their reproductive capability. Indirectly, soil heating alters organic matter, which increases nutrient availability (particularly nitrogen and carbon), and stimulates microbial growth rates. Although a complex interrelationship exists between soil heating and microbial populations in soils, it appears that duration of heating, maximum temperatures, and soil water content all may affect microbial responses (Dunn and others 1979). Generally, bacteria are more resistant to heating in both wet and dry soil than are fungi. The lethal temperature for bacteria was found to be 210° C in dry and 110° C in wet soil. Fungi have been found to tolerate temperatures of only 155° C in dry soil and 100° C in wet chaparral soils. Nitrifying bacteria appear to be particularly sensitive to soil heating, and even the most resistant of the Nitrosomonas bacteria can be killed in dry soil at 140°C and in wet soil at 75° C.

The sensitivity of microbial populations to burning over wet soils points to the necessity for evaluating the tradeoffs between microbial populations, soil nitrogen, and soil wettability during prescribed fires. Both soil wettability and nitrogen losses are reduced by burning over wet soils because the soil temperatures are lower, less nitrogen is lost by volatilization, and water repellency is less. Microbial populations, and possibly seeds, may be adversely affected by burning over wet soil. If the seeds of many of the short-lived perennial nitrogen-fixing plants are adversely affected by burning over moist soils, then the tradeoffs between nitrogen losses and microorganisms must be considered in terms of both short- and long-term plant succession and site productivity.

Cover Manipulation

Disturbing the vegetation on a site by type conversion may release high concentrations of nitrate nitrogen in streamflow. Type conversion resulting from logging in forests (Vitousek and Melillo 1979) land converting brush to grass (Davis this session)[1] may both release large amounts of nitrate nitrogen. It is hypothesized that the disturbance affects both the mineralization of nitrogen and its retention in the soil. The nitrogen compounds released during the decomposition, which had been returned to the surface by the deep-rooted shrubs, are not returned by the shallower rooted grasses. Therefore, the nitrates are no longer cycled from the deeper soil depths but instead percolate downward with the water through the soil profile, and later appear in the streamflow. Although large amounts of nitrogen may be lost they probably do not affect site fertility but are more important in terms of downstream water quality. This nitrate loss could become an important management consideration if large conversions were proposed above reservoirs used for domestic and recreational purposes.

Other impacts that need to be considered when making brush to grass conversions are erosion on steep slopes and the possible contamination of downstream water if herbicides are used for brush control.

## RECOMMENDATIONS FOR FILLING INFORMATION GAPS

The information discussed above on the response of soils and mineral cycling to different management situations in mediterranean ecosystems needs to be presented in a format which can be used by the land manager for making on-the-ground decisions and assessments. Although state-of-knowledge publications provide excellent reviews of research findings, they do not satisfy the immediate needs of the manager. Instead guides or "handbooks" similar to the one developed by Boyer and Dell (1980) for assessing the effects of fire on Pacific Northwest soils seem to be more useful for management situations than are research reviews. These authors brought together existing information on fire effects in soils from scientific journals, state-of-knowledge publications, and by verbal communications with researchers. This material was presented in a format which could be used for assessing fire impacts under different prescribed burning conditions and residue treatments in the Pacific Northwest. Similar publications are needed for chaparral soils under the management situations discussed in this presentation. Specific handbooks needed and the information necessary for developing these are:

Handbook Relating Soil Heating to Fire Intensity--This publication should consider when: (a) fire intensity is determined by postfire visual estimation and temperatures are not measured, and (b) surface temperatures are measured. If only visual estimates are made of fire intensities, then soil temperatures must be based on data reported in the literature. Photographs of postfire conditions representing light, moderate, and intense burns would aid in classifying fire intensities. A section of the guide should also be devoted to describing the methods available for measuring soil and surface temperatures during prescribed burns. Sufficient information is currently available to write this handbook without waiting for the development of physical models relating fire intensity or behavior to soil heating. When stronger physical relationships are established, these can be used to refine and upgrade the initial handbook.

Handbook Relating Soil Heating to Changes in Soil Properties and Nutrient Cycling in Chaparral--This should be a comprehensive document outlining the effects of different degrees of soil heating on changes in: soil physical, chemical, and biological properties; nutrient availability; susceptibility to erosion; and site productivity. This handbook should consider the nutrient changes occurring when aboveground plant material is burned because these nutrients are deposited on the soil surface in a highly available form where they affect site productivity and are susceptible to loss by postfire erosion. The effect of burning over wet and dry soil and associated tradeoffs need to be addressed. The effects of repeated fire on steep slopes needs to be considered when prescribed burning is to be used to develop mosaic stands of different aged brush. Critical slope criteria already developed for brush to grass conversion need to be adapted to areas subjected to periodic burning programs.

Handbook Relating Biomass Removal to Nutrient Cycling and Site Productivity in Chaparral--The increasing interest in the potential use of chaparral biomass for energy and other uses makes it necessary to assess the impacts of crop removal on site productivity. The effect of removing an entire standing crop may be more important than merely removing tree boles during logging.

## LITERATURE CITED

Albini, Frank A. An attempt (and failure) to correlate duff removal and slash fire heat. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1975; Gen. Tech. Rep. INT-24. 16 p.

Bentley, J. R.; Fenner, R. L. Soil temperatures during burning related to postfire seedbeds on woodland range. J. For. 56:737-740; 1958.

Boyer, Donald E.; Dell, John D. Fire effects on Pacific Northwest forest soils. Northwest Region, Forest Serv., U.S. Dep. Agric.: 1980; R6 WM 040. 59 p.

DeBano, Leonard F. Water repellent soils: A state-of-the-art. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1981; Gen. Tech. Rep. PSW-46. 21 p.

DeBano, L. F.; Conrad, C. E. Nutrients lost in debris and runoff water from a burned chaparral watershed. In: Federal Inter-Agency Sediment. 1976: Conf. Proc. 3. p. 13-27.

DeBano, L. F.; Conrad, C. E. The effect of fire on nutrients in a chaparral ecosystem. Ecology 59(3):489-497; 1978.

DeBano, Leonard F.; Eberlein, Gary E.; and Dunn, Paul H. Effects of burning on chaparral soils: I. Soil nitrogen. Soil Sci. Soc. Amer. J. 43(3):504-509; 1979a.

DeBano, Leonard F.; Rice, Raymond M.; Conrad, C. Eugene. Soil heating in chaparral fires: Effects on soil properties, plant nutrients, erosion, and runoff. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Service, U.S. Dep. Agric.: 1979b; Res. Pap. PSW-145. 21 p.

Dunn, Paul H.; DeBano, Leonard F.; Eberlein, Gary E. Effects of burning on chaparral soils: II. Soil microbes and nitrogen mineralization. Soil Sci. Soc. Amer. J. 43(3):509-514; 1979.

Hellmers, Henry; Bonner, James F.; Kelleher, John M. Soil fertility: A watershed management problem in the San Gabriel Mountains of southern California. Soil Sci. 80(3):189-197; 1955.

Hosking, J. S. The ignition at low temperatures of the organic matter in soils. J. Agric. Sci. 38(3):393-400; 1938.

Ralston, Charles W.; Hatchell, Glyndon E. Effects of prescribed burning on physical properties of soil. In: Prescribed Burning Symposium Proceedings; 1971 April 14-16; Charleston, S.C. Asheville, N.C.: Southeastern Forest Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1971; p. 68-85.

Rothermel, Richard C.; Deeming, John E. Measuring and interpreting fire behavior for correlation with fire effects. Ogden, Utah: Intermountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Gen. Tech. Rep. INT-93. 3 p.

Rundel, Philip W. Ecological impact of fires on mineral and sediment pools and fluxes. In: Fire and Fuel Management in Mediterranean Climate Ecosystems: Research priorities and programmes. 1978; MAB Technical Note 11. 1 p.

Van Wagner, C. E. Duff consumption by fire in eastern pine stands. Can. J. For. Res. 2(1):34-39; 1972.

Vitousek, Peter M.; Melillo, Jerry M. Nitrate losses from disturbed forests: Patterns and mechanisms. For. Sci. 25(4):605-609; 1979.

Wells, Carol G.; Campbell, Ralph E.; DeBano, Leonard F.; Lewis, Clifford E.; Fredriksen, Richard L.; Frandlin, E. Carlyle; Froelich, Ronald C.; Dunn, Paul H. Effects of fire on soil: A state-of-knowledge review. Washington, D.C.: Forest Serv., U.S. Dep. Agric.: 1979; Gen. Tech. Rep. WO-7. 34 p.

White, E. M.; Thompson, W. W.; Gartner, F. R. Heat effects on nutrient release from soils under ponderosa pine. J. Range Manage. 26(1):22-24; 1973.

Wieslander, A. E.; Gleason, Clark H. Major brushland areas of the coast ranges and Sierra-Cascade foothills in California. Berkley, Calif.: California Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1954; Misc. Pap. 15. 9 p.