Final Report For Cooperative Agreement No. RMS-98103 And Cost Share Agreement No. 00-CS-11020000-026

William R. Jacobi, Department of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO

January 24, 2002

This report contains information on
Black Stain Root Disease of Pinyon Pine
compiled by two graduate students
Holly S. J. Kearns and Samuel F. Harrison

The "Small Scale Analysis of the Impact of Black Stain Root Disease Centers in Pinyon Pine" Report is by H. S. J. Kearns
and the
"Large Scale Approaches to Investigating Pinyon Mortality in Southwest Colorado" Report is by S. F. Harrison

Cooperators:

We would like to acknowledge the following cooperators who helped make this project possible with funding, advice and/or encouragement.

Forest Health Personnel:
Dr. Roy Mask, Entomologist, Forest Health Management, Gunnison, CO.
Dr, Jim Worell, Pathologist, Forest Health Management, Gunnison, CO.
Dr. Tom Eager, Entomologist, Forest Health Management, Gunnison, CO.
John Guyon, Pathologist, Forest Health Management, Logan, UT.
Dr. Pete Angwin, Pathologist, Forest Health Management, Redding CA

Forest Health Monitoring:
Michelle Frank, Entomologist, Lakewood, CO.

Forest Health Technology Enterprise Team:
Dr. Eric Smith, Biological Statistician

Forest Service Research Station Personnel:
Dr. Jose Negron, Entomologist, Rocky Mountain Research Station.
Dr. John Lundquist, Pathologist, Rocky Mountain Research Station.

Colorado State University Personnel:
Dr. William R. Jacobi, Professor of Forest and Shade Tree Pathology
Dr. Robin M. Reich, Professor of Forest Biometrics, 20%
Dr. Gene Kelly, Associate Professor of Soil Science.
Samuel F. Harrison, Graduate Student
Holly Kearns, Graduate Student

Colorado State Forest Service
Mike Schomaker, Pathologist
Dan Ochocki, District Forester
Jim Hubbard, Head

Southern Ute BIA
Jim Friedley, Silviculturist

San Juan National Forest
Dan Green, Forester, Dolores Ranger District
Phil Kemp, Supervisory Forester, Dolores Ranger District
Eric Lindroth, GIS Specialist, Dolores Ranger District

FINAL REPORT
ON THE
SMALL SCALE ANALYSIS OF THE IMPACT OF BLACK STAIN ROOT DISEASE CENTERS IN PINYON PINE

HOLLY S. J. KEARNS AND WILLIAM R. JACOBI

DEPARTMENT OF BIOAGRICULTURAL SCIENCES AND PEST MANAGEMENT, COLORADO STATE UNIVERSITY, FORT COLLINS, CO

TABLE OF CONTENTS

Abstract	v
Literature Review	1-42
Introduction	43
Materials and Methods	46
Results and Discussion	55
Conclusions	79
Literature Cited	82
Appendices	89-110

ABSTRACT OF HOLLY KEARNS' THESIS

BLACK STAIN ROOT DISEASE IN THE PINYON - JUNIPER WOODLANDS OF SOUTHWESTERN COLORADO

Pinyon-juniper woodland is the largest forest cover type in Colorado, covering over 1.8 million ha. Reports of pinyon pine (*Pinus edulis*) dying in unprecedented numbers have made pinyon mortality a top priority for land managers in southwestern Colorado. Substantial increases in use of pinyon - juniper woodlands for housing and recreation in recent years has turned this problem into a regional issue. Primary mortality agents associated with increased pinyon mortality are black stain root disease (BSRD) and Ips bark beetles. Black stain root disease is a vascular wilt disease of pinyon pine caused by the native fungal pathogen *Leptographium wageneri* var. *wageneri* (Kendr.) Wingf..

In the summer of 1999, a study was undertaken to examine BSRD caused discrete areas of mortality (mortality centers) in pinyon - juniper woodlands in SW Colorado. The effects of BSRD on the composition and structure of pinyon - juniper woodlands at the tree, shrub, and herbaceous plant levels and on tree seedling regeneration were assessed. Thirty discrete BSRD mortality centers were examined, with three transects established within each center. For every tree within each transect, we recorded location, species, height, diameter at root crown, tree status, decline agents, and presence of black stain and Ips. Shrub and seedling plots of 40 m^2 were established at the mid-point of the transect and 9.14 m beyond the transect in which the percent shrub cover by species and the number of tree seedlings were recorded. Two - twenty by fifty centimeter plots were established at both the mid-point of the transect and 9.14 m beyond the transect in which the percent herbaceous cover by species and the percent cover by bare soil, litter, and rock were recorded. Discrete BSRD mortality centers had a mean area of 0.28 ha and a mean ratio of perimeter to area 3.3 times higher than a perfect circle indicating they were not expanding evenly in all directions. Mortality centers contained both pinyon

regeneration and surviving pinyon. The majority (68%) of all pinyon was dead; 76% of all pinyon were affected by BSRD and 70% of all had evidence of Ips bark beetle attack. BSRD significantly affected both the structure and composition of the woodlands, reducing live pinyon density by 63% and creating stands dominated by pinyon snags and logs. BSRD through removal of the pinyon overstory did not significantly impact shrub composition, percent cover, or diversity. Herbaceous percent cover was significantly higher within mortality centers and frequency responses were species specific. Pinyon regeneration was not significantly altered; and juniper regeneration was significantly higher within mortality centers than surrounding areas.

To determine the viability of the pathogen in the roots of dead pinyon, root samples taken from older dead pinyon were isolated from in the laboratory. To determine the length of time pinyon snags and logs persist to provide habitat, erosion protection, and other ecosystem properties, tree cores and/or stem cross-sections were obtained from sound pinyons in all represented tree classes, mounted, sanded, and cross-dated to determine year of mortality. The pathogen was regularly isolated from pinyon roots dead for 5 to 8 years and, once, from the root of a pinyon estimated to have been dead for 16 years indicating that the pathogen may persist on site to infect subsequent pinyon populations. The oldest dated pinyon mortality had been dead for 26 years, indicating that mortality within these discrete centers had occurred recently. The breakdown of pinyon snags and logs was rapid; the oldest datable pinyon status class had been dead for an average of 16.2 years pinyon. Pinyon snags may persist for up to 25 years.

To determine the rate at which discrete BSRD mortality centers are expanding and whether this rate is influenced by site characteristics, data on distance between pinyons and their respective years of mortality were analyzed. The rate of expansion of mortality was variable between the 30 BSRD centers, but averaged 1.1 m/yr and had a maximum rate of 2.0 m/yr. The rate of mortality center expansion was not significantly effected by available water capacity, percent organic matter, or pH of soils; pinyon density; nor any other site data recorded.

BLACK STAIN ROOT DISEASE CENTERS IN PINYON PINE

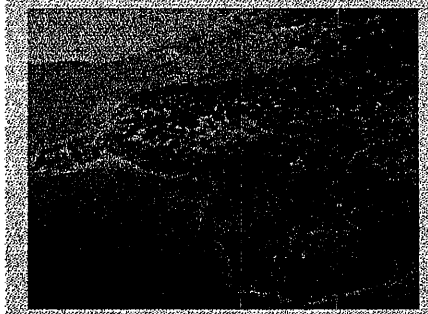
Holly S. J. Kearns and William R. Jacobi

Department of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO 80523

Introduction

Pinyon-juniper woodland is the largest forest cover type in Colorado, covering over 1.8 million ha. Reports of pinyon pine (*Pinus edulis*) dying in unprecedented numbers has made pinyon mortality a top priority for land managers in southwestern Colorado. Substantial increases in use of pinyon - juniper woodlands for housing and recreation in recent years has turned this problem into a regional issue. Primary mortality agents associated with increased pinyon mortality are black stain root disease (BSRD) and Ips bark beetles.

Black stain root disease, a vascular wilt disease of pinyon pine caused by the fungal pathogen *Leptographium wageneri* var. *wageneri* (Kendr.) Wingf., was first identified in Colorado at Mesa Verde National Park in 1942. Local spread of the pathogen occurs through root contacts and grafts between infected individuals and healthy trees. Insects may act as the vector across larger distances, although at this time the insect vector has not been identified. Mortality attributable to BSRD can at times appear as discrete mortality centers, or, in areas where mortality centers have merged, create a mosaic of mortality across the landscape. Pinyon affected by black stain are often attacked by Ips bark beetles; the most common species on pinyon is *Ips confusus* (Leconte), which may act to increase mortality by attacking healthy pinyon adjacent to disease weakened trees.



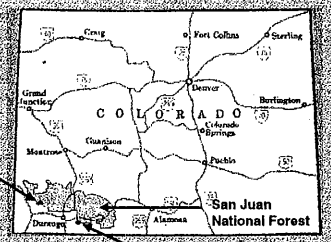
Aerial view of black stain mortality centers (gray areas) at McPhee Reservoir.

Study Objectives

In the summer of 1999, this study was undertaken to examine the effects of *Leptographium wageneri* var. *wageneri* where discrete areas of mortality (mortality centers) had been created in pinyon - juniper woodlands in SW Colorado by answering the following questions:

1) Does BSRD significantly impact the composition and structure of pinyon - juniper woodlands at the tree, shrub, or herbaceous plant levels?
- Is BSRD significantly altering tree regeneration within mortality centers?
- How long do pinyon snags and logs persist to provide habitat, erosion protection, and other ecosystem properties?
- How long can the pathogen remain viable within the roots of dead pinyon putting subsequent generations of pinyon at risk?
- At what rate are discrete BSRD mortality centers expanding? Are there site characteristics that influence the rate of expansion?

Study Site Locations



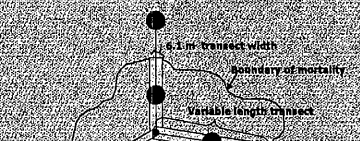
McPhee Reservoir

Southern Ute Reservation

Methods and Materials

- Thirty discrete mortality centers with visually confirmed black stain were located on the San Juan NF and Southern Ute Reservation in SW Colorado. All boundaries and plot centers were delineated by GPS.
- Three transects were established within each mortality center.
- For every tree within each transect we recorded location, species, height, diameter at root crown, tree status, decline agents, and presence of black stain and Ips.
- Tree cores and/or stem cross-sections were obtained from sound pinyon trees in all represented tree classes, mounted, sanded, and cross-dated to determine year of mortality.
- 40 m² shrub and seedling plots were established at the mid-point of the transect and 9.14 m beyond the transect in which the percent shrub cover by species and the number of tree seedlings were recorded.
- Two - twenty by fifty centimeter plots were established at both the mid-point of the transect and 9.14 m beyond the transect in which the percent herbaceous cover by species and the percent cover by bare soil, litter, and rock were recorded.
- Root samples and stem cookies taken from older dead pinyon were isolated from in the laboratory to determine viability of the pathogen.

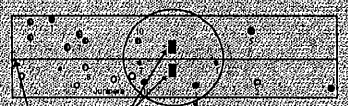
Plot Sampling Scheme



Location of Trees and Their Status

Sample Transect

(Plot 1167 Transect 1)

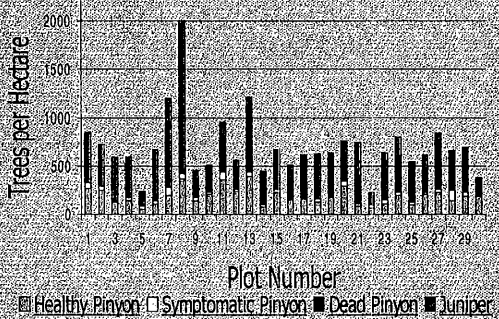


Outlined circles represent tree locations and numbers represent tree status. Classes 1 - healthy, 2-4 declining, 5-12 dead.

Results

- Discrete BSRD mortality centers had a mean area of 0.28 ha and a mean ratio of perimeter to area 3.3 times higher than a perfect circle indicating they were not expanding evenly in all directions.
- 86% of all trees within mortality centers were pinyon, which ranged in age from 26 to 375 years.
- 68% of all pinyon were dead; 76% were affected by BSRD and 70% had evidence of Ips bark beetle attack.
- Mean live pinyon density was reduced by 63% within mortality centers; juniper was not significantly affected.
- Within mortality centers 25.1% of pinyon were healthy, 6.6% were chlorotic, 46.4% were standing dead, and 21.0% were downed dead.
- Four herbaceous cover types and one shrub species showed significantly higher frequency of occurrence within mortality centers.
- Grasses had a mean percent cover of 10.8% within mortality centers, which was significantly higher than 3.9% cover in surrounding areas.
- The oldest dated pinyon mortality had been dead for 26 years, indicating that mortality within these discrete centers had occurred recently.
- The pathogen was regularly isolated from samples estimated to have been dead for 5 years, occasionally from samples dead a mean of 8 years, and once from the sound root of a pinyon dead for 16 years.
- The rate of expansion of mortality was variable between the 30 BSRD centers, but averaged 1.1 m/yr and had a maximum rate of 2.0 m/yr.
- The rate of mortality center expansion was not significantly effected by available water capacity, percent organic matter, or pH of soils; pinyon density; nor any other site data recorded.

Tree Densities of BSRD Mortality Centers by Species and Condition



Note: Plots 1-22 are located at McPhee Reservoir and plots 23-30 are located near Ignacio

Seedling, Shrub, and Herb Data

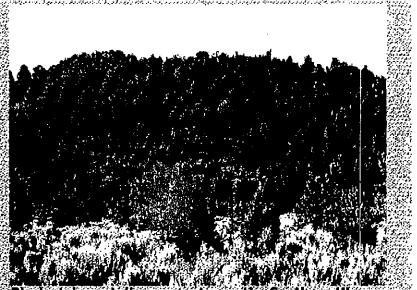
	Inside Mortality Centers	Outside Mortality Centers
Pinyon Seedlings	552 / ha	612 / ha
Juniper Seedlings	67 / ha *	33 / ha
Percent Shrub Cover	20.8	23.5
Number of Shrub Species	4.7	4.4
Percent Herbaceous Cover	20.2 **	9.4
Number of Herbaceous Species	6.6	5.4

* Difference is significant at $\alpha = 0.1$ based on t-test
** Difference is significant at $\alpha = 0.05$ based on t-test

Pinyon Snag and Log Persistence

Tree Status Class	Mean Years Dead
5 Red needles attached	1.3 a
6 Intact bark, many fine twigs, few needles	2.1 a
7 Bark partially missing, no needles, many twigs	4.7 b
8 Snag, 5 - 33 % branches broken, few twigs	8.4 c
9 Snag, >40 % branches broken, very few twigs	13.2 d
10 Downed, 5-33% branches broken, few twigs	9.8 c
11 Downed, >40 % branches broken, very few twigs	14.4 d, e
12 Downed, stem broken, few branches	16.2 e

Means followed by different letters are statistically different at $\alpha = 0.01$ level based on least square means



Black stain root disease center on the Southern Ute Reservation

Typical BSRD center in SW CO

Pinyon pine seedling

Pinyon pine root showing characteristic black stain

Conclusions

- Mortality centers contain both pinyon regeneration and surviving pinyon.
- BSRD significantly affected both the structure and composition of the woodlands, reducing live pinyon density by 63% and creating stands dominated by pinyon snags and logs.
- BSRD through removal of the pinyon overstory did not significantly impact shrub composition, percent cover, or diversity.
- Herbaceous percent cover was significantly higher within mortality centers.
- Pinyon regeneration was not significantly altered; juniper regeneration was significantly higher within mortality centers than surrounding areas.
- The breakdown of pinyon snags and logs is rapid; the oldest datable pinyon status class had been dead for an average of 16.2 years pinyon. Pinyon snags may persist for up to 25 years.
- Expansion rates of mortality centers averaged 1.1 m/yr and were not related to site or soil attributes.
- The pathogen was regularly isolated from pinyon roots dead for 5 to 8 years and, once, from the root of a pinyon estimated to have been dead for 16 years indicating that the pathogen may persist on site to infect subsequent pinyon populations.

Some of the Remaining Research Needs Regarding Black Stain Root Disease in Pinyon Pine

- Examination of the long-term effects on woodland composition and structure.
- Landscape level analyses to determine impacts and extent of and increases in pinyon mortality.
- Investigation of the natural resistance apparent in healthy pinyon surrounded by pinyon in all stages of death.
- Identification of an insect vector and analysis of the vector's behavior.
- Clarification of the relationship between Ips bark beetles and BSRD.

Acknowledgements

Cooperators: Jim Fridley, Sam Harrison, Mary Kemp, Phillip Kemp, Page Lindsey, John Lundquist, Robin Reich, George San Miguel, Eric Smith, Skip Smith, Leslie Stewart, Jim Worrall

Funding: Bureau of Indian Affairs; Colorado State Forest Service; Colorado State University Agricultural Experiment Station; Department of Bioagricultural Sciences and Pest Management, Colorado State University; USDA Forest Service, Forest Health Management - Gunnison; USDA Forest Service, Forest Health Monitoring Program; USDA Forest Service, Forest Health Technology Enterprise Team - Fort Collins; USDA Forest Service, San Juan National Forest

Chapter One
Literature Review

I. The Host

A. Pinyon pine (*Pinus edulis* Engelm.)

1. Distribution

Pinyon is the dominant pine species in nearly 14.9 million ha of woodlands in the southwestern United States, primarily in Colorado, Arizona, Utah, and New Mexico (Figure 1.1). Pinyon pines are codominant with juniper species (*Juniperus* spp.) in the pinyon-juniper woodlands of the semi-desert zone that cover approximately 24.7 million ha from Texas to California (Ronco 1990). There are over 1.8 million hectares of pinyon-juniper forest type in Colorado (Landis and Helburg 1976), making pinyon-juniper the dominant forest cover type in Colorado.

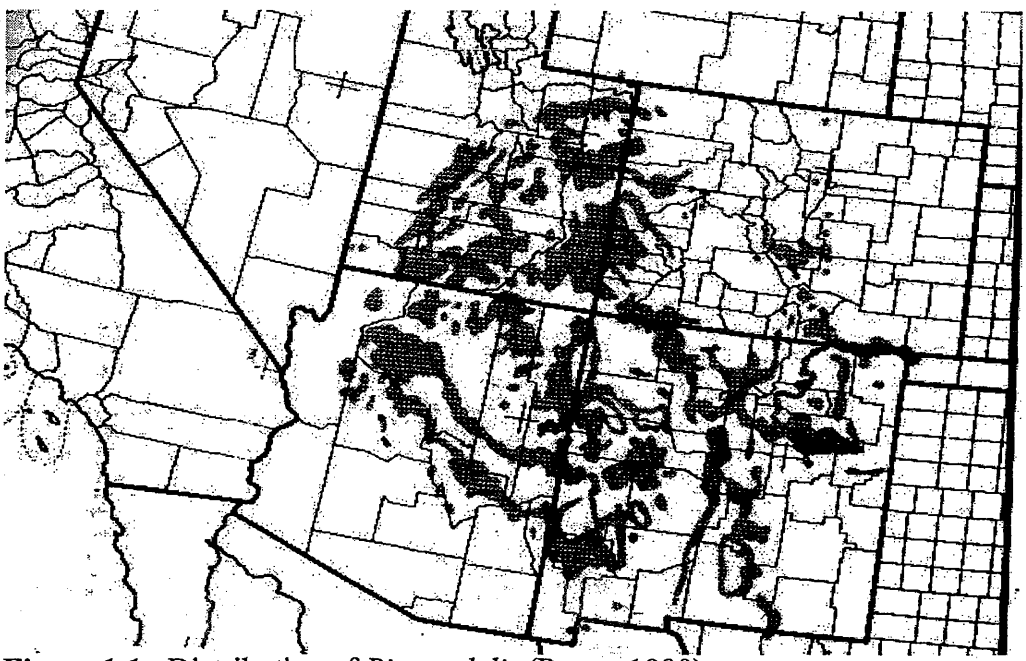


Figure 1.1. Distribution of *Pinus edulis* (Ronco 1990).

2. Silvics

Pinyon is a long-lived tree; dominant trees within stands are often 400 years old, and pinyons 800 to 1,000 years old have been found. Pinyons grow very slowly, though they maintain this level of growth with little loss of vigor throughout the life of the tree. Mean annual diameter growth of pinyon peaks at about 1.8 cm per decade, when trees are approximately 50 years old. Depending on the site, mature trees range between 3.0 and 15.5 m tall and 15 to over 76 cm in diameter at breast height (d.b.h.). The largest living pinyon recorded grows in New Mexico and measures 172 cm d.b.h. and 21.0 m in height, and has a crown spread of 15.8 m. Pinyons achieve their tallest heights and tend to develop single stems on the higher, wetter sites of the woodland zone, just below the ponderosa pine type. At lower elevations, pinyon may be multi-stemmed with bushy and sprawling crowns (Ronco 1990).

The density of pinyon in woodlands is extremely variable, ranging from few or none to several hundred stems per hectare. Mixed woodlands are usually denser and more productive than pure stands of either pinyon or juniper, and can approach or exceed 3,459 stems/ha (Ronco 1990). The higher densities within woodlands are attributed to differences in rooting habit and drought tolerance of the two species. Pinyons have a lower photosynthetic rate at higher water stresses compared to that of junipers, which allows more complete site utilization and higher tree densities in mixed stands (Ronco 1990). The rooting habit of pinyon is characterized by both lateral and vertical root systems. Roots of pinyons less than 3 m tall have been traced to depths of 6.4 m in underlying rock. Lateral roots typically develop to a depth of 15 to 41 cm and can exceed the crown radius by a factor of two or more. The extensive root system and relatively

rapid rate of root elongation, especially of young seedlings, enhance the ability of pinyon to survive under arid environments. Pinyon is a sun-adapted plant and is classified as intolerant of shade. It also appears unable to compete with grasses for moisture during the seedling stage following germination (Ronco 1990).

Trees reach cone-bearing age at 25 years when they are 1.5 to 3.0 m tall, but do not produce large quantities of seed until age 75 to 100. Female cones take nearly three complete growing seasons to mature. Cones may each contain from 10 to 20 seeds. The seeds of pinyon are large and wingless and are not adapted to wind dissemination. Seed dispersal beyond tree crowns depends primarily upon the behavior of four corvid species of birds – Clark's nutcracker (*Nucifraga columbiana*), Steller's jay (*Cyanocitta stelleri*), scrub jay (*Aphelocoma coerulescens*), and pinyon jay (*Gymnorhinus cyanocephalus*). Although these species consume large quantities of seed in autumn, they also cache abundant amounts for use throughout winter months. The caches of Clark's nutcracker and Steller's jay are typically located at higher elevations and may serve to expand the elevational range of pinyon, whereas the caches of scrub jay and pinyon jay are found in existing woodland areas (Ronco 1990). Clark's nutcracker has been observed travelling up to 22 km between seed source and caching area (Gottfried 1987). The birds do not recover all of the seeds they bury thus providing a seed source for subsequent germination and seedling establishment, particularly if caches are located in a suitable microenvironment, such as alongside shrubs or downed trees. Typically, substantial seed crops are produced every 4 to 7 years, and between 83 and 96 percent of seeds may germinate. Rodents, such as cliff chipmunks, pinyon mice, and wood rats, are major predators of pinyon seed, caching as much as 35 to 70 liters of viable seed (Ronco 1990).

Unfavorable climatic conditions make natural regeneration difficult to achieve. Seed predation and heavy grazing pressure, especially by sheep and goats, also play a role in natural regeneration failure (Ronco 1990). Due to their short lived seeds and nurse plant requirement, disturbances that remove overstory trees and shrubs may have a great impact on pinyon regeneration. Pinyon seeds are generally considered short-lived with little inherent dormancy providing only a temporary seedbank with most germination occurring the spring following dispersal (Chambers et al. 1999). The regeneration of large openings is slow. Although pinyon is considered intolerant to shade, grows best in full sunlight, and can germinate in the open; seedlings must be protected from the harsh environment, and seedling establishment in open environments is rare. Regeneration typically takes place in the shade of older pinyon and juniper tree canopies, under shrubs, or beside downed trees. Shade ameliorates microclimate factors and reduces moisture and temperature stresses. However, in dense stands, seedlings that become established beneath mature trees have little probability of maturing unless the adult tree dies. Seeds germinate in spring and summer following dispersal, depending on soil moisture and temperature. Summer germination typically coincides with the onset of the rainy season (Chambers et al. 1999, Gottfried 1987, Ronco 1990).

3. Economic values

Use of pinyon – juniper woodlands in the southwest began in the early 1600's with the introduction of grazing and fuelwood collection. The heavy yellow wood of pinyon is used primarily for firewood. Pinyon is favored for fuelwood because it has a higher heat value than any of its associates, except oaks, and burns with a pleasant and distinctive aroma. Firewood is the most widely used product derived from pinyon-

juniper woodlands and continues to be a primary source of energy for rural populations in much of the Southwest. Pinyon is not widely used for sawn products due to its poor growth form and small size even though it has physical properties similar to those of ponderosa pine and is considered suitable for processing. Small mills utilize pinyon to produce mine timbers and railroad ties, which are used primarily in open pit mines because of their toughness and resistance to breakage. Pinyon has also occasionally been used for pulping in the Southwest, but only to alleviate shortages of normally used species. It is also occasionally processed for charcoal. The edible nuts are probably the most valuable product of pinyon. A large tree in a good crop year may yield over 9.1 kg of seed, and better stands will produce an estimated 336 kg/ha. Annual crops of pinyon nuts are estimated to range between 454,000 and 907,000 kg, and can reach as high as 3.6 million kg. Pinyons are also being grown for commercial Christmas tree sales (Ronco 1986, Ronco 1990). In recent years, pinyon-juniper woodlands have been used increasingly for residential and recreational purposes.

4. Damaging Agents

Mature pinyon can be affected by many species of fungi, insects, parasitic nematodes, and parasitic plants (e.g. Hepting 1971, Lindsey personal communication, Ronco 1990). Pinyon are also very susceptible to fire while they are small (1 to 2 m), but apparently become more resistant as they grow larger and their bark becomes thicker (Ronco 1990). Table 1.1 lists some of the most common damaging agents found on pinyon.

Table 1.1. Common causal agents of pinyon damage (compiled from Hepting 1971, Lindsey personal communication 2001, Ronco 1990)

Fungi	*Aleurodiscus mesaverdensis* – decay *Armillaria mellea* – root and butt rot *Athelia bombacina* – decay *Bifusella saccata* – needle cast *Coleosporium crowellii* – needle rust *Coleosporium jonesii* – needle rust (on *Ribes, Grossularia*) *Cronartium occidentale* – pinyon blister rust *Cryptoporus volvatus* – white sapwood rot *Elytroderma deformans* – needle cast *Fomitopsis pinicola* – brown cubical rot *Gloeophyllum saepiarium* – brown cubical sap rot *Heterobasidion annosum* – root and butt rot *Peridermiun occidentale* – rust *Phaeolus schweinitzii* – root and butt rot *Phellinus pini* – heart rot *Pleurotus ostreatus* - white heart and sap rot *Pycnoporus cinnabarinus* – white sap rot *Trechispora mollusca* – rot *Trichaptum abietinum* – pitted sap rot *Tubulicrinis glebulosa* – white rot *Tubulicrinis medius* – decay
Insects	*Chionaspis pinifoliae* – pine needle scale *Coleotechnites edulicola* – pinyon needle miner *Conophthorus edulis* – pinyon cone beetle *Contarinia* species - gallmidge *Dendroctonus ponderosae* – mountain pine beetle *Dioryctria albovittella* – pinyon tip moth *Eucosma bobana* – cone moth *Lophocampa ingens* – tiger moth *Ips confusus* – pinyon ips *Ips lecontei* – Arizona five-spined ips *Janetiella* species – pinyon stunt needle gallmidge *Matsucoccus acalyptus* – pinyon needle scale *Neodiprion edulicolus* – pinyon sawfly *Refinia arizonensis* – pinyon pitch nodule moth *Pineus coloradensis* – adelgid *Pinyonia* species –gallmidge
Parasitic plants	*Arceuthobium divaricatum* – pinyon dwarf mistletoe
Nematodes	*Helocotylenchus* species - parasitic on pinyon roots *Tylenchus* species - parasitic on pinyon roots *Xiphinema* species - parasitic on pinyon roots

B. Pinyon-Juniper Woodlands

Pinyon-juniper woodlands occupy the lowest and warmest forested zone in the United States. In elevation, the woodlands are mainly found between 1370 and 2440 m. The elevational range occupied by pinyon-juniper woodlands is relatively uniform at about 610 m, although the range in any particular location may be significantly narrower. In Colorado, the range of pinyon-juniper woodlands extends from 1830 to 2440 m. The climate is generally described as semiarid and is characterized by hot summers, cold winters, and a high number of clear days with intense solar radiation and windy conditions, which favor high evapotranspiration rates. Precipitation ranges from 250 mm to 560 mm throughout the pinyon-juniper zone (Ronco 1990).

Pinyon-juniper woodlands are located mainly on rocky plateaus, mesas, foothill terraces, and lower mountain slopes; between the low plains covered by grassland, desert shrub, or chaparral vegetation and the high mountains just below the zone dominated by either submontane shrubs or ponderosa pine. The woodlands are found on a wide variety of soil depths and textures that range from coarse, rocky gravels to fine, compacted clays. The lower limit of growth is most likely related more to the inability of pinyon trees, especially seedlings, to tolerate water stress arising from decreasing precipitation and subsequent reduction of total moisture, rather than to soil or temperature factors. In contrast, the upper limit appears to be a function of greater biotic competition resulting from increased moisture (Ronco 1990).

Stands within pinyon-juniper woodlands can express a great deal of diversity in structure and composition even though they are made up of relatively few tree species. Some stands consist of virtually closed canopies of a single tree species with sparse or no

understory vegetation. Others are open with widely scattered pines, junipers, or both along with grasses and shrubs. The long history of grazing in the pinyon-juniper type has provided trees with a competitive advantage over understory species resulting in older, denser multi-aged stands (Ronco 1986, Ronco 1990).

Succession in pinyon-juniper woodlands follows a fairly consistent pathway. The generalized successional model and the approximate length of time following a stand replacing fire event in southwestern Colorado is as follows: 1) bare soil and dead standing trees – 0 years, 2) annual plants – 2 years, 3) annual and perennial grass / forbs – 4 years, 4) shrubs – 25 years, 5) shrubs / open trees – 100 years, 6) climax pinyon-juniper woodland – 300 years (West and Van Pelt 1987). The first herbaceous plants to become established following fire are typically those species that were present on the site prior to the fire event. Junipers are generally the first trees to regenerate burned areas and, according to Ronco (1986), dominate the site within approximately 70 years after which they are succeeded by pinyon.

II. The Pathogen

A. Distribution

Leptographium wageneri is considered a native pathogen of western North American forests. It is found only in the western United States and southwestern Canada (Figure 1.2) (Tainter and Baker 1996).

B. Hosts

In addition to pinyon pine, *Leptographium wageneri* is commonly found in ponderosa pine (*Pinus ponderosa* Laws.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), lodgepole pine (*Pinus contorta* Dougl.), singleleaf pinyon (*Pinus monophylla*

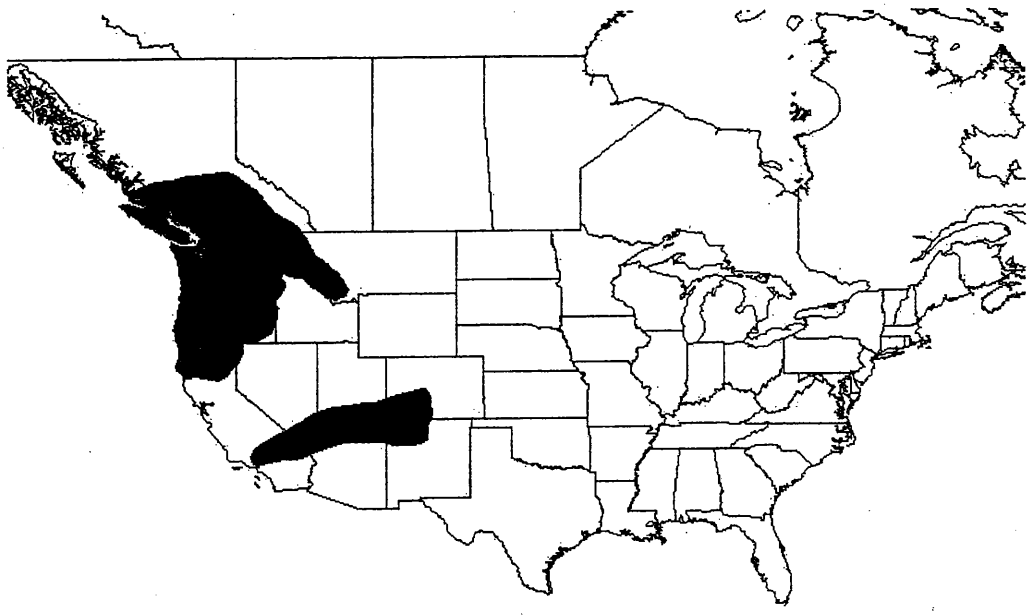


Figure 1.2. Distribution of black stain root disease in North America (drawn after Figure 17.16 Tainter and Baker 1996).

Torr. & Frem.) and Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.). It has also been reported in western white pine (*Pinus monticola* Dougl.) and spruce (*Picea* spp.) in British Columbia (Hunt and Morrison 1986); mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) in Oregon (Goheen and Hansen 1978); grand fir (*Abies grandis* (Dougl.) Lindl.), white fir (*Abies concolor* Gord. & Glend.) (Goheen and Hansen 1978), sugar pine (*Pinus lambertiana* Dougl.), and knobcone pine (*Pinus attenuata* Lemm.) in California (Smith and Graham 1975). Lodgepole pine is considered an extremely susceptible species, and two of the varieties of *L. wageneri* (hard pine and Douglas-fir) are equally pathogenic and capable of invading and killing the majority of inoculated trees. Webber and Hansen (1990) found that Scots pine (*Pinus sylvestris* L.) and Austrian pine (*Pinus nigra* Arnold) can also be infected by *Leptographium wageneri*. Scots pine is extremely susceptible to the pathogen. The introduction of the pathogen to Europe or Britain could potentially be

dangerous to the extensive lodgepole and Scots pine plantations there (Webber and Hansen 1990).

C. Taxonomy and Identification

Kendrick first classified the causal agent of black stain root disease in 1962 as *Verticicladiella wagenerii* (*Verticicladiella wagenerii* sp. nov.). Kendrick's classification was based on the presence of sympodula, which are conidiogenous cells characterized by continued growth through the development of a succession of apices, each of which originates below and to one side of the previous apex. Kendrick examined the type culture, which was isolated from a *Pinus monophylla* root, and found that maximum radial growth on malt agar occurred at 15 °C. He described the hyphae as septate, relatively straight, occasionally branched, smooth walled, 3.0 – 6.5 μm wide, forming fine, interwoven radial fibrils noticeable at the diffuse but regular margin. Sparse, aerial hyphae interspersed with conidiophores also occur in culture. Conidiophores are characterized as being large, arising directly from repent hypha, and lacking rhizoidal hyphae. The stipe is up to 775 μm long and up to 12 septate; 4.0 – 12.4 μm wide at the base, brown to dark-brown in color and fading slightly near the apex. The primary metulae (conidiophore branches) vary in number from 2 to10, usually from 3 to 5, develop in a slightly divergent cluster at the apex of the stipe, and are usually long, narrow, and concolorous with the stipe. Above the primary metulae are two to four more series of metulae, which are typically hyaline and thin walled. The conidiogenous cells are crowded and are irregular in the apical regions due to the presence of scars resulting from the abscission of conidia (Kendrick 1962).

The conidia are described as obovoid, elliptical or clavate, typically truncate at the base, smooth-walled, and sometimes slightly curved near the base, measuring 2.0 – 7.6 x 1.7 – 3.8 μm. Conidia accumulate in a mucilaginous mass, which is hyaline in young conidiophores becoming a translucent brown especially in the closely contiguous conidiophores at the center of the colony. Smaller conidiophores with irregular lateral or dendritic branching are also present on malt agar (Kendrick 1962).

In 1985, Wingfield reclassified the genus *Verticicladiella* and renamed the fungus *Leptographium wageneri* (Kendrick) Wingfield, comb. nov. (Wingfield 1985). This regrouping of Verticicladiella species into the genus *Leptographium* was based in the inability to distinguish the two genera (*Verticicladiella* and *Leptographium*) on the basis of conidial development. Both genera contain species that exhibit both sympodial and annellidic (percurrent proliferation by lengthening and growing through the terminal end in the direction of the long axis leaving transverse bands) conidial development on a single conidiophore. Wingfield concluded by proposing the reduction of the genus *Verticicladiella* to synonymy with *Leptographium* (Wingfield 1985).

In 1984, Harrington and Cobb noted that *Leptographium wageneri* could be classified into three morphologically and physiologically distinct variants based on mycelial characters and host specificity. The pinyon variety differed from the hard pine and Douglas-fir varieties for several characteristics including mycelial pigment in culture on potato dextrose agar (PDA), the width and color of the mycelial margin in culture on PDA, the colony diameter at 25 C°, conidiophore production on water agar, swelling of the conidiophore stipe apex, and its primary hosts. Pinyon isolates infected and killed 44% of inoculated pinyon seedlings compared to 3% mortality in pinyon seedlings

infected with Douglas-fir isolates and 13% mortality in seedlings infected with hard pine isolates in cross-inoculation studies. Harrington and Cobb (1984) found that the Douglas-fir and hard pine varieties each tended to be more pathogenic to their primary host than to other inoculated species. Pinyon isolates also vary in their isozymes (one of a family of enzymes with different molecular weights and electron charges such that they separate in electrophoresis) to the extent that they appear strikingly different from the other two variants (Otrosina and Cobb 1987).

The variety that infects pinyon and singleleaf pinyon pines is now classified as *Leptographium wageneri* (Kendr.) Wingf. var. *wageneri* (Wingfield 1985). The anamorph of the variant that infects hard pines has been classified as *Leptographium wageneri* var. *ponderosum* Harrington & Cobb (Harrington and Cobb, comb. nov., 1987); previously *Verticicladiella wageneri* var. *ponderosa* Harrington & Cobb *var. nov.* (Harrington and Cobb1986). The variety that infects Douglas-fir has been classified as *Leptographium wageneri* var. *pseudotsugae* Harrington & Cobb (Harrington and Cobb 1987).

The teleomorph of the variety that infects hard pines (*Leptographium wageneri* var. *ponderosum*) is described as *Ophiostoma wageneri* (Goheen & Cobb) Harrington (1987); previously *Ceratocystis wageneri* Goheen & Cobb (1978). The teleomorph of the hard pine variety is known from a single collection from a bark beetle gallery in an infected ponderosa pine root. No teleomorph of *Leptographium wageneri* var. *wageneri* or var. *pseudotsugae* has been reported (Harrington and Cobb 1987).

D. Isolation

Isolation techniques for *Leptographium wageneri* var. *wageneri*, as developed by Harrington (1992), entail keeping colonized tissue cool after field collection until isolation can be made as temperatures in excess of 30° C are considered lethal. Slivers of discolored wood are removed from colonized root or root collar tissue and placed on selective media of 1.5% water agar amended after autoclaving with 200 μg/ml cycloheximide and 100 μg/ml streptomycin sulfate. Members of the genera *Leptographium* and *Ophiostoma* are tolerant to high concentrations of cycloheximide, which facilitates their isolation and purification in culture. Cycloheximide concentrations of 1μg/ml inhibit protein synthesis in most eukaryotic organisms, but *Ophiostoma* species can tolerate levels exceeding 1000 μg/ml. Most fungal contaminants, with the exception of some yeasts and species of *Penicillium*, are completely inhibited when cycloheximide is added to media at concentrations of 200 μg/ml (Harrington 1992). *Leptographium wageneri* var. *wageneri* will readily produce distinctive conidiophores on malt extract agar (MEA) with 1% malt extract and on water agar. Cultures can be grown under either light or dark conditions in a growth chamber with maximum growth occurring at 15 to 17° C (Harrington 1992). Isolations have also been successful from the needles of infected individuals. Smith (1967) was able to isolate the fungus from the juvenile needles of infected ponderosa pine seedlings.

E. Physiology / Pathological Anatomy

The macroscopic and microscopic patterns of colonization of *Leptographium wageneri* in Douglas-fir were examined by Hessburg and Hansen (1987). They found that once the fungus becomes established in the root collar, it grows into the stem and

spreads quickly throughout the root system. In colonized trees and seedlings, vertical columns of chocolate-black stain are tapered to a point at their advancing margins, and within growth rings the stain columns often divide near their tip, producing several vertically advancing margins. In earlywood, new stain columns are typically brown and diffuse; while in latewood, the stain columns are usually concentrated and black. Stain columns adjoining necrotic cambium are commonly resin soaked, covered by a partially hardened layer of oleoresin, and surrounded by a reaction zone the color of normal heartwood. Large stain columns frequently branch radially and colonize the early wood of successive growth rings, which results in the appearance of concentric arcs of stain in cross section. An individual stain column can cross as many as 15 successive growth rings (Hessburg and Hansen 1987).

Smith (1967) found hyphae of *Leptographium wageneri* only in mature tracheids, where they were typically confined to longitudinal tracheids and were rarely found in ray tracheids of ponderosa pine seedlings and were located only in longitudinal tracheids in singleleaf pinyon seedlings. Colonization by *L. wageneri* is primarily vertical with hyphae located in the tracheids, but not in xylem parenchyma (Harrington and Cobb 1983). The hyphae of *L. wageneri* are hyaline at the hyphal tips and amber-brown in tracheids following the advancing margin. Mature hyphae are often coated with a coarse, granular, dark amber sheath, which may more than double the diameter of the hyphae. Hyphal growth in tracheid lumens is frequently serpentine and helicoid (Hessburg and Hansen 1987).

Hyphae grow adjacent to the lumenal wall and are anchored to it by hyphal wall or sheath material. Hyphae are commonly branched near bordered pit pairs on the radial

walls of tracheids. The pathogen moves between tracheids through bordered pit pairs on common radial walls. Cell wall penetration was never detected nor was any evidence of cell wall disruption or decay observed. Parenchyma cells are never necrotic prior to hyphal colonization of their adjacent tracheids. Ray parenchyma cells adjacent to colonized axial tracheids eventually die and their cell walls become amber colored, but this occurs behind the advancing margin of colonization. Within the sapwood, earlywood is more often colonized than latewood. Latewood tracheid lumens are elliptical in cross section and are smaller in than those in earlywood. Both the lumens and the bordered pits of latewood tracheids effectively become occluded when colonized by hyphae. Hyphae of *L. wageneri* are only able to enter earlywood of the adjacent growth ring from latewood tracheids with tangential wall pitting. Stain columns advance radially in three primary ways: (1) through ray tracheids; (2) through bordered-pit pairs on tangential walls of the last-formed latewood tracheids; and (3) via the deviation from true axial declination of longitudinal tracheids (Hessburg and Hansen 1987, Smith 1967).

Leptographium wageneri does not appear to depend on cellulose or pectic substances as a primary source of nutrition. Since hyphae are often localized around living cells, it is possible that they may to some extent survive on substances that seep out from parenchyma into adjacent tracheid lumens. Sapwood xylem tracheids are seemingly nutritionally sufficient to support swift and extensive fungal growth. The hyphae, which grow preferentially in earlywood longitudinal xylem and often in the current year's growth, have access to the storage sugars, salts, and photosynthates that are directed to expanding tracheids. Maturing tracheids in various stages of cytoplasmic autolysis provide hyphae access to cytoplasmic constituents and encrusted cytoplasm. Hyphae in

new earlywood, the region of greatest translocation, also have access to solutes of xylem sap (Hessburg and Hansen 1987).

F. Pathogenesis

Black stain root disease is unique among conifer root diseases in that it is caused by a staining fungus rather than a root-decaying fungus. In terms of pathogenesis, black stain diverges from typical root diseases in the absence of cambial invasion prior to tree death and wood decay (Cobb 1988). The disease shares many characteristics with vascular wilts of trees including confinement of the fungus to the xylem and its corresponding absence from the cambium and phloem, the presence and pattern of xylem staining, the colonization of only actively conducting xylem tracheids and no other cell type, the propensity of hyphae to almost fill the tracheid lumens, the ability to become systemic throughout the host's vascular system, the inability to directly penetrate or decompose cell walls requiring movement via bordered pit pairs, and the formation of tyloses in infected xylem tissue (Cobb 1988, Smith 1967).

In each of its conifer hosts, *Leptographium wageneri* only colonizes mature, non-living, xylem tracheids. Translocation only occurs in sapwood xylem and is confined to earlywood, except in the current year's xylem. Therefore, colonization of axial tracheids in the current year's latewood is important, as this is the only period latewood tracheids are utilized in water transport. Hyphae in tracheid lumens increase resistance to the flow of xylem sap, and extensive colonization of earlywood in outer growth rings significantly reduces water transport to transpiring foliage. Sequential invasion of bordered pits ultimately eliminates tracheid involvement in translocation. As adjacent tracheids are colonized, pits aspirate and tracheid embolism occurs. Trees eventually lose their ability

to translocate sufficient quantities of xylem sap to meet the daily demands of evapotranspiration as xylem colonization and gum plugging of tracheids becomes extensive. This results in an increase in the level of net non-recovery from daily transpiration stress, which ultimately results in death of the tree (Hessburg and Hansen 1987).

Phloem transport may also be impaired even though there is no hyphal colonization of the secondary phloem. Disruption of normal phloem transport is only evident adjacent to areas of extensively colonized current year's xylem in the roots. The appearance of hypertrophied sieve cells and flattened albuminous cells indicates that photosynthate does not empty rapidly enough from rays into the xylem. Loss of normal function of xylem ray cells next to colonized tracheids may reduce or eliminate the transfer of photosynthate from phloem to xylem (Hessburg and Hansen 1987).

The effects of infection by *Leptographium wageneri* on host tree physiology were examined by Helms et al. (1971) through studies on ponderosa pine seedlings growing under field conditions. The primary visible effect of seedling colonization was rootlet mortality. Approximately one month after inoculation, colonization was sufficient to noticeably affect the physiological functioning of the host seedlings, but no external symptoms of infection were apparent. Within two months of inoculation, the seedlings were consuming considerably more photosynthate in respiration than was being manufactured by photosynthesis, and seedlings were beginning to exhibit chlorosis. Maximum foliar water potential in healthy seedlings during midday periods in summer was quite uniform, and averaged –1.2 to –1.4 MPa. Two months after inoculation, average midday foliar water potential of diseased plants was approximately –3.0 to –3.6

MPa. Within five months, all diseased seedlings had died. Increased vascular colonization by *L. wageneri* with time was accompanied by decreases in both host transpiration and net photosynthesis. Root diseases and vascular wilts can cause a reduction in transpiration due to a disruption of the water economy of the host (Helms et al. 1971).

G. PathogenViability

Leptographium wageneri is believed to compete weakly as a saprophyte after the death of the host (Harrington 1992); however, it has been isolated from the roots of dead trees. The pinyon form of the fungus was isolated from the roots of a pinyon pine that had been dead for ten years (Wagener and Mielke 1961). The fungus also maintains its ability to produce conidia in culture over long periods. In spite of this, natural regeneration of pinyon pine in old disease centers has been successful in Mesa Verde National Park (Wagener and Mielke 1961). The length of time the pathogen is able to survive in these environments and infect subsequent host populations remains unclear. The hard pine variety has been isolated from the roots of lodgepole pine stumps excavated 1 year after felling in British Columbia. Hunt and Morrison (1986) obtained isolates from 1 – 4 cm diameter roots at distances up to 63 cm from the root collar. They were not able to isolate the fungus from any stumps excavated after 2 years, indicating that it remains viable in lodgepole pine stumps for only a short time after felling. The 2-year-old stumps had a much larger proportion of the root system colonized by decay fungi (Basidiomycetes) (Hunt and Morrison 1986). In ponderosa pine stands, opening of the stand by logging after disease discovery resulted in the apparent death of the fungus

perhaps due to higher soil temperatures ensuing from the removal of the overstory (Wagener and Mielke 1961).

H. Transmission

Several researchers have observed that that the fungus is able to penetrate unwounded roots, which led to the conclusion that the fungus is capable of spreading from tree to tree through root contacts (Smith 1967, Wagener and Mielke 1961). In greenhouse pathogenicity tests on wounded and unwounded ponderosa pine and Douglas-fir seedlings, Harrington and Cobb (1983) found that the fungus was able to infect without wounding. However, Hessburg and Hansen (1987) found that colonization and penetration of living cortical and cambial tissues by hyphae does not occur in Douglas-fir, supporting their observation that openings to the xylem are required for fungal infection and that simple contact between roots is not sufficient for transmission to occur. Instead, penetration was found to occur at the base of emerging rootlets where the path to xylem tissue is open, and at wounds. Further study of Douglas-fir seedlings revealed six types of infection courts: pruned rootlet stubs, broken roots, bark abrasions, sites of new lateral root emergence, attached split or fractured living roots, and the point of attachment of dead fine roots (Hessburg and Hansen 2000).

The roots of 10 to 15 year old Douglas-fir trees in Oregon were excavated by Hessburg and Hansen (1986a) who found that root graft transmission of the fungus followed the lines of functional axial xylem. In young, densely stocked Douglas-fir stands, grafting is typically frequent, as is the corresponding incidence of black-stain root disease. They determined that the probability of intertree root contact (and grafting) increases with increasing size and age of trees and decreases with increasing slope

distance between trees. While root grafting provides a means of inter-tree proliferation of the pathogen, it is most likely not the primary means of intertree spread in young Douglas-fir plantations, where tree density is low and root grafting is sporadic. They also determined that contact is not necessary for successful inter-tree transmission of the pathogen. *Leptographium wageneri* can exit from roots of Douglas-fir, grow for a limited distance outside the host, and successfully establish itself in a new host. However, a lack of intertree root contact diminishes the ability of the fungus to find suitable infection courts within a suitable time frame outside of the host. Hessburg and Hansen (1986a) concluded that local spread of *L. wageneri* within infection centers is likely composed of at least three components: 1) root graft transmission, 2) spread taking place between rootlets in contact or in close proximity to each other, and 3) insect vectoring of conidia to adjacent healthy trees. The occurrence of transmission depends on the frequency of root grafting, which is regulated by stand and site features (including species mix, stand density and tree spacing, tree age and size, and slope). Root infection occurs by direct growth of hyphae to open infection courts. Natural openings or wounds to exposed xylem are necessary for infection of healthy roots. When roots with wounds were incubated in moist chambers at 17° C profuse conidiophore production occurred at the lesions, which may act as sources of external inoculum for transmission of the pathogen (Hessburg and Hansen 1987).

In Colorado, root excavations have revealed numerous root contacts but few actual grafts between pinyons within disease centers (Landis and Helburg 1976). Black stain could be traced from tree to tree through these root connections. The pattern of stain development from older infections to adjacent trees confirmed the function of root

contacts and grafts in local spread of black stain root disease in pinyon pine (Landis and Helburg 1976).

Goheen (1976) found that 92% of diseased ponderosa pines showed evidence of infection unrelated to grafts or root contacts and proposed that fine rootlets were the principle infection courts in pines. Hicks et al. (1980) found that the majority of infections in ponderosa pine seedlings in California occurred through small rootlets (≤ 5mm in diameter) within 15 cm of, but not in actual contact with, infected roots and within 20-50 cm of the soil surface. This indicates that the pathogen is capable of moving through soil either by hyphal growth, by vector, or as water-borne spores. They were able to isolate the fungus from forest soils and determine that most propagules were likely spores. This determination was based on the fact that removal of large mineral and organic particles, to which much of the mycelia in soil would be expected to be attached, did not decrease the number of colonies appearing on plates. However, fragments of *Leptographium wageneri* mycelia also were observed in soil samples, suggesting that the fungus may grow through soil as hyphae or mycelial strands. In a laboratory study, *L. wageneri* was shown to readily grow for up to 4 to 6 cm from inoculum sources through nonsterile forest soil (Hicks et al. 1980).

I. Vectors

Two lines of evidence support the hypothesis that insect vectors act as a means of transmission for *Leptographium wageneri.* Landis and Helburg (1976) found insect galleries adjacent to stain columns of *L. wageneri* in pinyon pine. Goheen and Cobb (1978) found conidiophores of *L. wageneri* and perithecia of the sexual stage, *Ophiostoma wageneri*, only in insect galleries excavated in diseased roots of ponderosa

pine. In addition, insects are known to serve as vectors for several other pathogenic species of *Leptographium*. Both perithecia and conidiophores of *Leptographium* fungi produce spores borne in a sticky, mucilaginous matrix that are well adapted for contact dispersal but ill suited for wind or water-splash dispersal. Vectors may contact inoculum of these pathogens on diseased brood trees and then disperse to feed on healthy, wounded, or stressed trees, inoculating new hosts in the process (Witcosky and Hansen 1985). Interestingly, insects may not be the only vectors of this pathogen. *L. wageneri* has also isolated from nematodes, several species of which are known to feed on the roots of potential tree hosts (Hicks et al. 1980).

Goheen and Cobb (1978) excavated the roots of ponderosa pine trees and discovered conidiophores of *Leptographium wageneri* in insect galleries carved into the roots. The majority of the galleries and conidiophores were located on small diameter roots (2 – 5 cm) on comparatively small trees (< 40 cm d.b.h.) in the intermediate to suppressed crown classes. Galleries containing conidiophores were located in roots that were 10 – 100 cm below the soil surface. The conidiophores were associated with the galleries of *Hylastes macer* Lec., *Dendroctonus valens* Lec., one cerambycid (*Spondylis upiformis* Mannerheim), and one buprestid (likely *Buprestis arrulenta* Linn.). Conidiophores were found in 24% of the *H. macer* galleries and in less than 1% of the *D. valens,* buprestid, and cerambycid galleries examined. The majority of the *H. macer* galleries containing conidiophores were located on the undersides of roots. The previously undiscovered sexual fruiting bodies, or perithecia, were found in insect galleries in seven of the excavated roots. The discovery of both the imperfect and perfect states of the pathogen in the galleries of root-inhabiting insects supported the hypothesis

that insects are involved in long distance spread of the pathogen. The insect vector relationship was further supported by a close association between xylem staining and insect galleries in distal regions of some roots. As an adult, *H. macer* often attacks the roots of weakened trees, appears to be attracted to wounds, and is more active when the soil is moist; conditions associated with proliferation of *L. wageneri* (Goheen and Cobb 1978).

Further evidence to support the insect vector theory was reported by Witcosky and Hansen (1985), who consistently recovered 3 species of beetle from young infected Douglas-fir in managed stands in Oregon. *Hylastes nigrinus* (Mann.) (Scolytidae), *Steremnius carinatus* (Boh.) (Curculionidae), and *Pissodes fasciatus* (LeC.) (Curculionidae) comprised 97% of the insects found consistently colonizing diseased Douglas-fir in all stages of decline. Jacobi (1992) reported the same three beetle species as the most commonly trapped insects in active black stain root disease centers in 18 to 21 year old Douglas-fir plantations in British Columbia. As *Leptographium wageneri* colonizes the root systems of infected trees, heavily infected roots become highly suitable for insect oviposition and brood production. Beetles infest the root system sequentially, increasing the opportunity for contact between emerging beetles and viable inoculum. During gallery formation and pupation, the beetles take off the overlying cambial parenchyma and expose, or sever, tracheids in the outermost annual rings, the area of the root and stem xylem most commonly colonized by *L. wageneri*. Colonized tracheids must be exposed before *L. wageneri* can invade insect galleries since the hyphae are incapable of directly penetrating tracheid cell walls or parenchyma cells (Witcosky and Hansen 1985).

In order to demonstrate that root-feeding bark beetles can vector black stain root disease (BSRD), Harrington et al. (1985) artificially contaminated beetles with conidia of *Leptographium wageneri*, which has been found to produce conidia in the galleries of *Hylastes nigrinus*. Contaminated adult *H. nigrinus* beetles then fed on Douglas-fir seedlings, made wounds suitable for infection by the pathogen, and successfully introduced the pathogen into those feeding wounds. Although the frequency of transmission was low, the authors concluded that local epidemics of BSRD can occur when vector populations are high, there is abundant inoculum of the pathogen for contamination of the vectors, and there is suitable attraction and concentration of the vectors to either fresh wounds or disturbed stands (Harrington et al. 1985).

Insect interaction with black stain root disease is more complex than merely acting as a vectoring agent. Research is limited on this topic, but researchers have speculated that Ips bark beetles often attack broken, fallen, and dying pinyon affected by BSRD. The most common species of Ips bark beetles on pinyon is *Ips confusus*, which can act to increase mortality by attacking healthy pinyon adjacent to disease weakened trees when insect populations are high (Eager 1999, Wagener and Mielke 1961). Root-feeding bark beetles can introduce pathogenic fungi that kill host tissues and create a more amenable environment for insect development. When insects attack trees stressed by BSRD, other pathogenic species vectored by root-feeding bark beetles may help kill the roots and accelerate the death of the entire tree (Harrington and Cobb 1983).

III. The Disease

A. History

The symptoms of the disease were first noted in 1938 by forest entomologists working in ponderosa pine in Lassen County, California. Within Mesa Verde National Park, in southwestern Colorado, pinyon pine decline and mortality have been recorded since 1906. Approximately 12,000 dead and dying pinyons were cut and burned in the park between 1933 and 1934 (Wagener and Mielke 1961). A large proportion of those stumps was later found by Wagener and Mielke to contain the characteristic stain for the disease. In 1942, a pathogenic root disease, named black stain root disease, was recorded in the park and was postulated to have been the cause of the widespread pinyon mortality in the 1920's and 30's (Wagener and Mielke 1961). The pathogen was first isolated from Douglas-fir in 1965 in northern California (Cobb and Platt 1967).

B. Site Conditions

1. General Characteristics

Black stain root disease has been confirmed throughout the range of pinyon in western Colorado but has not been detected in any pinyon stands east of the Continental Divide density (Landis and Helburg 1976). In Colorado, BSRD is generally found on the more productive pinyon sites, often along the pinyon-mixed conifer transition zone, which are characterized by cool and moist environments, high elevations, deep soils, and high tree density (Landis and Helburg 1976). BSRD may be limited by temperature. Smith (1967) found that temperatures greater than 21° C restricted both the fungus and the development of disease. Higher quality sites with deeper soils and greater soil moisture could provide cooler temperatures and, therefore, a more favorable environment

for the pathogen since the fungus is sensitive to increasing temperatures (Landis and Helburg 1976). The restriction of the disease in Colorado to pinyon west of the Rocky Mountains may be related to the generally warmer and drier site conditions on which pinyon occurs on the east side (Harrington and Cobb 1984).

Elevations of infection centers in western Colorado range from 1890 to 2450 m. Mean monthly minimum and maximum temperatures average -8° and 28° C respectively at Mesa Verde National Park. The disease generally occurs in areas with relatively low annual precipitation, which averages 46 to 51 cm in western Colorado. At Mesa Verde National Park, disease incidence was highest in deeper soils toward the center of the mesas (Wagener and Mielke 1961). Wagener and Mielke (1961) also noted that annual mortality attributed to the disease was widely variable with peak periods of mortality thought to be associated with years in which summer rains were distributed throughout the season to maintain suitably high soil moisture levels. In heavily infested pinyon stands, disease pockets commonly merge creating an irregular mosaic of mortality (Landis and Helburg 1976).

In California, disease centers in ponderosa pine range in elevation from 1220 to 2150 m. Mean monthly minimum and maximum temperatures range from -17 to -9° C and 25 to 29° C respectively at California sites, which are also characterized by low annual precipitation of 46 to 51 cm in northeastern California and 76 cm with high variability in southern California (Wagener and Mielke 1961). In the central Sierra Nevada, a high proportion of the largest and most active infection sites occur in moist, cool areas, and spread of the pathogen appears to be more rapid in gullies and small creek drainages (Wilks et al. 1985).

In Washington and Oregon, the disease is most commonly found in 10- to 30-year-old Douglas-fir plantations and dense natural regeneration. Disease centers range in size from .001 ha (1 tree) to 4 ha (several hundred trees) and contain groups of dead trees interspersed with and surrounded by symptomatic and healthy live trees. Approximately 80% of mortality centers are associated with disturbed areas (road edges, clear-cut margins, thinnings, drainage problems, and previous soil disturbance such as compaction and displacement), suggesting that stressed trees may have increased susceptibility to infection by *Leptographium wageneri*. Although stress is not generally considered a component of tree susceptibility to *L. wageneri*, stressed trees are attractive to root feeding bark beetles, which are thought to act as vectors of the pathogen. Within young Douglas-fir stands, larger trees with well developed root systems are more likely to become infected than smaller trees with limited root systems. The mean tree diameter and the proportion of trees in the dominant and co-dominant crown classes were higher for infected trees than non-infected trees (Goheen and Hansen 1978, Hansen 1978). Harrington et al. (1983) found an apparent trend toward more disease in Douglas-fir at closer spacings, but differences in disease incidence among the spacing regimes were not statistically significant at the 0.05 level.

In British Columbia, black stain root disease is found in both Douglas-fir and lodgepole pine. Infected lodgepole pine stands are predominantly characterized as well- to over-stocked, ranging in elevation from 460 to 1675 m with approximately 80% of collections located above 900m where soils tend to be cool. Typically the disease was restricted to trees 45 years and older with a mean stand age of 80 years. Infection centers were found, initially, to be small, distinct, and abundant within stands. This suggested

the possibility that many vectors entered the stands and inoculated host trees within a relatively short interval of time (Hunt and Morrison 1986). In Douglas-fir stands the distribution of the pathogen is mainly coastal, occurring on sites with a wide range of soil textures, slopes, moisture regimes, and soil disturbance histories. The disease is found in young Douglas-fir plantations and natural regeneration and in natural stands of Douglas-fir greater than 35 years old. Morrison and Hunt (1988) reported that sites with bedrock near the surface and well drained, coarse textured soils with a history of soil disturbance had the highest incidence of BSRD. In young stands, the disease occurred more frequently near roads. Young Douglas-fir stands in British Columbia had a high rate of mortality, but the mortality rate declined with increasing stand age. Trees older than 30 often had another root disease in conjunction with BSRD, and after age 25 mortality from black stain alone was rare (Morrison and Hunt 1988).

2. Soils

Edaphic factors may have a direct effect upon the fungus as well as upon host susceptibility. Growth of *Leptographium wageneri* through soil has been demonstrated and could be a significant method of dispersal between diseased and healthy roots. Goheen et al. (1978) examined the effect of soil moisture on infection of ponderosa pine. The wettest soil treatments produced the largest numbers of infected seedlings, and incidence of infection decreased significantly as soil treatments became drier with the smallest numbers of infected seedlings occurring in the treatments subjected to the greatest moisture stresses. With successively drier soil treatments colonized circumference decreased and total vertical colonization decreased. Although the extent of *L. wageneri* colonization was not significantly different between infected trees in wet

and dry treatments, the significant differences in numbers of infections strongly suggest that infection by *L. wageneri* is favored by high soil moisture. Soil moisture may be affecting infection through its effects on the pathogen, the host, or both (Goheen et al. 1978).

According to Wilks et al. (1983), disease centers in ponderosa pine in the central Sierra Nevada are associated with high levels of buried organic matter and soluble and exchangeable soil manganese. Infection levels were highest in well-aerated treatments characterized by high redox potentials, and generally lower in treatments where very low redox potentials indicated strongly reducing conditions. Belowground colonization was higher under moist, well- aerated conditions typified by moderate redox potentials than under near-anaerobic conditions characterized by very low redox potentials or under dry conditions characterized by high redox potential. Redox potentials provide a measure of the tendency of a system to reduce or oxidize chemicals. High levels of soil moisture and oxidizable organic matter lower soil redox potential by impeding aeration and by donating electrons, respectively. Soluble and exchangeable manganese levels are inversely correlated with mean redox potentials prior to inoculation (Wilks et al. 1983). Wilks (1985) studied the relationship between site wetness, soil redox potentials, and soil temperatures to rate of disease spread in naturally occurring *Leptographium wageneri* disease centers. Redox potentials were generally very high, indicating strong oxidizing conditions and well-aerated soil, and relatively constant and were not directly related to rates of disease spread. Soil temperature also showed no independent relationship to disease spread. Water potentials were significantly related to the previously observed spread rates, which suggests that disease spread is facilitated by higher soil moisture

conditions. It may therefore be possible to generate hazard ratings based on soil moisture data (Wilks et al. 1985).

C. Colonization

Infection is regulated to some extent by temperature. Smith (1967) examined the role of temperature in infection of ponderosa pine seedlings by *Leptographium wageneri*. The seedlings were inoculated with *L. wageneri* var. *ponderosum* and grown for two months at 4 temperatures. At 16° C, 90% of the seedlings were infected, and at 21° C, 30% were infected; no seedlings were infected at either 27° or 32° C. Hessburg and Hansen (1986b), working with Douglas-fir seedlings, also found that cool soil temperatures favor seedling infection. Soil temperatures less than or equal to 18° C favored infection by *L. wageneri*; temperatures greater than 18° C decreased the likelihood of infection. Percent infection for all seedlings was at 92% at 10° C and 97% at 17° C but was significantly less at 19% for the seedlings kept at 28° C. Both vertical and circumferential growth rates of *L. wageneri* in seedling xylem were more rapid at 17° then 10° C. Vertical hyphal growth rates in roots averaged 6 mm/day when sampled 95 days after inoculation and 4.3 mm/day when sampled 270 days after inoculation. Fungal growth rates tapered off rapidly as overall tree health declined (Hessburg and Hansen1986b).

Colonization is widespread in the root systems of symptomatic trees. The root collar and many to most roots are colonized to some degree before overall tree decline is apparent. Radial colonization of successive annual rings occurs early in root infections, and an average of 8 annual rings, including current year's xylem, was colonized in inoculated seedlings. As a result, the number of successive annual rings colonized in

to colonize under or around the lesions in adjacent xylem (Hessburg and Hansen 1986b, 1987).

Wagener and Mielke (1961) found that the fungus caused a progressive decline in radial growth for 1 to 8 years prior to death of an infected pinyon. Trees did not put on a growth ring for the year in which mortality occurred. Goheen and Hansen (1978) reported that virtually all Douglas-fir die within 2 years of the stain becoming apparent at the root crown, and dead trees infected with black stain root disease had a mean of 41% of the stem circumference occupied by stain.

E. Symptoms

A tree may be extensively colonized by *Leptographium wageneri* without any above ground evidence of disease. The first visible above ground symptoms of infection by black stain root disease are a significant decline or cessation of growth of the current year's terminal shoot and a reduction in needle length of new adult needles. Terminal growth stops and tree death occurs 1 to 8 years following the appearance of crown symptoms. Reduced needle retention, crown thinning, and chlorosis are common. Needle chlorosis and restricted root development of seedlings are also found in singleleaf pinyon and ponderosa pine (Smith 1967, Smith and Graham 1975). Young Douglas-fir, on the other hand, rarely exhibit noticeable chlorosis or terminal growth reduction before dying (Morrison and Hunt 1988).

The fungus produces a characteristic dark-brown to black stain in the sapwood of infected roots and at the root crown. The stain appears as vertical streaks in the sapwood and is typically confined to annual rings and thus appears arc-shaped in cross section. This stain pattern differs from typical sapstain fungi, which occur primarily in wood rays

and produce a wedge-shaped stain pattern. In pinyon and singleleaf pinyon pines, the dark stain is rarely found more than a foot or two above the soil level. The color of the stain is variable among infected species depending upon wood moisture content, resin-soaking of the wood, and the condition of the cambium (live or dead). In Colorado, disease centers contain infected trees in all stages of decline. Pinyon of all ages and size classes are affected except for small seedlings, which apparently escape infection due to their restricted root systems (Landis and Helburg 1976).

Witcosky and Hansen (1985) noted that symptoms of infection by *Leptographium wageneri* in Douglas-fir are manifested by reduced leader and branch growth, chlorosis, reduced needle length, reduced needle retention, a distress cone crop, and, on occasion, resinous lesions on the lower stem. Goheen and Hansen (1978) also described the progression of symptoms in Douglas-fir infected by *L. wageneri*. First, leader and branch tip growth declines followed by crown thinning through the loss of older needles accompanied by a progressive change in needle color, passing from green to dull green to yellow to red. Stress cone crops and resinosis are also occasionally associated with infected trees. While younger Douglas-fir typically die within 2 years of the appearance of crown symptoms, older Douglas-fir regularly exhibited symptoms for up to 10 years before dying, and some older trees with crown symptoms not only survived but also appeared to recover (Hansen and Goheen 1988).

F. Rate of Spread

An understanding of the expected rate of expansion of mortality centers can provide land managers with a tool for evaluating the pattern and rate of mortality and improving prediction of the potential impact of the disease in affected forested

ecosystems. Many different approaches have been taken to estimate rates of spread. Nelson and Hartman (1975) used black and white aerial photos taken in 1946 and 1972 to examine spread of *Phellinus weirii* in high elevation mixed conifer stands in Oregon. Relative growth rate in culture was compared to the rate of disease development as measured on photos. Relative growth rate of clones on malt agar had no apparent relationship to measured radial expansion of disease centers (Nelson and Hartman 1975).

Spread of *Leptographium wageneri* in ponderosa pine dominated stands aged 60 to 80 years old was evaluated by Cobb et al. (1982) through analysis of a series of aerial photos taken over a 15 year period. Mortality center boundaries were divided into octants by extending eight radial lines from the geometric center as it first appeared on the photo, in order to characterize variation along the perimeters in stand and site characteristics. From aerial photos, the average whole center radial spread rate for the entire perimeters of all 52 centers was 1.0 meter/year. This was determined as the mean spread rate along the perimeter of all octants comprising each disease center. Twenty-nine percent of all octants showed no spread through the study, often due to the presence of unfavorable stand or site conditions including changes in species composition and tree density and the presence of rock outcrops. Maximum rate of spread along any octant was 7 meters/year. Only pine density was significantly related to the rate of spread, while analyses of species composition, mortality center size, and soil moisture showed no significant relationship to the rate of spread. In stands with less than 60 ponderosa pine per hectare, spread rates of octants averaged 0.01 m/yr, when density increased to 500 trees/ha spread rate averaged 1.0 m/yr, and at densities of approximately 900 trees/ha spread rate was nearly 2.0 m/yr. Soil moisture categories and disease center size did not

play a significant role in determining rate of spread. Previous studies indicated that the fungus is capable of spreading underground a maximum of 20 to 22 meters between adjacent trees (Cobb et al. 1982). Wilks (1985) reported that in the central Sierra Nevada, enlargement of ponderosa pine mortality centers is variable over time, both within and between centers.

Disease spread in black stain root disease centers in 5 to 28 year old Douglas-fir plantations in Washington and Oregon was monitored by Hansen and Goheen (1988) over a 10 year period. Stem mapping techniques were used to evaluate the radial advance of mortality along 8 radii in each plot. The mortality rate was significantly lower in plantations $\geq$ 20 years old than in those $<$ 20 years. Mortality increased over the 10 year study by 5.8 times for the plantations $<$20 years old and 3.9 times for the plantations $\geq$ 20 years old, suggesting that mortality progresses less rapidly as trees age. These findings are in accord with those of Morrison and Hunt (1988) who reported that mortality rate decreases with increasing stand age. Thinning apparently had no effect on disease increase; thinned and unthinned stands did not differ in mortality rate. Infection centers had an average radial expansion rate of about 0.7 m/yr (Hansen and Goheen 1988). In another field study, in 20 year old Douglas-fir, fungal growth rates in inoculated roots were 1.6 – 2.2 m/yr, which corresponded to observed rates of infection center expansion (Hessburg and Hansen 1986b).

Not all trees within disease centers are killed; living trees frequently separate killed trees. There are several possible explanations for this observed phenomenon including the role of natural resistance in the host, hosts that "escape" due to lack of root contact or proximity to infected individuals, and the role of insect vectors in transmission

of the pathogen. Within disease centers in Douglas-fir only 31% of the trees were killed; whereas, in pinyon and ponderosa pines, approximately 75% of the trees were killed as the fungus advanced. These differences between Douglas-fir and pinyon and ponderosa pine may be a reflection of the relative importance of insect vectors in the three host systems, as well as differing environments and host susceptibilities (Hansen and Goheen 1988). In pinyon, the majority of trees that avoid infection are small trees with correspondingly limited root systems, which likely do not come in close contact with the infected roots of other trees. In Colorado, the progress of the disease through pinyon woodlands was about 12 m in 6 years, or approximately 2 m/yr (Wagener and Mielke 1961).

G. Management

Three methods of control were evaluated by Sharon and Johnson (1987) for their ability to limit lateral spread of disease centers in pinyon pine in southwestern Colorado. The three methods were: 1.) tree removal – felling all dead and diseased trees within a root disease center in addition to the first healthy trees along the perimeter of the disease center, 2.) soil fumigation with 350 ml of Vapam pored into holes 20 to 30 cm deep at approximately 46 cm spacing to create a barrier, and 3.) placement of a mechanical polyethylene barrier into a 46 to 61 cm deep by 15 to 30 cm wide trench between healthy and diseased trees. None of the treatments were effective at preventing expansion of mortality centers. Failure of these techniques may have been due, in part, to difficulties associated with determining symptom-free trees as disease-free and the subsequent placement of chemical and mechanical barriers based on those determinations. For example, trees with no apparent aboveground symptoms may have heavily infected distal

roots, and trees positive for black stain were found beyond established barriers (Sharon and Johnson 1987). At this time, management of black stain root disease in pinyon is limited to identification of high hazard sites, cultural techniques to maintain tree vigor and spacing to avoid intertree transmission, replacing susceptible pinyon with non-susceptible junipers (Cobb 1988), and the "do nothing" option.

In Douglas-fir plantations, current management recommendations for black stain root disease include planting non-susceptible species in existing BSRD centers, and avoiding site disturbances and tree injuries to prevent establishment of new infection centers. In high hazard areas, which are those within 1.6 km of existing BSRD centers, recommendations include the avoidance of tractor logging to minimize soil disturbance, the planting of mixed species, and timing of precommercial thinnings between June and early August (Hansen et al. 1988). The recommendations for management in ponderosa pine are similar: identify high hazard areas, avoid monocultures, plant mixed species with less than 25% ponderosa pine component, and avoid wounding trees, soil compaction, and other site disturbances (Cobb 1988). In lodgepole pine stands in British Columbia harvesting stands at the pathological rotation, then regenerating to lodgepole is advocated since the pathogen is not thought to survive in stumps more than 2 years after harvest (Morrison and Hunt 1988).

Literature Cited

Chambers, J. C., Schupp, E. W., and Vander Wall S. B. 1999. Seed dispersal and seedling establishment of piñon and juniper species within the piñon-juniper woodland. *In* Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West, 15-18 Sept. 1997, Provo, UT. *Compiled* by S. B. Monsen and R. Stevens. USDA For. Serv., Rocky Mountain Research Station. RMRS-P-9. Ogden, UT: pp 29 – 34

Cobb, F. W., Jr. 1988. *Leptographium wageneri*, cause of black-stain root disease: a review of its discovery, occurrence and biology with emphasis on pinyon and ponderosa pine. *In Leptographium* root diseases on conifers. *Edited* by T. C. Harrington and F. W. Cobb, Jr. American Phytopathological Society Press, St. Paul, MN. pp 41 – 62.

Cobb, F. W., Jr. and Platt W. D. 1967. Pathogenicity of *Verticicladiella wagenerii* to Douglas fir. Phytopathology 57: 998 – 999.

Cobb, F. W., Jr., Slaughter, G. W., Rowney, D. L., and DeMars, C. J. 1982. Rate of spread of *Ceratocystis wageneri* in ponderosa pine stands in the central Sierra Nevada. Phytopathology 72:1359 – 1362.

Eager, T. J. 1999. Factors affecting the health of pinyon pine trees (*Pinus edulis*) in the pinyon-juniper woodlands of western Colorado. *In* Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West, 15-18 Sept. 1997, Provo, UT. *Compiled* by S. B. Monsen and R. Stevens. USDA For. Serv., Rocky Mountain Research Station. RMRS-P-9. Ogden, UT: pp. 397 – 399.

Goheen, D. J. 1976. *Verticicladiella wagenerii* on *Pinus ponderosa*: epidemiology and inter-relationships with insects. Ph.D. thesis. University of California, Berkeley. 118 p.

Goheen, D. J. and Cobb, F. W., Jr. 1978. Occurrence of *Verticicladiella wagenerii* and its perfect state, *Ceratocystis wageneri* sp. nov., in insect galleries. Phytopathology 68: 1192 – 1195.

Goheen, D. J., Cobb, F. W., Jr., and McKibbin, G. N. 1978. Influence of soil moisture on infection of ponderosa pine by *Verticicladiella wagenerii*. Phytopathology 68: 913 – 916.

Goheen, D. J. and Hansen, E. M. 1978. Black stain root disease in Oregon and Washington. Plant Disease Reporter 62: 1098 – 1102.

Gottfried, G. J. 1987. Regeneration of pinyon. *In* Proceedings – Pinyon-Juniper Conference, 13-16 Jan. 1986, Reno, NV. *Compiled by* R. L. Everett. Gen. Tech. Rep. INT-215. USDA Forest Service Intermountain Research Station, Ogden, UT. pp.. 249 – 254.

Hansen, E. M. 1978. Incidence of *Verticicladiella wagenerii* and *Phellinus weirii* in Douglas-fir adjacent to and away from roads in western Oregon. Plant Disease Reporter 62: 179 – 181.

Hansen, E. M. and. Goheen, D. J. 1988. Rate of increase of black-stain root disease in Douglas-fir plantations in Oregon and Washington. Canadian Journal of Forest Research 18: 942 – 946.

Hansen, E. M., Goheen, D. J., Hessburg, P. F., Witcosky, J. J., and Schowalter, T. D. 1988. Biology and management of black-stain root disease in Douglas-fir. *In Leptographium* root diseases on conifers. *Edited by* T. C. Harrington and F. W. Cobb, Jr. American Phytopathological Society Press, St. Paul, MN. pp. 63 – 80.

Harrington, T. C. 1988. *Leptographium* species, their distributions, hosts and insect vectors. *In Leptographium* root diseases on conifers. Edited by T. C. Harrington and F. W. Cobb, Jr. American Phytopathological Society Press, St. Paul, MN. pp 1-39.

Harrington, T. C. 1992. *Leptographium*. *In* Methods for research on soilborne phytopathogenic fungi. *Edited by* L. L. Singleton, J. D. Mihail, and C. M. Rush. American Phytopathological Society Press, St. Paul, MN. pp 129 – 133.

Harrington, T. C. and Cobb, F. W., Jr. 1983. Pathogenicity of *Leptographium* and *Verticicladiella* spp. isolated from roots of western North American conifers. Phytopatholgy 73: 596 – 599.

Harrington, T. C. and Cobb, F. W., Jr. 1984. Host specialization of three morphological variants of *Verticicladiella wagenerii*. Phytopathology 74: 286 – 290.

Harrington, T. C. and Cobb, F. W., Jr. 1986. Varieties of *Verticicladiella wageneri*. Mycologia 78: 562 – 567.

Harrington, T. C. and Cobb, F. W., Jr. 1987. *Leptographium wageneri* var. *pseudotsugae*, var. nov., cause of black stain root disease on Douglas-fir. Mycotaxon XXX:501 – 507.

Harrington, T. C., Cobb, F. W., Jr., and Lownsbery, J. W. 1985. Activity of *Hylastes nigrinus*, a vector of *Verticicladiella wageneri*, in thinned stands of Douglas-fir. Canadian Journal of Forest Research 15: 519 – 523.

Harrington, T. C., Reinhart, C., Thornburgh, D. A., and Cobb, F. W., Jr. 1983. Association of black-stain root disease with precommercial thinning in Douglas-fir. Forest Science 29: 12 – 14.

Helms, J. A., Cobb, F. W., Jr., and Whitney, H. S. 1971. Effect of infection by *Verticicladiella wagenerii* on the physiology of *Pinus ponderosa*. Phytopathology 61: 920 – 925.

Hepting, G. H. 1971. Disease of forest and shade trees of the United States. USDA For. Ser. Ag. Handbook 385: 308 – 309.

Hessburg, P.F. and Hansen, E. M. 1986a. Mechanisms of intertree transmission of *Ceratocystis wageneri* in young Douglas-fir. Canadian Journal of Forest Research 16: 1250 – 1254.

Hessburg, P. F. and Hansen, E. M. 1986b. Soil temperature and rate of colonization of *Ceratocystis wageneri* in Douglas-fir. Phytopathology 76: 627 - 631.

Hessburg, P.F. and Hansen, E. M. 1987. Pathological anatomy of black stain root disease of Douglas-fir. Canadian Journal of Botany 65: 962 – 971.

Hessburg, P.F. and Hansen, E. M. 2000. Infection of Douglas-fir by *Leptographium wageneri*. Canadian Journal of Botany 78: 1254 - 1261.

Hicks, B.R., Cobb, F. W., Jr., and Gersper, P. L. 1980. Isolation of *Ceratocystis wageneri* from forest soil with a selective medium. Phytopathology 70: 880 – 883.

Hunt, R. S. and Morrison, D. J. 1986. Black-stain root disease on lodgepole pine in British Columbia. Canadian Journal of Forest Research 16: 996 – 999.

Jacobi, W. R. 1992. Potential insect vectors of the black stain root disease pathogen on southern Vancouver Island. Journal of the Entomological Society of British Columbia 89: 54 - 56.

Kendrick, W. B. 1962. The *Leptographium* complex: *Verticicladiella* Hughes. Canadian Journal of Botany 40: 771 – 797.

Landis, T. D. and Helburg, L. B. 1976. Black stain root disease of pinyon pine in Colorado. Plant Disease Reporter 60: 713 - 717.

Lindsey, J. P. 2001. Personal communication. Fungi on *Pinus edulis*. Fort Lewis College, Durango, CO.

Morrison, D.J. and Hunt, R.S. 1988. *Leptographium* species associated with root disease of conifers in British Columbia. *In*: *Leptographium* Root Diseases on Conifers. *Edited by* T. C. Harrington and F. W. Cobb, Jr. American Phytopathological Society Press, St. Paul, MN. pp. 81-95.

Nelson, E. E. and Hartman, T. 1975. Estimating spread of *Poria weirii* in a high-elevation mixed conifer stand. Journal of Forestry 73: 141-142.

Otrosina, W. J. and Cobb, F. W., Jr. 1987. Analysis of allozymes of three distinct variants of *Verticicladiella wageneri* isolated from conifers in western North America. Phytopathology 77: 1360 – 1363.

Ronco, F. P., Jr. 1986. Stand structure and function of pinyon-juniper woodlands. *In* Proceedings – Pinyon-Juniper Conference, 13-16 Jan. 1986, Reno, NV. *Compiled by* R. L. Everett. Gen. Tech. Rep. INT-215. USDA Forest Service Intermountain Research Station, Ogden, UT. pp. 14 – 22

Ronco, F. P., Jr. 1990. *Pinus edulis* Engelm. *In* Silvics of North America. *Technical coordinators* R. M. Burns and B. H. Honkala. Agricultural Handbook 654. USDA Forest Service, Washington, DC. pp 327 – 337.

Sharon, E. M. and Johnson, D. W. 1987. Evaluation of control measures for black stain root disease in pinyon pine in southwestern Colorado. USDA For. Serv., Rocky Mountain Region Tech. Rep. R2-39. Lakewood, CO.

Smith, R. S., Jr. 1967. *Verticicladiella* root disease of pines. Phytopathology 57: 935 – 938.

Smith, R. S., Jr., and Graham, D. 1975. Black stain root disease of conifers. USDA Forest Service Forest Pest Leaflet 145.

Tainter, F. H. and Baker F. A. 1996. Principles of Forest Pathology. John Wiley & Sons, Inc., New York, NY: 684 – 690.

Wagener, W. W. and Mielke, J. L. 1961. A staining-fungus root disease of ponderosa, Jeffrey, and pinyon pines. Plant Disease Reporter 45: 831 - 835.

Webber, J. F. and Hansen E. M. 1990. Susceptibility of European and north-west American conifers to the North American vascular pathogen *Leptographium wageneri*. European Journal of Forest Pathology 20: 347 – 354.

West, N. E. and Van Pelt, N. S. 1987. Successional patterns in pinyon-juniper woodlands. *In* Proceedings – Pinyon-Juniper Conference, 13-16 Jan. 1986, Reno, NV. *Compiled by* R. L. Everett. Gen. Tech. Rep. INT-215. USDA Forest Service Intermountain Research Station, Ogden, UT. pp. 43 – 52.

Wilks, D. S. Gersper, P. L., and Cobb, F. W., Jr. 1985. Association of soil moisture with spread of *Ceratocystis wageneri* in ponderosa pine disease centers. Plant Disease 69: 206 – 208.

Wilks, D. S., Gersper, P. L., and Cobb, F. W., Jr. 1983. Relation of soil redox potential to infection of ponderosa pine by *Ceratocystis wageneri*. Phytopathology 73:1120 – 1125.

Wingfield, M. J. 1985. Reclassification of *Verticicladiella* based on conidial development. Transactions of the British Mycological Society 85: 81 – 93.

Witcosky, J. J. and Hansen, E. M. 1985. Root-colonizing insects recovered from Douglas-fir in various states of decline due to black-stain root disease. Phytopathology 75: 399 – 402.

BLACK STAIN ROOT DISEASE IN THE PINYON – JUNIPER WOODLANDS OF SOUTHWESTERN COLORADO

Introduction

Pinyon – juniper woodland (PJ) is the largest forest cover type in Colorado covering over 1.8 million hectares (Landis and Helburg 1976), most of which grows on the western slope of the Continental Divide. Prehistoric populations in the Southwest made extensive use of PJ for more than 10,000 years (Cartledge and Propper 1993). These woodlands have traditionally been utilized for fuelwood production, grazing, and production of edible pine nuts (Ronco 1990). Substantial increases in use of pinyon - juniper woodlands for housing and recreation have occurred in recent years (Eager 1999). Increased activity in pinyon – juniper woodlands has been accompanied by a heightened awareness that mortality of pinyon (*Pinus edulis* Engelm.) has and continues to take place. Reduced fire frequency resulting from the decline in Native American-caused fires, reduction of fine fuels through livestock grazing, and, more recently, fire suppression activities (Miller et al.1995) is creating a more advanced successional state in these woodlands, which along with elevated levels of human activity is thought to be contributing to the recently observed pinyon mortality (Eager 1999).

Primary mortality agents of pinyon include black stain root disease, a vascular wilt disease of pinyon pine caused by the fungal pathogen *Leptographium wageneri* (Kendr.) Wingf. var. *wageneri*, and the pinyon Ips bark beetle (*Ips confusus* Leconte) (Eager 1999). Black stain root disease (BSRD) was first identified in Colorado at Mesa Verde National Park in 1942, but is likely to have been observed as early as 1906 (Wagener and Mielke 1961). Black stain root disease is considered a native disease of western forests (Tainter and Baker 1996). Local spread

of the disease occurs through root contacts and grafts between infected individuals and healthy trees (Hessburg and Hansen 1986). Mortality of pinyon attributable to BSRD often has different appearances on the landscape, at times appearing as discrete mortality centers while in areas that are heavily infested, disease centers merge and appear as a mosaic of mortality covering extensive areas (Landis and Helburg 1976). Insects may act as the vector across larger distances, although vectors of the pinyon variant have not yet been identified. Insect vectors have been identified for both the Douglas-fir and hard pine variants of *Leptographium wageneri* (Witcosky and Hansen 1985, Harrington et al. 1985, Goheen and Cobb 1978). Pinyons affected by BSRD are often attacked by Ips bark beetles; the most common species found on pinyon is *Ips confusus*, referred to as the pinyon Ips. Ips beetles act as agents of thinning and recycling by attacking and feeding on declining and dying trees, but when populations are high they may act to increase mortality by attacking healthy pinyon adjacent to disease weakened trees (Eager 1999, Landis and Helburg 1976, Wagener and Mielke 1961).

Previous research on BSRD has focused predominately on two other varieties of *Leptographium wageneri* that infect hard pines and Douglas-fir due to the hosts' commercial value as timber species. The disease in pinyon has been less intensively studied. Consequently, very little is known about the short-term or long-term impacts of BSRD on the pinyon – juniper woodlands ecosystem. Pinyon is highly susceptible to *L. wageneri* infection, which typically results in mortality, while junipers are not susceptible and are not directly affected by BSRD. Continued high mortality of pinyon could potentially shift the species composition of these forests towards dominance by juniper species. Land managers recognize the values, products, and benefits of these woodlands, and have a mandate to maintain healthy, sustainable, and productive ecosystems. Removal of pinyon through BSRD caused mortality potentially could

have detrimental effects on wildlife and ecosystem properties by altering species composition and stand structure, and through changing nutrient cycling and hydrologic regimes.

In the summer of 1999, a study was undertaken to examine the effects of *Leptographium wageneri* var. *wageneri* on pinyon - juniper (*Juniperus osteosperma* (Torr.) Little and *Juniperus scopulorum* Sarg.) woodlands in southwestern Colorado. The objectives of this study were to examine the effects of *Leptographium wageneri* var. *wageneri* where discrete areas of mortality (mortality centers) had been created in pinyon - juniper woodlands by answering the following questions:

1) Does BSRD significantly impact the composition and structure of pinyon-juniper woodlands at the tree, shrub, or herbaceous levels?
2) Is BSRD significantly altering tree regeneration within mortality centers?
3) How long do pinyon snags and logs persist to provide habitat, erosion protection, and other ecosystem properties?
4) How long can the pathogen remain viable within the roots of dead pinyon putting subsequent generations of pinyon at risk?
5) At what rate are discrete BSRD mortality centers expanding? Are there site characteristics that influence the rate of expansion?

Study Sites

Thirty mortality centers were surveyed. All sampled mortality centers fit the following criteria: a pattern of expanding mortality with dying or newly dead trees defining edges surrounded by green, healthy trees, and visually confirmed black stain in at least one tree. Black stain root disease mortality centers that fit the criteria were sampled whenever they were

encountered. The samples were thus not spatially located in a random manner, but there was no intentional bias in the sample for any size structure, species composition, or environment. Twenty-two mortality centers were located near McPhee reservoir, north of Cortez, CO within the western portion of the San Juan National Forest. Eight mortality centers were located in a second study area, which straddles the boundary of the Southern Ute Reservation and the San Juan NF, east of Ignacio, CO and is approximately 113 kilometers east of the McPhee sites. These study sites were selected due to their accessibility, the presence of logistical support, and the expressed concern by land managers regarding the management implications of observed pinyon mortality. Elevations of mortality centers ranged from 1945 to 2334 m, essentially covering the middle portion of the elevational range of pinyon in Colorado (Ronco 1990). Mortality center attributes including percent slope, aspect, a description of general topography, slope position, UTM coordinates, elevation, area, and circumference of disease centers were recorded and are listed in Appendix 1.

Materials and Methods

Mortality Center Characteristics

At each plot, the circumference of the mortality center was defined at the midpoint between the last chlorotic or dead pinyon and the first green, non-symptomatic pinyon encountered. Plot center was established at the location of the oldest estimated pinyon mortality, based on the condition of the snag or log, within the plot. Plot centers were monumented with the placement of rebar and tagging the nearest sound tree; the distance and bearing to plot center from the tagged tree were recorded to aid future plot center relocation efforts. All boundaries and plot centers were geo-referenced and measured using Trimble Navigation's GeoExplorer II Global Positioning System (GPS) unit. Trimble Pathfinder Office software (Sunnyvale, CA) was

used to download, differentially correct, and group the individual fixes to form point and polygon files, then to create export files for the GIS software package Arc/Info (ERSI, Version 7.2, Redlands, CA). Arc/Info was used for GPS file handling, editing the resulting coverage, and GIS cross-program file preparation. Maps indicating mortality center locations were designed using GIS files from the USGS and the San Juan National Forest (Appendix 2). General soil characteristics of mortality centers as determined from USDA Natural Resources Conservation Service (NRCS) SSURGO (Soil Survey Geographic database) GIS layers and USDA NRCS map unit descriptions are provided in Appendix 3 (Pannell 2000 and Ramsey 2001). Directions to each plot and related information are found in Appendix 4.

Three transects were established within each mortality center. Transects radiated out from plot center with a minimum of 45° between the centerline of transects. Whenever possible transects were placed so as to include declining pinyon. When only one transect included chlorotic pinyon, remaining transect centerlines were located at 120° intervals. Transect properties included slope, compass bearing (using a declination of 12°E), and length (Appendix 5). Transects were 6.1 meters wide and varied in length from 7.9 to 74.4 meters with a mean transect length of 33.2 meters, ending at the first green, non-symptomatic pinyon beyond all declining and dead trees (Figure 2.1). For every tree, snag, or log whose base fell within the transect the following were recorded: location measured as the distance along the center line from plot center; species, height (total standing height or total length of log segments to estimate height when standing and whole), diameter at root crown measured as the average of two caliper measurements taken at 90° from each other at 10 cm, tree status based on a 14 class system designed to describe tree/snag/log condition (Table 2.1 - modified from Sharon 1985; Dr. D. Omdal, Personal Communication, Washington Department of Natural Resources, P.O. Box

47037, Olympia WA 98504-7037), presence of damaging agents, and symptoms and signs of black stain and Ips (Figure 2.2).

Shrub Cover and Tree Seedlings

Circular shrub and seedling plots of 40 m^2 were established at the mid-point of each transect, representing conditions within the mortality center, and at 9.14 meters beyond the end of the transect, representing the unaffected forest. Shrub cover by species, including all non-coniferous woody plants >30 cm tall, and the number of pinyon, juniper, and ponderosa pine seedlings were measured. A complete list of shrub species is provided in Appendix 6.

Herbaceous Vegetation and Ground Cover

Two - 20 X 50 cm rectangular plots were established at the mid-point and 9.14 meters beyond the end of the transect to represent conditions within the mortality center and in the adjacent unaffected forest, respectively. Percent herbaceous cover by species, including all non-woody plants and woody plants <30 cm tall, and percent cover by bare soil, litter, and rock were recorded. Herbaceous level plants, except grasses and mosses, were identified when possible to the species level. A complete listing of all recorded herbaceous species can be found in Appendix 7.

Snag and Coarse Woody Debris

Tree increment cores and/or stem cross-sections were obtained from sound pinyons in all tree status classes present within individual mortality centers to date mortality, determine expansion rates of mortality centers, and determine persistence of pinyon snags and coarse woody debris. Increment cores were taken as close to ground level as possible and perpendicular to the slope to minimize tension and compression wood effects on ring size. Stem cross-sections were obtained when possible from older tree status classes. Increment cores and stem

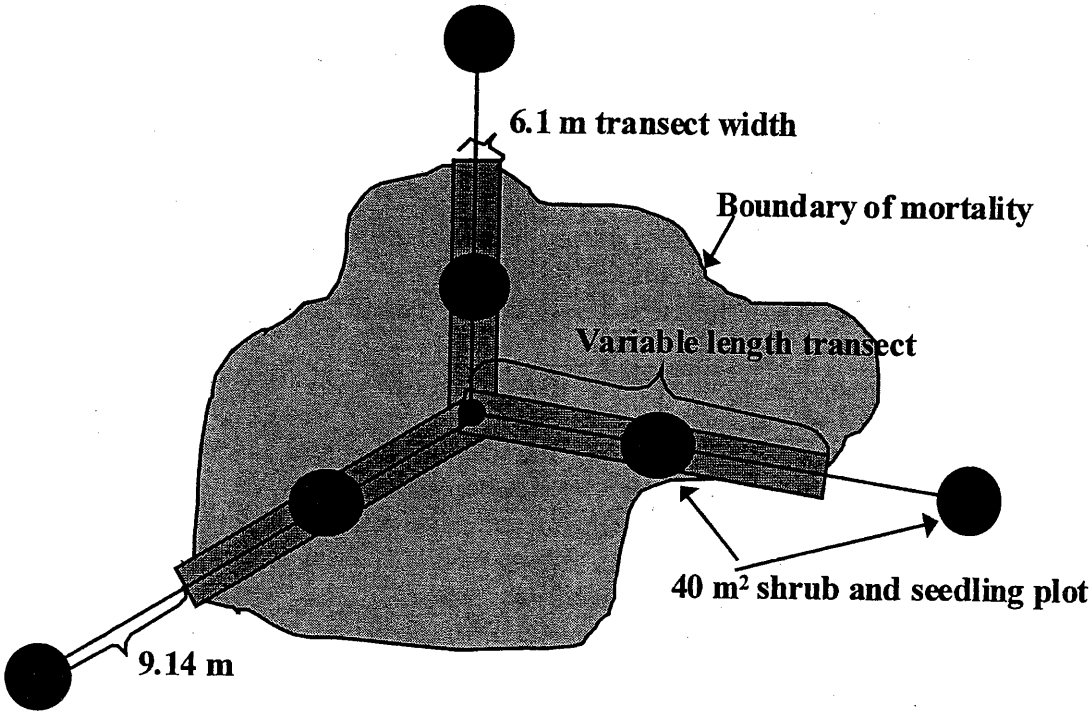
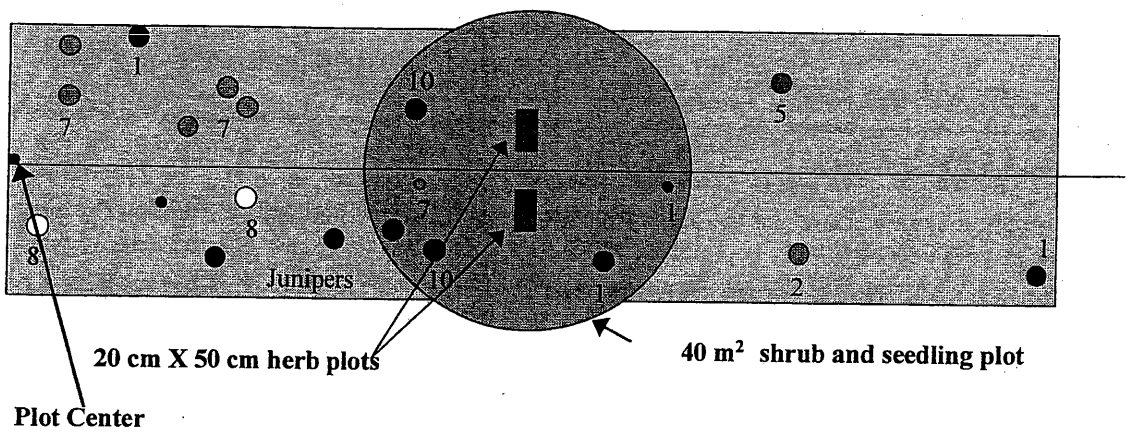


Figure 2.1. Plot sampling scheme for black stain root disease mortality centers in pinyon – juniper woodlands



Circles represent tree locations and numbers represent tree status.

Figure 2.2. Sample transect illustrating location of trees and placement of shrub/seedling and herbaceous layer plots in black stain root disease mortality centers in pinyon – juniper woodlands

Table 2.1. Tree status rating system applied to black stain root disease centers in pinyon – juniper woodlands (modified from Sharon 1985; Omdal Personal Communication)

Tree Status Class	Description
1	No chlorosis; tree foliage appears normal green color, healthy
2	One-third of crown displays chlorotic foliage (based on # of branches)
3	Two-thirds of crown displays chlorotic foliage (based on # of branches)
4	All branches exhibit chlorotic foliage (general yellowing, some red needles but majority are yellow)
5	Crown with red/brown foliage; tree dead; foliage remaining on twigs
6	Few to no needles, many fine twigs, intact bark, sound heartwood
7	No needles, many twigs, bark may be missing in patches, relatively intact crown, sound heartwood
A/ B/ C/ D	A = Sapwood and heartwood sound; B = Sapwood and heartwood decayed; C = Sapwood firm, heartwood decayed; D = Sapwood decayed, heartwood firm
8 A / 8 B / 8 C / 8 D	No needles, few twigs, 5 – 33% branches broken, bark loose or missing in places, crown broken
9 A / 9 B / 9 C / 9 D	Very few twigs remaining, crown broken, most branches broken, bark loose or missing
10 A / 10 B / 10 C / 10 D	Downed, few twigs, 5 – 33% branches broken, bark loose or missing in places, like #8
11 A / 11 B / 11 C / 11 D	Downed, very few twigs remaining, most branches broken, bark loose or missing, like #9
12 A / 12 B / 12 C / 12 D	Downed, stem broken into pieces, few branches
13	Well deteriorated, extensive loss of original mass, original shape apparent to undistinguishable, becoming incorporated into soil
14 A / 14 B / 14 C / 14 D	Cut Stump

cross-sections were mounted on wooden blocks, sanded, and examined with a binocular microscope. Cross-dating was conducted using the skeleton plot technique (Stokes and Smiley 1968) based on chronologies developed from live trees on each site. The master chronologies developed for the McPhee and Ignacio study sites were based on increment cores obtained from a minimum of 20 live, healthy trees (Appendix 8). This process of cross-dating was utilized to determine the date of mortality, which was assumed to be the last year in which a growth ring was added. Because tree ring analyses were for comparative purposes, no adjustments were

made to determine true age, and tree ages were defined as ages at coring height. A total of 277 cores and stem cross sections from the 30 mortality centers at McPhee and Ignacio were cross-dated to determine the year in which the last growth ring had been added. Ages and the year that the last growth ring was added for all sampled pinyon are provided in Appendix 9.

In order to supplement snag and coarse woody debris data collected from the two study sites, black stain root disease monitoring plots established within Mesa Verde National Park by U.S. Forest Service personnel were relocated and visited. Mesa Verde is a 21,045 ha National Park located in the high plateau country of southwestern Colorado, between the Cortez and Ignacio sites. Elevations in the park vary from 1980 to 2590 meters, and the climate is classified as cold, middle latitude, semiarid (Omi and Emrick 1980). In 1978, U.S. Forest Service personnel established seven variable radius plots in order to examine mortality rates. Trees were tagged, referenced to plot center, and the condition and cause of death, if applicable, were recorded (Sharon 1985). The plots were all revisited in 1980, 1982, 1984, and1986. Three of the seven plots were remeasured in 1992. We visited five of the plots in 1999, one in 2000, and were unable to relocate the seventh plot. The six Mesa Verde plots contained between 17 and 113 tagged pinyon, and a total of 293 pinyon were reexamined and classified according to tree status based on the 14 - class system designed to describe tree/snag/log condition (Table 2.1). The number of years dead was then determined for each tree based on Forest Service records as the midpoint between last year recorded live and first year recorded as dead. These data on number of years dead by tree status class were then compared with the data assembled from tree ring analyses at the two study sites and used to determine mean years dead by tree status class.

Pathogen Viability

Pinyon root and root crown samples were isolated from in the laboratory to confirm presence of the pathogen and determine its viability in dead pinyon. The sampled tissues were kept cool after collection in the field until processed and then cut into thin (< 1 cm thick) slices with a band saw. Isolations were made from root and root crown tissues from which the bark had been removed and small slivers of discolored wood produced using a scalpel. A 1.5 % water agar amended after autoclaving with 200 mg/L cycloheximide and 100 mg/L streptomycin was used as the selective medium (Harrington, 1992). Cultures were kept at 15° to 17° C in a dark growth chamber then transferred to 4.5% malt extract agar after approximately 3 weeks. Cultures were identified on the basis of mycelial and conidiophore characteristics. *Leptographium wageneri* var. *wageneri* has a conidiophore with a solitary, brown to dark brown, septate stipe arising directly from repent hyphae. The primary metulae (2 – 20 in number) occur in a slightly divergent cluster at the apex of the stipe, are typically long and narrow, and are concolorous to slightly paler in color than the stipe (Figure 2.3). These primary metulae give rise to 1 to 4 more series of metulae, which are generally hyaline. The conidia accumulate in a slimy mass, which is clear in young conidiophores and becomes golden brown upon drying. The hyphae are septate, amber to dark-brown in color, smooth-walled, and varying between straight, branched, and sinuous (Kendrick 1962, Harrington and Cobb 1986). Presence of *Leptographium wageneri* var. *wageneri* in culture was verified by Dr. T.C. Harrington, Department of Plant Pathology, 351 Bessey Hall, Iowa State University, Ames, IA 50011, and those verified cultures acted as the basis of comparison for all other isolations.

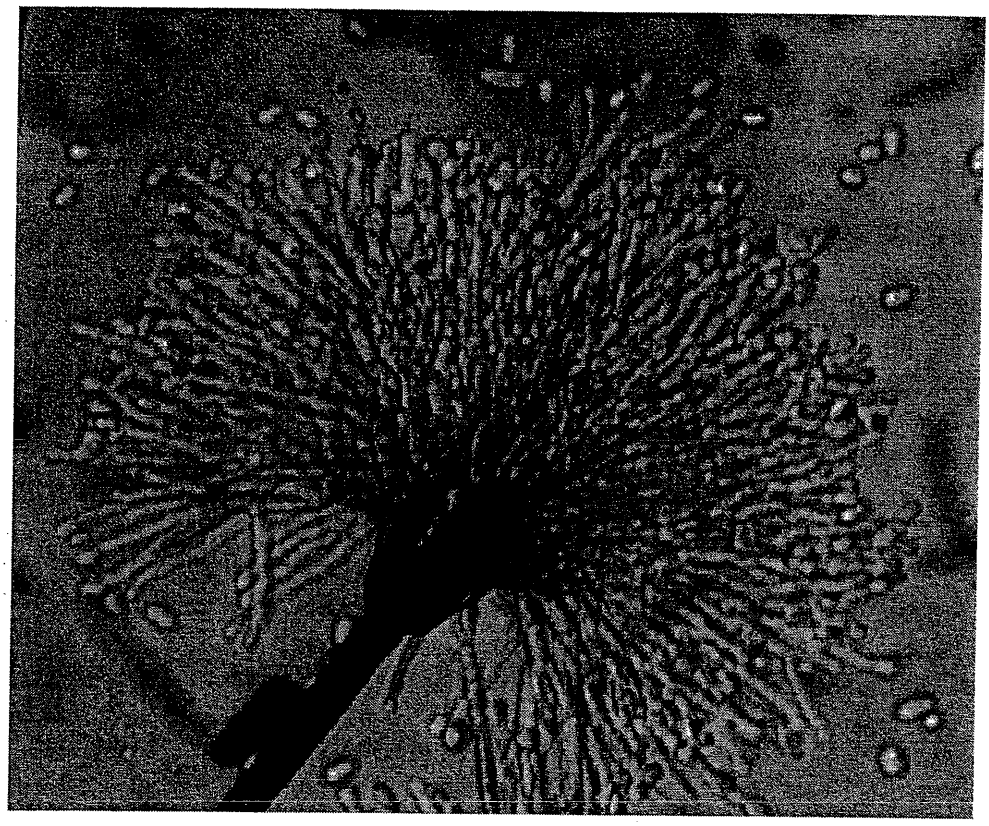


Figure 2.3. Conidiophore of *Leptographium wageneri* var. *wageneri*

Rate of Mortality Center Expansion

The first dead pinyon in each transect was treated as the initiation point for disease in that transect. For all other pinyon in an individual transect, the change in distance and the change in number of years dead relative to the first dead pinyon was calculated.

Data Analyses

Mortality Center Characteristics. Statistical analyses were performed utilizing the SAS (Cary, NC) Mixed and GLM statistical procedures. Summary statistics were calculated for tree measurements, including diameter at root crown, height, BSRD infection, and status. Analysis of variance, correlation, and t-tests were performed to examine relationships between values

including tree measurements, number of trees infected, tree location along transects. The study was considered a randomized block design for statistical evaluation.

Vegetation Diversity. To determine the effect of *Leptographium wageneri* var. *wageneri* infection on herbaceous and shrub layer vegetation we utilized species richness and diversity indices. Species richness is the total number of species in a community and was determined by employing direct counts of species numbers present in samples of equal size. Diversity indices incorporate both species richness and species evenness, how species abundances are distributed among species present, into a single value (Ludwig and Reynolds 1988). In a diverse community, the typical species is rare. Diversity can be defined as the average rarity within a community (Patil and Taillie 1982). Three indices of diversity were utilized, Shannon's index, Simpson's index, and Hill's ratio of evenness, to examine differences in diversity between infection centers and surrounding areas.

Shannon's index has been one of the most universally employed indices in community ecology. It provides a measure of the average degree of uncertainty of predicting the species of a given individual picked at random from a community, and is given by the formula $H' = -\sum (P_i * \ln [P_i])$ where P_i is the percent cover of a given species divided by the total percent cover of all species. Simpson's index, which varies from 0 to 1, is a measurement that accounts for species richness and percent of each species, gives the probability that two individuals drawn at random from a population belong to the same species, and is calculated by employing the formula $\lambda = \sum ((\%\ \text{cover}_i\ (\%\ \text{cover}_i - 1))/ (\text{total}\ \%\ \text{cover}\ (\ \text{total}\ \%\ \text{cover} - 1))$. If the probability that both individuals belong to the same species is high, then the diversity of the community sample is considered low. Hill's modified ratio as an index of evenness is defined by the formula E =

$((1/\lambda)-1) / (e^{H'}- 1)$ and approaches 0 as a single species becomes more dominant within a community (Ludwig and Reynolds 1988).

Pinyon Snag and Log Persistence. Mean number of years dead was determined for each pinyon status class based on data from tree ring analyses and Mesa Verde BSRD plots. T-tests were applied to determine significant differences in number of years dead between pinyon status classes. Analysis of variance was performed to determine the effect of site (McPhee, Ignacio, and Mesa Verde) on adjusted least square mean ages of pinyon snags and logs.

Rate of Mortality Center Expansion. The mean rate of expansion was calculated using a split plot design and analysis of covariance to determine the relationship between the change in distance and the change in number of years dead within each transect for the 30 examined black stain mortality centers. Analysis of covariance and correlation analysis were performed to examine effects of physical and chemical soil properties, slope, aspect direction, slope position, general topography, mean stand age, and tree density on the rate of expansion. Soil properties including pH, permeability, mean bulk density, available water capacity, cation exchange capacity, organic matter content, and clay content were derived from USDA Natural Resources Conservation Service (NRCS) SSURGO (Soil Survey Geographic database) GIS. These soil property data were averaged for each horizon from the range of values provided, and a weighted average of the relative contribution each of the horizons made was determined for three cumulative soil depths (0.0-0.3 m, 0.3-0.6 m, and 0.6 – 0.9 m).

Results and Discussion

Mortality Center Characteristics

The composition and structure of BSRD mortality centers were compared with the communities found in the adjacent non-affected woodlands in order to address our first question:

Does BSRD significantly impact the composition and structure of pinyon-juniper woodlands at the tree, shrub, or herbaceous levels? Black stain root disease caused pinyon mortality can appear as both distinct mortality centers and as a mosaic of mortality over extensive areas. For this study, only discrete BSRD mortality centers exhibiting an expanding pattern of mortality were examined. We start with a general description of the mortality centers and the trees that comprise them.

Black stain root disease centers varied in size, shape, and general site characteristics. Discrete BSRD mortality centers, as delineated using GPS, had a mean area of 0.28 hectares (range 0.07 to 0.63 ha) and a mean perimeter of 287.4 m (range 124.5 to 513.3 m) (Appendix 1). The total area of the 30 mortality centers was 8.46 ha. Mortality centers were irregularly shaped, having a mean ratio of perimeter to area 3.3 times higher (range 2.1 to 5.5 times higher) than the ratio of perimeter to area of a perfect circle indicating that these mortality centers are not expanding evenly in all directions. Mortality centers were found on slopes ranging from 1 to 46% and on all aspects. The majority of mortality centers were located on topography generally described as even, but centers were also found on topography characterized as concave and as convex. Furthermore, plots were located in all possible slope position categories.

The trees that compose the overstory of BSRD mortality centers in southwestern Colorado are predominately pinyon pine and two species of juniper. Pinyon pine was present within all mortality centers and had a mean height, including all trees live and dead, of 3.7 m and a mean diameter at root crown of 15.2 cm (Table 2.2). Live pinyon within BSRD mortality centers had a significantly smaller mean diameter at root crown then dead pinyon ($p < 0.01$) at 14.1 and 15.8 cm, respectively. Live pinyon had a significantly larger mean height then dead pinyon ($p < 0.001$) at 4.0 and 3.5 m, respectively, which may be in part attributable to the decomposition of

pinyon snags and logs. Utah juniper (*Juniperus osteosperma*) was present on 17 of 22 mortality centers at McPhee Reservoir and all 8 mortality centers near Ignacio, comprised 76.2% of non-pinyon tree species present on transects, and had a mean height of 3.8 m and a mean diameter at root crown of 18.6 cm. Rocky Mountain juniper (*Juniperus scopulorum*) was present on 13 of 22 mortality centers at McPhee Reservoir and 2 of 8 mortality centers near Ignacio, comprised 20.9% of non-pinyon tree species present on transects, and had a mean height of 3.7 m and a mean diameter at root crown of 15.7 cm. Ponderosa pine (*Pinus ponderosa*) was present on only 3 of 22 mortality centers at McPhee Reservoir and none of the 8 mortality centers near Ignacio, comprised 2.9% of non-pinyon tree species present on transects, and had a mean height of 8.1 m and a mean diameter at root crown of 35.7 cm.

Table 2.2. Characteristics of the trees that make up the overstory within 30 black stain root disease mortality centers

Attribute	N	Mean	Standard Deviation
Pinyon Diameter at Root Crown	1063	15.2 cm	9.0
Pinyon Height	1063	3.7 m	1.7
Utah Juniper Diameter at Root Crown	131	18.6 cm	11.8
Utah Juniper Height	131	3.8 m	1.9
Rocky Mountain Juniper Diameter at Root Crown	36	15.7 cm	9.5
Rocky Mountain Juniper Height	36	3.7 m	1.3
Ponderosa Pine Diameter at Root Crown	5	35.7 cm	17.7
Ponderosa Pine Height	5	8.1 m	3.8

Sampled pinyon, including live and dead trees, ranged in age from 26 to 375 years (Figure 2.4). Ages were defined as ages at the coring height just above ground level; no adjustments were made to determine true age because age estimates were for comparative

purposes only. The pinyon within these mortality centers were young, with 61% of aged pinyon less than 100 years old, 84% of aged pinyon less than 150 years old, and only 16% 150 years or older. These stands are relatively young considering the pinyon can live to 1,000 years or more (Ronco 1990), and may have become established following harvesting for fuelwood, but no stumps have persisted on these sites, nor was there any evidence of previous fire.

Figure 2.4. Age class distribution of pinyon (live and dead) within 30 black stain root disease mortality centers in southwestern Colorado

The majority of pinyon within mortality centers was dead and affected by black stain root disease. Within mortality centers, 56% of all trees were dead; 68.3% of all pinyon were dead while 14.5% of all other tree species were dead. Non-symptomatic (Status 1) pinyons

immediately outside of disease centers were significantly larger in diameter and height than the healthy, non-symptomatic (Status 1) pinyons within the mortality centers. Of all pinyon measured within the mortality centers 31.7% were surviving, including both healthy, non-symptomatic pinyon and chlorotic but living pinyon. Of 973 pinyons in mortality centers, 110 (11.3%) had confirmed black stain, 629 (64.6%) had suspected black stain, and 234 (24.0%) had no indication of the presence of black stain root disease. The high proportion of pinyon with suspected black stain infection is a result of the difficulty in making definitive identification one year after death. Following death of the pinyon host, the characteristic dark stain confined by annual rings often becomes more diffuse making definitive identification difficult. Pinyons characterized by suspected black stain infection were those trees with dark stain present in the sapwood of the roots and/or root crown, adjacent to pinyon identified as infected by black stain, and having no evidence of other causes of mortality. Back stain infection, both confirmed and suspected, averaged 75.3% of all pinyon within individual transects. Pinyon with suspected and confirmed black stain infection did not differ significantly in height from those that were not infected, but were significantly larger in diameter at root crown. As larger trees would be expected to have more extensive root systems through which roots would more likely come into contact or proximity to roots harboring the pathogen, this finding is not surprising.

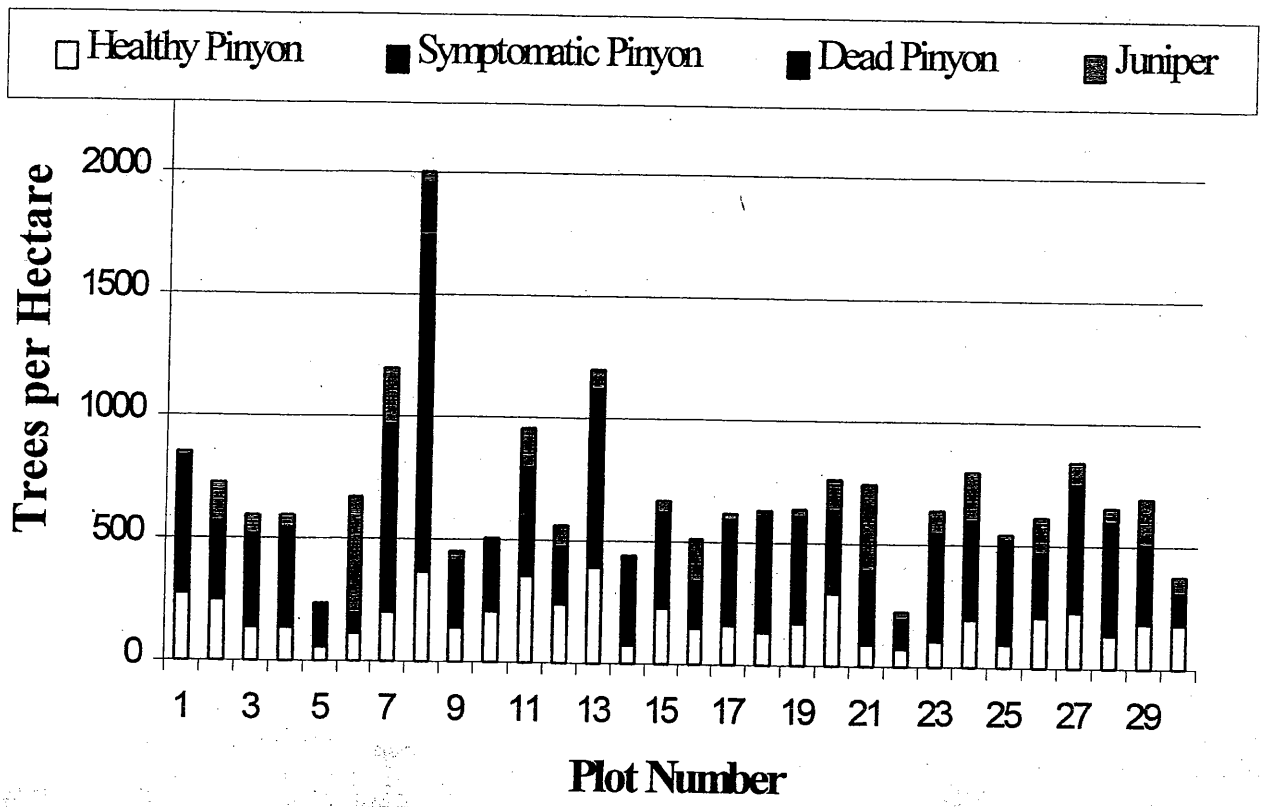
Ips bark beetles often attack broken, fallen, and dying pinyon affected by BSRD. The most common species on pinyon was *Ips confusus*, which can act to increase mortality by attacking healthy pinyon adjacent to disease weakened trees when insect populations are high (Eager 1999, Wagener and Mielke 1961). Presence of Ips bark beetles was confirmed in 9.7% (94 of 973) and suspected in 60.2% of pinyons measured. Confirmation was based solely on the presence of insect bodies, while characteristic "Y" shaped gallery patterns consisting of a cleared

out nuptial chamber with several radiating egg galleries identified suspected Ips occurrence. The relationship between BSRD and Ips was equivocal; 6.5% of pinyon had either suspected or confirmed BSRD but no evidence of Ips, while only 0.4% of pinyon had confirmed or suspected Ips but no evidence of BSRD, and the majority of pinyon, 69.5% had suspected or confirmed presence of both BSRD and Ips.

Is black stain root disease significantly altering the composition and structure of the overstory within disease centers?

Black stain root disease significantly reduced the density of pinyon within disease centers and did not significantly alter the juniper population. We examined the condition of trees within mortality centers to determine the composition of the mortality centers prior to infection by BSRD and the current condition of the mortality centers. Within mortality centers, pinyon was the dominant tree species, and the density of trees varied greatly. Of 1,235 trees measured within transects, 86% were pinyon and 14% were ponderosa pine, Rocky Mountain juniper, or Utah juniper. Total tree densities, including all trees live and dead, within mortality centers were extremely variable, ranging from 223 to 2003 trees per hectare (tph) with a mean tree density of 701 tph. Total tree densities in the unaffected woodlands surrounding mortality centers, which included only live trees, ranged from 82 to 1318 tph and averaged 555 tph, which was not significantly different from the mean total tree densities within BSRD mortality centers. The lack of a significant difference between the total tree densities of mortality centers and surrounding woodlands indicates that tree densities were similar in the two areas prior to infection by black stain root disease. Total pinyon density, live and dead, ranged from 195 to 1963 tph with a mean density of 598 tph (Figure 2.5). Live pinyon densities, including both

healthy and symptomatic trees, within mortality centers ranged from 84 to 433 tph with a mean of 221 tph, while dead pinyon densities ranged from 56 to 1538 tph and averaged 377 tph. Mean live pinyon density for the 30 BSRD mortality centers has been reduced by 63% from mean density of all pinyon, which at one time would have all been alive. Pinyon densities in the surrounding woodlands ranged from 82 to 1153 tph and averaged 458 tph. The densities of live pinyon are significantly lower ($P<0.001$) within mortality centers then in the surrounding areas. Juniper, including both species, density within mortality centers ranged from 0 to 477 tph with a mean density of 101 tph and in surrounding areas ranged from 0 to 412 tph with an average of 93 tph. Juniper density in the surrounding, unaffected woodlands was not significantly different from that found within mortality centers.



Note: Plots 1-22 are located at McPhee Reservoir and plots 23-30 are located near Ignacio

Figure 2.5. Tree densities by species and condition within 30 black stain root disease mortality centers

Black stain root disease centers are composed primarily of pinyon snags and logs. Pinyon status within mortality centers was as follows: 25.1% were healthy green trees (Figure 2.6), 6.6% were chlorotic, 46.4% were standing dead, 21.0% were downed dead, and 1.0% were cut stumps. For the other tree species combined the distribution of tree status classes was 84.3% healthy trees, 1.2% chlorotic, 2.3% snags, 4.7% downed dead, and 7.6% cut stumps. Of all dead pinyon, 43.2% had decay in either the heartwood, sapwood, or both. Decay fungi were identified by Dr. J. P. Lindsey, Department of Biology, Fort Lewis College, Durango, CO and included *Pycnoporus cinnabarinus* (Jacq. ex Fr.) Karst., *Gloeophyllum sepiarium* (Wulf. ex Fr.) Karst., *Trichaptum abietinum* (Fr.) Rhy., and *Stereum* sp.. Wood borers, ants, and termites were also actively breaking down snags and coarse woody debris. The most commonly occurring decline agents aside from black stain root disease and Ips beetles were non - Ips bark beetles, wood borers, and brown cubical rot which were found in 38.6, 41.2, and 5.3 % of all trees, respectively. Wood borers were found on larger diameter trees and non - Ips bark beetles more

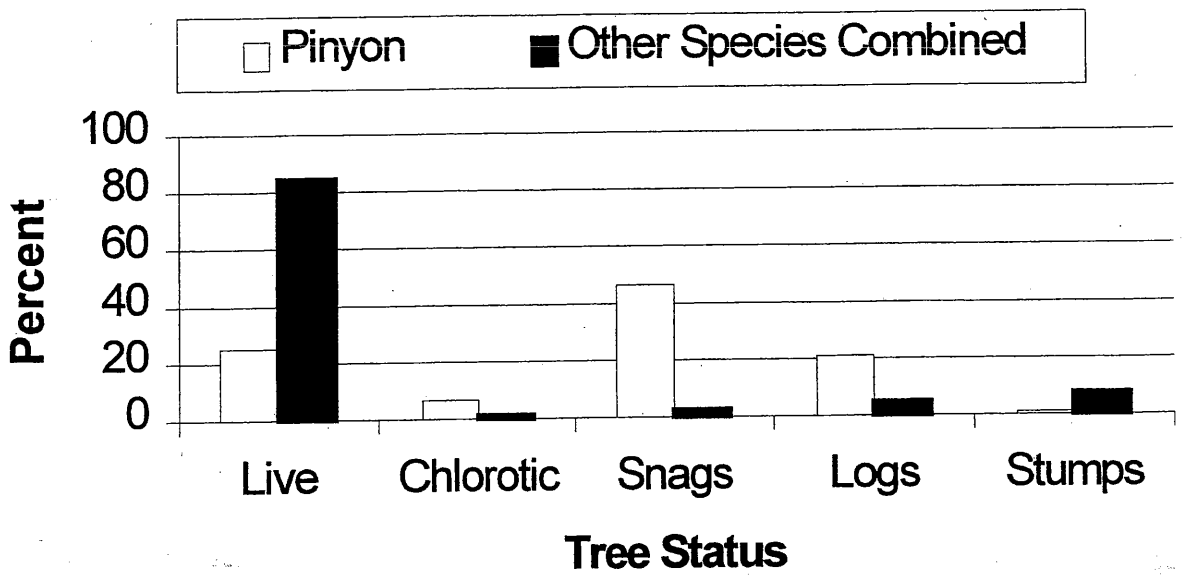


Figure 2.6. Distribution of tree statuses within 30 black stain root disease mortality centers (Pinyon: N=973, Other Species Combined: N=172).

commonly attacked shorter trees, but both were more likely to be found on the pinyons close to plot center that had been dead longer than those pinyons further from plot center. Brown cubical rot was also found on more commonly on trees that had been dead longer, were shorter, and larger in diameter than trees that were not being decayed by brown cubical rot.

Is BSRD significantly affecting the composition and structure of pinyon-juniper woodlands at the shrub level?

Mountain mahogany (*Cercocarpus montanus*) was the only shrub species to show a significantly higher occurrence inside than outside mortality centers. For all other species there were no significant differences in occurrence between mortality centers and surrounding areas (Table 2.3). Fourteen shrub species were identified within black stain root disease centers (Appendix 6). Frequency of occurrence of shrub species was calculated as the percent of 90 shrub plots either inside or outside the 30 mortality centers with the species present. The most commonly occurring shrub within mortality centers was serviceberry (*Amelanchier alnifolia* and *A. utahensis*), which was present on 50 of the 90 shrub plots inside mortality centers. Outside of mortality centers, the most commonly occurring shrub species was Gambel's oak (*Quercus gambelii*), which was present on 50 of the 90 shrub plots outside mortality centers. Alpine prickly current (*Ribes montigenum*) was the least commonly occurring shrub species and was found on only 1 of the 90 shrub plots inside mortality centers and none of the 90 shrub plots outside mortality centers.

Table 2.3. Frequency of occurrence of shrub species inside and outside 30 black stain root disease mortality centers

	Inside		Outside		Difference	
Species	**%**	**S. E.**	**%**	**S. E.**	**%**	**p**
Amelanchier species	55.6	5.8	47.8	6.1	7.8	0.229
Artemisia tridentata	38.9	6.8	40.0	6.1	-1.1	0.856
Cercocarpus montanus	35.6	5.7	25.6	6.3	10.0	0.083
Chrysothamnus nauseosus	4.4	2.1	2.2	1.5	2.2	0.326
Fendlera rupicola	33.3	7.5	30.0	6.5	3.3	0.620
Peraphyllum ramosissimum	32.2	7.4	24.4	6.8	7.8	0.109
Prunus virginiana	0.0	0.0	2.2	1.5	-2.2	0.161
Purshia tridentata	14.4	5.9	10.0	5.1	4.4	0.161
Quercus gambelii	52.2	6.7	55.6	5.4	-3.3	0.712
Rhus trilobata var. *trilobata*	2.2	1.5	2.2	1.5	0.0	1.000
Ribes leptanthum	1.1	1.1	2.2	1.5	-1.1	0.573
Ribes montigenum	1.1	1.1	0.0	0.0	1.1	0.326
Symphoricarpos albus	13.3	5.0	12.2	4.9	1.1	0.573
Yucca baccata	2.2	1.5	1.1	1.1	1.1	0.326

Shrub species did not differ significantly in the percent cover between mortality centers and surrounding areas. Mean percent shrub cover was calculated as the mean of percent shrub cover of 3 shrub plots either inside or outside 30 mortality centers. Mean shrub cover within the 40 m^2 shrub plots for all species combined inside mortality centers was 20.8% (Table 2.4), while outside of mortality centers it was slightly higher at 23.5%. Total percent shrub cover was not significantly related to size of mortality center, nor was there a significant relationship between mean shrub cover and number of tree seedlings present within mortality centers. In comparisons of mean percent cover between mortality centers and surrounding areas, none of the differences between mean percent cover of any shrub species within mortality centers and outside of mortality centers were statistically significant ($p=0.05$). Gambel's oak contributed the highest percent cover both within disease centers and surrounding areas.

Table 2.4. Mean percent cover by shrub species inside and outside 30 black stain root disease mortality centers.

	Inside		Outside		Difference	
Species	**% Cover**	**S.E.**	**% Cover**	**S.E.**	**% Cover**	**p**
Amelanchier species	2.6	0.5	2.8	0.7	-0.2	0.769
Artemisia tridentata	1.6	0.5	2.0	0.5	-0.3	0.585
Cercocarpus montanus	1.4	0.3	1.4	0.6	0.0	1.000
Chrysothamnus nauseosus	0.1	0.0	0.0	0.0	0.1	0.161
Fendlera rupicola	0.9	0.2	0.7	0.2	0.2	0.248
Peraphyllum ramosissimum	2.0	0.7	1.2	0.5	0.8	0.212
Prunus virginiana	0.0	0.0	0.2	0.2	-0.2	0.281
Purshia tridentata	1.0	0.5	0.6	0.4	0.4	0.203
Quercus gambelii	10.4	2.3	14.2	2.5	-3.8	0.224
Rhus trilobata var. *trilobata*	0.2	0.2	0.0	0.0	0.2	0.351
Ribes leptanthum	0.0	0.0	0.1	0.1	-0.1	0.252
Symphoricarpos albus	0.5	0.2	0.3	0.2	0.2	0.202
All Shrub Species Combined	20.8	2.2	23.5	2.6	-2.7	0.357

Shrub cover did not change significantly in the number of species present between mortality centers and surrounding areas. Mean species richness within mortality centers was 4.70 and in surrounding areas was 4.43 (Table 2.5). Mortality center size had no effect on the number of shrub species present. The least squares means values derived for Simpson's index and Shannon's index indicate that the distribution of proportional abundances among species was essentially the same for both mortality centers and surrounding areas. Hill's evenness ratio also indicates that there is no significant difference in the abundance of different shrub species between BSRD mortality centers and surrounding areas.

Table 2.5. Mean values of diversity indices for shrub layer vegetation inside and outside 30 black stain root disease mortality centers

	Inside		Outside		Difference	
Index	**Mean**	**S. E.**	**Mean**	**S. E.**	**Mean**	**p**
Species Richness	4.70	0.32	4.43	0.26	0.27	0.392
Simpson's index	0.53	0.03	0.54	0.03	-0.00	0.920
Shannon's index	0.46	0.10	0.39	0.10	0.07	0.306
Hill's Evenness	0.68	0.07	0.73	0.07	-0.05	0.606

The results from the shrub layer analyses indicate that mortality of pinyon caused by black stain root disease is not having a significant impact on associated shrub species. Only one shrub species, mountain mahogany (*Cercocarpus montanus*), showed a significant difference in frequency between mortality centers and surrounding areas. There were no significant shifts in cover of shrub species or in shrub layer diversity, nor was there any apparent association between the shrub layer composition and structure and mortality center size or corresponding age. Successional models of pinyon – juniper woodlands indicate that shrub species respond after approximately 25 years to fill the openings created by disturbance (West and Van Pelt 1987). As the studied mortality centers originated more recently than 25 years, the lack of a response in the shrub community is not surprising, and as more time passes a shrub level response may be expected.

Is BSRD significantly affecting the composition and structure of pinyon-juniper woodlands at the herbaceous level?

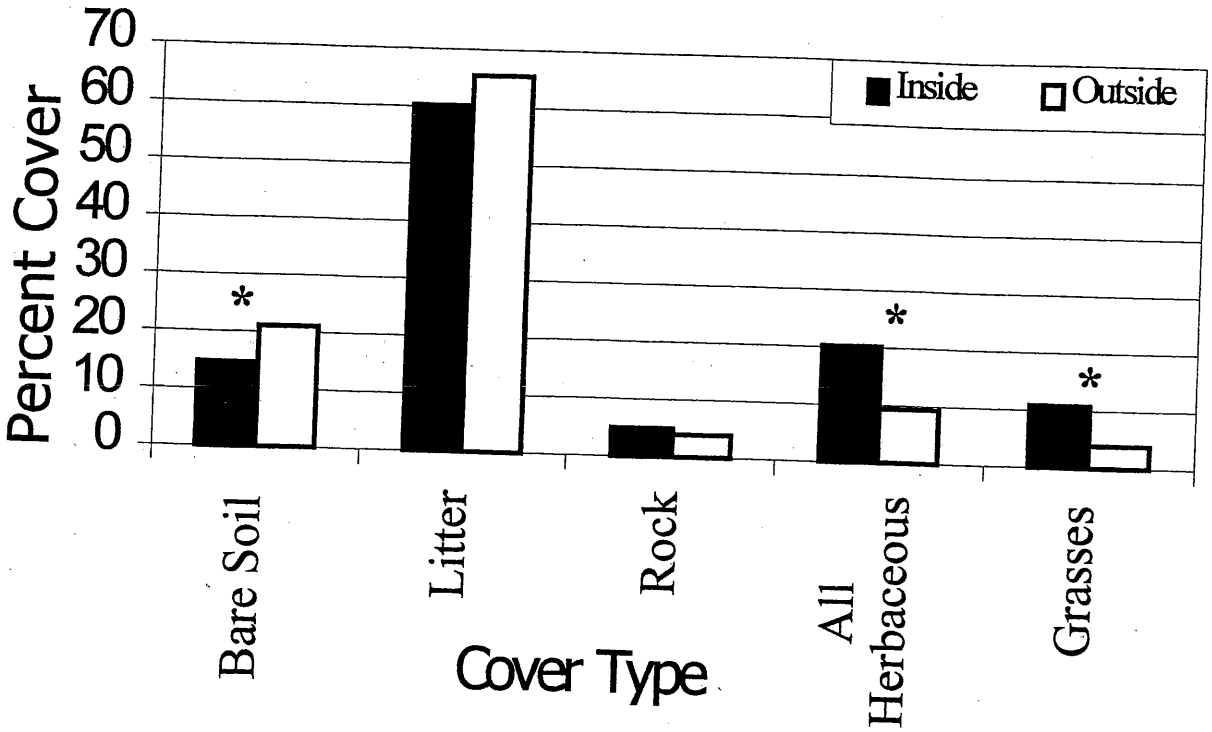
At the herbaceous level, where all non-woody plants and woody plants less than 30.5 cm tall were considered, significant differences were found between mortality centers and surrounding areas. Four herbaceous plant cover types were found more frequently within

mortality centers and exhibited statistically significant differences in occurrence between mortality centers and surrounding areas (Table 2.6). Out of a total of 78 types of herbaceous level plant cover identified (Appendix 7), grasses were the most commonly occurring herbaceous plant type in both mortality centers and surrounding areas, but had a significantly higher occurrence within mortality centers. *Achillea lanulosa* (yarrow), *Carduus nutans* (musk thistle), and *Erigeron flagellaris* (trailing fleabane) were also found more frequently within mortality centers. The differences in occurrence of herbaceous level plant cover types between black stain mortality centers and surrounding areas indicate that reduction of the overstory pinyon population through BSRD caused mortality is having an effect on the composition of herbaceous level community, although the response by herbaceous level plants is species specific.

Table 2.6. Frequency of occurrence of common herbaceous level plants inside and outside 30 black stain root disease mortality centers[1]

	Inside		Outside		Difference	
Herb Layer Plants	**%**	**S. E.**	**%**	**S. E.**	**%**	**p**
Grasses	71.1	5.1	52.2	5.1	18.9	0.002
Achillea lanulosa	7.2	2.5	2.2	1.1	5.0	0.037
Alisma minus	8.9	4.4	4.4	2.5	4.4	0.103
Artemisia ludoviciana	7.2	2.4	6.1	2.0	1.1	0.702
Carduus nutans	7.2	3.1	0.6	0.6	6.7	0.021
Ceratocephala orthoceras	5.0	2.5	3.3	1.7	1.7	0.522
Collinsia parviflora	5.0	2.5	3.3	1.9	1.7	0.415
Comandra umbellata	3.3	1.5	5.6	2.8	-2.2	0.459
Erigeron flagellaris	5.6	2.3	0.6	0.6	5.0	0.017
Lomatium triternatum	5.0	2.1	7.2	3.0	-2.2	0.403
Mosses	4.4	1.9	6.1	1.9	-1.7	0.448
Penstemon linarioides	5.0	2.3	6.1	2.3	-1.1	0.625
Penstemon species	5.6	2.2	4.4	2.3	1.1	0.690
Quercus gambelii	3.3	1.2	5.6	2.2	-2.2	0.380

1) Frequencies of the fourteen most common herbaceous level plant types (found on 5% or more of herbaceous layer plots) as the percent of 180 herbaceous plots either inside or outside of mortality centers with that cover type present.



* = Differences are significant at p=0.05

Figure 2.7. Mean percent cover of ground cover types inside and outside 30 black stain root disease mortality centers

within mortality centers was 6.60 and in surrounding areas was 5.43. Though this measure is not an actual count of individual species present since not all species were identified, it does indicate that there were on average more types of herbaceous cover present within mortality centers than the unaffected surrounding forest. Of the 78 types of herbaceous cover identified, 45% were found both in mortality centers and surrounding areas, 32% were unique to mortality centers, and 23% were found only in the areas outside black stain root disease mortality centers. Herbaceous cover was significantly higher within mortality centers, and frequencies of individual species or cover types were significantly altered. While it is possible to conclude that black stain root disease is having a measurable affect on the herbaceous community, the impact on diversity is

Mean percent herbaceous cover was 20.2% within disease centers, which was significantly higher (p=0.0002) than the 9.4% herbaceous cover found in surrounding areas (Figure 2.7). Grasses, which were found within all mortality centers, had a mean percent cover of 10.8% inside mortality centers and a significantly lower (p=0.0006) 3.9% cover outside mortality centers. Musk thistle, *Carduus nutans*, an introduced weed species associated with disturbed areas, was not only found more frequently within mortality centers, but its percent cover was also significantly higher (p=0.0437) within mortality centers than in surrounding areas. Percent ground covered by bare soil was significantly higher (p=0.0432) outside of mortality centers at 21.0% than inside mortality centers with 14.7%, but coverage by litter and rock did not differ significantly (p=0.2141 and p=0.5611, respectively) between disease centers and surrounding areas. Overall cover by non-herbaceous ground cover types, which were bare soil, litter, and rock combined, was significantly higher (p=0.0002) at 90.6% outside mortality centers than the 79.8% within disease centers. The higher herbaceous and grass cover within mortality centers is likely attributable to increased resource availability due to the removal of overstory cover through pinyon mortality by black stain root disease and the decomposition of pinyon snags and logs. Conversely, the higher cover by non-herbaceous ground cover types found outside mortality centers is presumably related to lower resource availability due to higher canopy cover by pinyon. Black stain root disease through removal of the pinyon overstory is apparently altering the structure of the herbaceous level within pinyon – juniper woodlands.

Diversity analyses could not be accurately applied to herbaceous level vegetation. The indices are predicated on identification of each individual species, rather than the mixture of broad cover types, such as grasses and mosses, and individual herbaceous species that were applied in this study. Mean number of herbaceous cover types within the 100 cm^2 herb plots

indeterminate. Successional models for pinyon-juniper woodlands indicate that this more rapid response of the herbaceous level to the opening of the woodlands through pinyon mortality relative to the lack of apparent response at the shrub level is not unexpected. Following stand replacement fire events, woodlands can be expected to be colonized by annual and perennial grasses and forbs within 4 years, while shrubs respond to openings more slowly and are predicted to be present approximately 25 years following the disturbance (West and Van Pelt 1987).

Is black stain root disease significantly altering tree regeneration within disease centers?

Pinyon regeneration was occurring within mortality centers. There were slightly fewer pinyon seedlings, 552 per hectare, within mortality centers than the 612 per hectare found in surrounding areas, but the difference was not statistically significant. Pinyon seedlings were present on 74% (67 of 90) of the seedling plots inside mortality centers and on 63% (57 of 90) of the seedling plots outside mortality centers. Seedling density in the 40 m^2 seedling plots ranged from 0 to 20 pinyon seedlings within mortality centers and from 0 to 19 seedlings on plots outside of mortality centers. Pinyon seedlings were found within 29 of the 30 mortality centers and in 27 of the 30 areas surrounding mortality centers. There was no significant relationship between mortality center size and the number of seedlings present. Regeneration of pinyon seedlings was occurring within mortality centers likely through the caching activities of birds and seed production of surviving pinyons within mortality centers. Whether these seedlings will successfully occupy the sites remains to be seen. Regeneration typically takes place in the shade of pinyon and juniper tree canopies, under shrubs, or beside downed trees. Shade ameliorates microclimate factors by reducing moisture and temperature stresses, but pinyon is considered

shade intolerant and seedlings that become established beneath mature trees and dense shrubs may have little chance of maturing. There may also be a risk of black stain root disease infection as roots of establishing pinyon seedlings grow into contact or proximity with roots of infected trees.

Seedling density of juniper species, *Juniperus osteosperma* and *J. scopulorum* combined, was significantly higher at the p=0.10 level within mortality centers than surrounding areas (67/ha and 33/ha respectively). However, juniper seedlings were present only on 19 of the 90 seedling plots inside mortality centers and on 10 of the 90 seedling plots outside mortality centers. Thus, occurrence of juniper regeneration was much lower than that of pinyon regeneration (21% and 74% of seedling plots within mortality centers, respectively). Seedling density in the 40 m^2 seedling plots ranged from 0 to 4 juniper seedlings within mortality centers and from 0 to 2 on plots outside of mortality centers. Juniper seedlings were found within 14 of the 30 mortality centers and in 8 of the areas surrounding mortality centers. Although, on average, juniper regeneration was higher within mortality centers than the non-affected surrounding forest, it exhibited lower density and occurrence then pinyon regeneration. These areas of black stain root disease caused pinyon mortality will likely continue to be dominated by pinyon through both surviving and regenerating pinyon. Long-term observations beginning in 1944 in one black stain root disease center at Mesa Verde National Park indicate that pinyon regeneration is occurring, surviving, and not exhibiting disease symptoms (James and Lister 1978).

How long do pinyon snags and logs persist to provide habitat and other ecosystem properties?

Analyses of tree rings have shown that mortality within our sample of discrete and active black stain root disease centers occurred fairly recently with the oldest dated dead pinyon material being 26 years old. The least square means for number of years dead for each of tree status classes 5 through 12 were determined from tree ring analyses (Table 2.7). Trees in status classes 2 through 4, which differ only in the percentage of the crown that is chlorotic, were considered alive, but they were, for the most part, no longer adding annual rings. Snags may persist for up to 25 years, with intact snags (Status 8) an average of 8.4 years old and broken snags (Status 9) a mean of 13.2 years old. Sound logs (Status 10) have been dead a mean of 9.8 years, while logs that are more fragmented (Status 11) have been dead for a mean of 14.4 years. Trees that are extremely broken up (Status 12) had been dead for 16.2 years. Status class 13 pinyon were too decayed to permit tree ring analysis, and the age of mortality associated with them could not be determined. Status class 14 pinyon were cut stumps that were not considered part of the snag / coarse woody debris continuum and thus have no associated age of mortality.

Table 2.7. Mean number of years dead by tree status class for pinyon in black stain root disease mortality centers

	Tree Status Class	Mean Years Dead
5	Dead, red needles	1.3 a
6	Intact bark, many fine twigs, few needles	2.1 a
7	Bark partially missing, no needles, many twigs	4.7 b
8	Snag, 5 - 33 % branches broken, few twigs	8.4 c
9	Snag, >40 % branches broken, very few twigs	13.2 d
10	Downed, 5-33% branches broken, few twigs	9.8 c
11	Downed, >40 % branches broken, very few twigs	14.4 d, e
12	Downed, stem broken, few branches	16.2 e

Means followed by different letters are statistically different at $p<0.001$ level

There was no significant difference in the length of time since the last growth ring was added between trees in status classes 2 through 6, indicating that once visible symptoms of disease, i.e. needle chlorosis and reduced terminal growth, are apparent death occurs fairly rapidly. There were no statistically significant differences in the ages of tree status classes 9 and 11 (p=0.0813) or between status classes 8 and 10 (p=0.0966), indicating that downed logs are not significantly older than snags in the same condition and that the amount of intact branches may be a better indicator of the age of dead material. With the oldest datable pinyon status class having a mean age of 16.2 years, there is indication that mortality within these discrete disease centers has been relatively quick and recent. Tree status class and the number of years dead were found to be significantly related. Site (McPhee, Ignacio, or Mesa Verde) had no statistically significant affect on the age of snags and logs, nor was there any significant interaction between tree status class and site (Table 2.8). The noticeable difference in the number of years dead of tree status 7 trees at the different study sites is at least partly attributable to the length of time between remeasurements on plots at Mesa Verde.

Table 2.8. Mean number of years dead of pinyon snags and logs by tree status and site in black stain root disease mortality centers

Tree Status	McPhee	Ignacio	Mesa Verde
7	4.8 a	4.9 a	7.5 b
8	7.3 c	8.7 c	9.6 c
9	13.3 d	13.3 d	13.3 d
10	10.4 e	8.6 e	9.7 e
11	16.7 f	14.3 f	14.2 f
12	n/a	n/a	16.2

Means within rows followed by different letters are statistically different at p=0.05 level

This tree status rating system, when applied to pinyon in southwestern Colorado, can act as a reasonable predictor of snag / coarse woody debris age. Coarse woody debris and snags

provide many important functions within forested ecosystems. Some of these include provision of wildlife habitat, substrate for plants and lichens, sources of nutrients and energy, sites for microbial nitrogen fixation, sources of soil organic matter, stability of soils, and structural complexity (Bull et al. 1997, Kozlowski and Pallardy 1997, Oliver and Larson 1990). The ability to predict the length of time that these desirable properties will be available may be of tremendous use to ecologists and wildlife biologists in estimating ecosystem properties and functions.

How long can the pathogen remain viable within the roots of dead pinyon putting subsequent generations of pinyon at risk?

Leptographium wageneri var. *wageneri* was successfully isolated from 64 samples obtained from 29 of the 30 mortality centers studied. The pathogen was regularly obtained from tree status 7 root samples, which died 5 years prior to excavation and occasionally from tree status 8 root material, estimated to have been dead 8 years. In one case, the pathogen was successfully isolated from the sound root of a pinyon in tree status class 12, which was estimated to have died 16 years prior to excavation. These results indicate that the pathogen remains viable within the roots of dead pinyon and may be capable of infecting subsequent populations of pinyon. However, the roots of pinyon in the older tree status classes are frequently too decayed to permit removal from the substrate and/or isolation of the pathogen. Thus the risk of infection to regenerating pinyon is likely small since root contact between pinyon seedlings and older dead infected material is restricted by the rapid breakdown of buried woody material and the incapability of the fungus of growing long distances through soil. Observations in the revisited plots at Mesa Verde National Park indicate that pinyon regeneration within BSRD centers is generally successful, as few dead or dying seedlings and saplings were noted.

At what rate are discrete BSRD mortality centers expanding?

The rate of expansion of mortality was variable between the 30 black stain mortality centers, but overall averaged 1.1 m/yr. Rate of expansion of mortality was used as a surrogate for rate of disease spread since the rate of fungal growth within host roots was not directly measured but would be, presumably, directly related to the rate of mortality. Apparently, the progression of mortality is not significantly faster in the more recently dead trees. Trees in status classes 2 through 7, which were those trees that are declining to newly dead, had a mean rate of linear expansion of 1.16m/yr (Table 2.9), as calculated from the 28 mortality centers having pinyon in those status classes. When status classes 2 through 12 were examined, the mean rate of linear expansion was 1.10 m/yr. Status classes 13 and 14 were left out of the analysis because the age of mortality associated with them could not be determined and they are not a part of the snag / coarse woody debris continuum, respectively. Although there was an apparent difference in mean rate of expansion between the two study sites, the differences were not statistically significant. Nor were there significant differences in mean rate of expansion among plots. The mean expansion rates obtained at each of the 30 studied mortality centers are provided in

Table 2.9. Mean expansion rates of black stain root disease mortality centers in pinyon – juniper woodlands

	Mean Expansion Rate Tree Status Classes 2-7		**Mean Expansion Rate Tree Status Classes 2-12**	
Site	**meters/year**	**S. E.**	**meters/year**	**S. E.**
McPhee	1.12	0.39	1.15	0.17
Ignacio	1.24	0.32	0.93	0.15
All Sites	1.16	0.18	1.10	0.07

Appendix 11. The maximum mean rate of expansion for a mortality center was 2.01 m/yr. The mean expansion rate calculated in this study is less than the 2 m/yr rate reported by Wagener and Mielke (1961) in one black stain root disease center at Mesa Verde National Park, but corresponds to rates reported in Douglas-fir by Hansen and Goheen (1988) and in ponderosa pine by Cobb et al. (1982). We had plots with expansion rates equal to those found by Wagener and Mielke (1961), but the overall mean expansion rate of the 30 mortality centers was less. An understanding of the expected rate of expansion of mortality centers can provide land managers with a useful tool for evaluating the pattern and rate of mortality and improving prediction of the potential impact of the disease in affected forested ecosystems.

Are there site characteristics that influence the rate of expansion?

Neither available water content, soil percent organic matter, soil pH, pinyon density, nor any other site data recorded were significantly correlated with rate of mortality expansion. *Leptographium wageneri* has been shown to grow through soil, and a relationship between soil characteristics and expansion rate of mortality centers may be expected. Soil chemistry attributes were determined for 26 of the 30 black stain mortality centers from USDA Natural Resources Conservation Service (NRCS) SSURGO (Soil Survey Geographic database) GIS layers and G.P.S. coordinates for mortality centers. Mean values for quantitative soil characteristics at 3 depths (0.0 – 0.3 m, 0.3 – 0.6 m, and 0.6 – 0.9 m) within the 26 mortality centers are listed in Table 2.10. Available water content was not significantly correlated with expansion rates in pinyon; while in ponderosa pine wetter soils produced more infections in seedlings, and soil water potentials were significantly related to spread rates (Goheen et al 1978,

Wilks 1985). Expansion rates were positively correlated with soil percent organic matter, soil pH, and pinyon density, but there were high leverage points in each analysis and the associated

Table 2.10. Mean values of quantitative soil variables from 26 black stain root disease mortality centers in pinyon – juniper woodlands

Soil Depth:	0.0 - 0.3 m		0.3 - 0.6 m		0.6 - 0.9 m	
Soil Property	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**
Clay (%)	17.50	6.69	20.50	6.82	20.53	7.36
Mean Bulk Density	0.86	0.44	1.00	0.11	0.44	0.45
Permeability (In/hr)	0.67	0.72	0.48	0.50	1.19	1.23
Avail. Water Capacity (In/In)	0.22	0.34	0.06	0.06	0.09	0.10
Organic Matter (%)	0.66	0.69	0.69	0.49	0.74	0.44
pH	5.84	0.91	5.39	1.09	2.65	2.57
Cation Exchange Capacity	8.06	8.90	8.94	9.92	11.04	8.14

correlations were considered spurious. In stands with fewer that 500 pinyon per hectare, mean expansion rate was 0.44 m/yr, when pinyon density ranged from 500 to 750 tph, mean expansion rates increased to 1.07 m/yr, and for stands with pinyon densities greater than 750 tph expansion rates averages 1.35 m/yr. However, regression analysis indicated that there was no statistically significant relationship ($p=0.2485$) between pinyon density and expansion rate. Plot attributes such as slope position, general topography, percent slope, tree density (all species), aspect direction, and mean age of pinyon were not significantly related to expansion rate. Cobb et al. (1982), examining 52 black stain root disease centers found that ponderosa pine density was the only factor significantly related to rate of spread. The failure to predict expansion rates based on site characteristics may be related to the placement of plot centers in this study and the assumption that mortality was initiated at that point, and thus that the first dead tree in each transect was the initiation point for all mortality within that transect. Examination of more mortality centers in pinyon – juniper woodlands may have increased our ability to find predictive

factors for rate of expansion of mortality. Black stain root disease mortality centers in the pinyon – juniper woodlands of southwestern Colorado are expanding, but the rates of expansion within those centers can not be predicted by the plot characteristics measured in this study.

Management Considerations

It will aid forest managers in developing management recommendations for pinyon-juniper woodlands to know that not only are approximately 25% of pinyon within black stain root disease mortality centers surviving, but pinyon are also regenerating within mortality centers at a mean density of 552 seedlings/ha. The concern that the composition of these woodlands may be at risk of shifting to dominance by juniper species appears to be small based on our sample of discrete mortality centers. The pathogen can remain viable within the roots of dead pinyon for up to 16 years, but this evidently is rare. More often, the roots of dead pinyon break down and are inhabited by decay fungi after being dead for 5 to 8 years. The ability of the pathogen to survive in dead material may present a risk to newly establishing pinyon, though the potential of transmission is probably small due to the relatively fast breakdown of pinyon in these ecosystems. Even so, land managers in the pinyon – juniper woodlands of southwestern Colorado may feel confident in replanting pinyon in high value areas such as campgrounds and recreation areas.

Fire is relatively rare in pinyon – juniper woodlands due in part to the lack of continuity of fine fuels to carry fires across the landscape. Pinyon are very sensitive to fire, and the presence of pinyon greater than 350 years old and the lack of evidence of fire indicate that fire has not been a recent factor in any of the study sites. There is concern that black stain root disease may increase the risk of fire by increasing fuel loads. This may be true in the short term,

but, in general, dead pinyons are devoid of fine fuels within 8 years of death. Larger pinyon fuels also break down rapidly, essentially becoming completely broken up after 16 years. Typically, these are open woodlands, and it is doubtful that the brief availability of pinyon fuels through black stain root disease related mortality will greatly increase the likelihood of major fire events.

No examination of control strategies was performed in this study. However, for high value pinyon stands, where control of black stain root disease is desired, we present some recommendations. Cultural techniques to maintain tree vigor and spacing to avoid intertree contact are recommended. Tree removal may be advocated as declining pinyon are attractive to Ips beetles whose populations may reach high levels and put otherwise healthy pinyon at risk. Trenching to disrupt root contacts may be effective at restricting expansion of mortality centers. Care must be taken with placement of the trenches, as pinyon heavily infected by *Leptographium wageneri* var. *wageneri* may appear healthy above ground. If trenches are employed, they should be located at a minimum distance equivalent to four crown widths beyond the last declining pinyon. No study has been done to rate effective trenching depths, but a minimum of 0.6 m is suggested, based on reported lateral rooting depths of 15 to 41 cm (Ronco 1990). Planting of non-susceptible species, or alternating pinyon with non-susceptible species at wider spacings, around new homesites should be considered.

Conclusions

This study has examined the impacts of black stain root disease caused discrete mortality centers in the pinyon – juniper woodlands of southwestern Colorado. Mortality centers were generally small, averaging 0.28 ha, irregularly shaped, and found on all types of soils, slopes,

aspects, and topography. This study has shown that the presence of black stain root disease can significantly affect both the structure and composition of these woodlands, reducing live pinyon density by 63% and creating stands dominated by pinyon snags and logs in which a mean of 75.3% of pinyon are infected with *Leptographium wageneri* var. *wageneri*. Pinyon regeneration was not significantly altered, while juniper regeneration within mortality centers was significantly higher than in surrounding areas. In these young mortality centers, shrub layer vegetation was not significantly impacted in composition, frequency of occurrence, percent cover, or diversity by presence of the disease or its removal of the pinyon overstory. Herbaceous cover was significantly higher within mortality centers, and black stain root disease evidently is acting to shift the composition of pinyon – juniper woodlands at the herbaceous level though the response was species specific. Recovery of these woodlands following disturbance is slow, and it will likely take 75 to 100 years for the pinyon population within old black stain root disease mortality centers to fully dominate these sites as they did prior to infection.

Tree ring analyses indicate that while pinyon snags may persist for up to 25 years, the breakdown of pinyon snags and logs is rapid. Pinyon that are extremely broken up, representing the oldest datable pinyon status class, had been dead for 16.2 years indicating that mortality within these discrete disease centers has been relatively quick. Expansion rates of mortality centers averaged 1.1 m/yr and was not predictable based on general plot or soil chemistry attributes. Although *Leptographium wageneri* var. *wageneri* is often referred to as a weak saprophyte, the pathogen was regularly isolated from the roots of pinyon dead for 5 to 8 years. In one instance, the pathogen was isolated from the sound root of a pinyon estimated to have died 16 years prior to excavation indicating its ability to survive within dead material for long periods.

The remaining research needs in black stain root disease of pinyon are many. This study examined the short-term impacts of black stain root disease infection, but there is a need to examine the longer-term effects on woodland composition and structure. Landscape level analyses to determine impacts and extent of and increases in pinyon mortality are also needed. Identification of the insect vector and analysis of the vector's behavior will aid control efforts and hazard predictions. The relationship between Ips beetles and black stain root disease also requires further elucidation. Management strategies need to be developed and tested in these increasingly valuable pinyon – juniper woodlands.

Literature Cited

Bull, E. L., Parks, C. G., and Torgersen, T. R. 1997. Trees and logs important to wildlife in the interior Columbia River basin. USDA For. Serv. Pacific Northwest Research Station, General Technical Report, PNW-GTR-391. Portland, OR: 55 p.

Cartledge, T. R. and Propper, J. G. 1993. Piñon-juniper ecosystems through time: information and insights from the past. *In* Managing Piñon-Juniper Ecosystems for Sustainability and Social Needs; proceedings of the symposium 1993 April 26 – 30; Sante Fe, NM. *Tech. coords.* Aldon, E. F. and Shaw, D. W. USDA For. Serv., Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-236. Fort Collins, CO: pp. 63-71.

Cobb, F. W., Jr., Slaughter, G. W., Rowney, D. L., and DeMars, C. J. 1982. Rate of spread of *Ceratocystis wageneri* in ponderosa pine stands in the central Sierra Nevada. Phytopathology 72:1359 – 1362.

Eager, T. J. 1999. Factors affecting the health of pinyon pine trees (*Pinus edulis*) in the pinyon-juniper woodlands of western Colorado. *In* Proceedings: Ecology and Management of Pinyon-Juniper Communities within the Interior West. *Compiled* by S. B. Monsen and R. Stevens. USDA For. Serv. Rocky Mountain Research Station.RMRS-P-9. Ogden, UT: pp. 397 – 399.

Goheen, D. J. and Cobb, F. W., Jr. 1978. Occurrence of *Verticicladiella wagenerii* and its perfect state, *Ceratocystis wageneri* sp. nov., in insect galleries. Phytopathology 68: 1192 – 1195.

Goheen, D. J., Cobb, F. W., Jr., and McKibbin, G. N. 1978. Influence of soil moisture on infection of ponderosa pine by *Verticicladiella wagenerii*. Phytopathology 68: 913 – 916.

Hansen, E. M. and Goheen, D. J. 1988. Rate of increase of black-stain root disease in Douglas-fir plantations in Oregon and Washington. Canadian Journal of Forest Research 18: 942 – 946.

Harrington, T. C. 1992. *Leptographium. In* Methods for research on soilborne phytopathogenic fungi. Edited by L. L. Singleton, J. D. Mihail, and C. M. Rush. American Phytopathological Society Press, St. Paul, MN. pp 129 – 133.

Harrington, T.C., and Cobb, F. W., Jr. 1986. Varieties of *Verticicladiella wageneri.* Mycologia 78: 562 – 567.

Harrington, T. C., Cobb, F. W., Jr. and Lownsbery, J. W. 1985. Activity of *Hylastes nigrinus*, a vector of *Verticicladiella wageneri*, in thinned stands of Douglas-fir. Canadian Journal of Forest Research 15: 519 – 523.

Hessburg, P.F. and Hansen, E. M. 1986. Mechanisms of intertree transmission of *Ceratocystis wageneri* in young Douglas-fir. Canadian Journal of Forest Research 16: 1250 – 1254.

James, R. L. and Lister, C. K. 1978. Insect and disease conditions of pinyon pine and Utah juniper in Mesa Verde National Park, Colorado. USDA For. Serv. Forest Insect and Disease Management, Rocky Mountain Region, Bio. Eval. R2-78-4, 16pp.

Kendrick, W. B. 1962. The *Leptographium* Complex: *Verticicladiella* Hughes. Canadian Journal of Botany 40: 771 – 797.

Kozlowski, T. T. and Pallardy, S. G. 1997. Physiology of woody plants. 2nd ed. Academic Press, San Diego, CA.

Landis, T. D. and Helburg, L. B. 1976. Black stain root disease of pinyon pine in Colorado. Plant Disease Reporter 60: 713 - 717.

Ludwig, J. A., and Reynolds, J. F. 1988. Statistical ecology: a primer on methods and computing. John Wiley & Sons, New York, NY. pp. 85 – 103.

Miller, R., Rose, J., Svejcar, T., Bates, J., and Palmer, K. 1995. Western juniper woodlands: 100 years of plant succession. *In* Desired Future Conditions for Piñon-Juniper Ecosystems; proceedings of the symposium; 1994 August 8 – 12; Flagstaff, AZ. *Tech. coords.*: Shaw, D. W., Aldon, E. F., and LoSapio,C. USDA For. Serv., Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-258. Fort Collins, CO: pp. 5 – 8.

Oliver, C. D. and Larson, B. C. 1990. Forest stand dynamics. McGraw-Hill, Inc., New York.

Omi, P. N., and Emrick, R. L. 1980. Fire and Resource Management in Mesa Verde National Park. Final Report: 84 pp.

Pannell, J. P. 2000. Personal communication. Map Unit Descriptions. USDA Natural Resources Conservation Service, Soil Survey Office, Durango, CO.

Patil, G. P., and Taillie, C. 1982. Diversity as a concept and its measurement. Journal of the American Statistical Association 77: 548 – 561.

Ramsey, D. 2001. Personal communication. Map Unit Descriptions. USDA Natural Resources Conservation Service, Cortez Field Office, Cortez, CO.

Ronco, Jr., F. P. 1990. *Pinus edulis* Engelm. *In*: Silvics of North America. Technical Coordinators R. M. Burns and B. H. Honkala. Agricultural Handbook 654. USDA For. Serv., Washington, DC. pp. 327 – 337.

Sharon, E. M. 1985. Black stain root disease of pinyon in Mesa Verde National Park. USDA For. Serv. Rocky Mountain Region 3420 Biological Evaluation R2-85-2. Lakewood, CO.

Stokes, M. A., and Smiley, T. L. 1968. An introduction to tree-ring dating. Univ. of Chicago Press.

Tainter, F. H. and Baker, F. A. 1996. Principles of forest pathology. John Wiley & Sons, Inc., New York, NY: 684 – 690.

Wagener, W. W. and Mielke, J. L. 1961. A staining-fungus root disease of ponderosa, Jeffrey, and pinyon pines. Plant Disease Reporter 45: 831 - 835.

West, N. E. and Van Pelt, N. S. 1987. Successional patterns in pinyon-juniper woodlands. *In* Proceedings – Pinyon-Juniper Conference, 13-16 Jan. 1986, Reno, NV. *Compiled by* R. L. Everett. USDA For. Serv., Intermountain Research Station, Gen. Tech. Rep. INT-215. Ogden, UT: pp. 43 – 52.

Wilks, D. S. 1985. Association of soil moisture with spread of *Ceratocystis wageneri* in ponderosa pine disease centers. Plant Disease 69: 206 – 208.

Witcosky, J. J. and Hansen, E. M. 1985. Root-colonizing insects recovered from Douglas-fir in various states of decline due to black-stain root disease. Phytopathology 75: 399 – 402.

APPENDICES

TABLE OF CONTENTS

Appendix 1.	Mortality Center Attributes	89
Appendix 2.	Maps of Study Sites	90
Appendix 3.	Soil Properties of 30 Black Stain Root Disease Mortality Centers	96
Appendix 4.	Directions to Plots	98
Appendix 5.	Transect Properties	101
Appendix 6.	Shrub Layer Species List	103
Appendix 7.	Herbaceous Layer Species List	104
Appendix 8.	Master Chronology for Tree Ring Analyses	106
Appendix 9.	Pinyon Ages and Years Dead by Tree Status	107
Appendix 10.	Mean Age of Pinyon within 30 Black Stain Root Disease Mortality Centers	113
Appendix 11.	Mean Expansion Rates of 30 Black Stain Root Disease Mortality Centers	114
Appendix 12.	Data Forms and Codes	115

Appendix 1. Attributes for 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands

Plot #	Legal T/R/S	Plot Aspect	Plot Slope (%)	Plot Topog.	Slope Position	UTM - WGS 1984 Zone 12 North			Area (ha)	Perimeter (m)
						Northing (m)	Easting (m)	Elev. (m)		
1101	38N/16W/25	178	10	Even	Top 1/3	4154990.2	715748.5	2133.5	0.286	259.8
1102	38N/16W/24	170	8	Even	Middle 1/3	4157368.3	715736.6	2230.9	0.555	486.0
1103	38N/15W/32	330	14	Even	Bottom 1/3	4154453.4	718014.0	2147.8	0.156	239.7
1104	38N/15W/29	330	3	Concave	Middle 1/3	4154878.7	718120.3	2141.6	0.388	364.8
1105	38N/15W/15	58	1	Convex	Top 1/3	4158915.4	721545.5	2239.8	0.459	394.0
1106	38N/15W/20	200	8	Even	Valley	4157766.6	718749.0	2216.7	0.130	161.0
1107	38N/15W/6	300	16	Even	Top 1/3	4153091.7	716333.9	2220.9	0.085	144.7
1108	38N/15W/30	246	8	Convex	Ridge	4155656.9	716082.0	2174.0	0.171	239.1
1109	37N/16W/2	70	4	Even	Ridge	4152472.0	713780.4	2149.7	0.421	379.7
1110	37N/15W/6	290	19	Even	Middle 1/3	4152967.3	716271.9	2212.0	0.360	431.4
1111	38N/15W/30	170	5	Even	Valley	4155499.0	716519.2	2141.6	0.223	264.4
1112	38N/15W/30	84	10	Concave	Bottom 1/3	4155350.9	716767.9	2135.4	0.410	364.5
1113	38N/15W/30	150	10	Even	Middle 1/3	4155479.5	716052.4	2156.0	0.192	242.1
1114	38N/15W/19	176	8	Even	Top 1/3	4156796.9	716021.8	2202.6	0.351	298.8
1115	39N/17W/14	230	5	Even	Ridge	4168584.6	704627.5	2298.2	0.330	269.7
1116	38N/15W/32	240	12	Convex	Middle 1/3	4154559.5	717771.8	2130.2	0.250	250.5
1117	39N/17W/13	150	5	Even	Ridge	4168797.1	704929.0	2310.6	0.069	124.5
1118	39N/17W/13	290	2	Even	Ridge	4168438.5	705131.9	2316.0	0.418	318.1
1119	39N/17W/13	250	5	Even	Ridge	4168846.7	705471.8	2334.2	0.331	340.4
1120	38N/15W/29	230	32	Even	Middle 1/3	4155221.6	718186.3	2140.7	0.112	200.9
1121	39N/17W/9	20	34	Even	Middle 1/3	4169238.8	700673.0	2028.3	0.161	231.8
1122	38N/15W/22	240	19	Even	Top 1/3	4156640.8	721204.6	2203.1	0.375	293.2
2201	33N/6W/27	3	45	Even	Middle 1/3	4109464.1	812294.8	2179.2	0.627	513.3
2202	33N/6W/28	320	20	Even	Bottom 1/3	4108967.0	810988.0	2080.9	0.263	272.1
2203	34N/6W/33	340	40	Even	Middle 1/3	4116842.6	810001.9	2155.2	0.327	330.2
2204	34N/6W/29	280	32	Even	Middle 1/3	4117698.3	808432.7	2138.2	0.112	219.9
2205	33N/6W/21	284	25	Concave	Middle 1/3	4109795.7	810910.9	2086.5	0.385	328.9
2206	33N/5W/9	62	46	Even	Middle 1/3	4113774.3	820958.6	1945.4	0.094	144.3
2207	33N/6W/22	332	44	Concave	Middle 1/3	4109508.3	812468.8	2179.6	0.281	322.1
2208	34N/6W/33	228	27	Concave	Middle 1/3	4117007.2	811147.6	2219.6	0.137	192.6

Note: Plots 1101-1122 located near McPhee Reservoir and Plots 2201-2208 located near Ignacio

Appendix 3. Soil Properties of Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands

Plot #	SRI / musym #	Soil Complex Major Components		General Description						
		Name	%	Soil Texture	Slope %	Depth	Parent Material	Permeability	AWC	E.R.D inches
1101	141	Wauquie	45	loam	6 - 25	very deep	sandstone/shale	moderate	low	60+
		Dolcan	40	loam	6 - 25	shallow to very shallow	sandstone/shale	moderately slow	very low	6 - 20
1102	53	Hesperus	85	loam	3 - 6	very deep	sandstone/shale	moderately slow	high	60+
1103	120	Sheek	35	loam	25 - 80	very deep	sandstone/shale	moderately slow	low	60+
		Archuleta	30	loam	25 - 80	shallow	sandstone/shale	moderately slow	very low	10 - 20
		Rock outcrop	20	ledges and cliffs of sandstone						
1104	80	Ormiston	50	stony clay loam	5 - 25	deep	sandstone	slow	low	40 - 60
		Beje	35	loam	5 - 30	shallow	sandstone	moderate	very low	10 - 20
1105	860	Granath	55	loam	0 - 15	very deep	sandstone	moderately slow	high	60+
		Nortez	30	loam	0 - 15	moderately deep	sandstone	slow	low	20 - 40
1106	527	Ormiston	50	loam	5 - 30	deep	sandstone	slow	low	60 +
		Beje	35	loam	5 - 30	shallow	sandstone	moderate	very low	10-20
1107	42	Gladel	45	sandy loam	3 - 9	shallow	sandstone	moderately rapid	very low	12-20
		Pulpit	35	loam	3 - 9	moderately deep	sandstone	moderately slow	moderate	20-40
1108	141	Wauquie	45	loam	6 - 25	very deep	sandstone/shale	moderate	low	60+
		Dolcan	40	loam	6 - 25	shallow to very shallow	sandstone/shale	moderately slow	very low	6 - 20
1109	126	Sideshow	45	clay loam	3 - 25	very deep	Mancos shale	slow	high	60+
		ZigZag	40	clay loam	3 - 25	very shallow to shallow	Mancos shale	slow	low	6 - 20
1110	42	Gladel	45	sandy loam	3 - 9	shallow	sandstone	moderately rapid	very low	12-20
		Pulpit	35	loam	3 - 9	moderately deep	sandstone	moderately slow	moderate	20-40
1111	145	Wetherill	80	loam	6 - 12	very deep	sandstone	moderately slow	high	60+
1112	454	Snowdon	35	cobbly loam	15 - 45	shallow	granite/schist	moderate	very low	10-20
		Sig	30	gravelly loam	15 - 45	shallow to very shallow	granite/schist	moderate	very low	8-20
		Rock outcrop	25	exposed cliffs, breaks, and knobs						
1113	141	Wauquie	45	loam	6 - 25	very deep	sandstone/shale	moderate	low	60+
		Dolcan	40	loam	6 - 25	shallow to very shallow	sandstone/shale	moderately slow	very low	6 - 20
1114	145	Wetherill	80	loam	6 - 12	very deep	sandstone	moderately slow	high	60+

Appendix 2. Maps of 30 Black Stain Root Disease Centers in the Pinyon- Juniper Woodlands of Southwestern Colorado

These are available on request from W.R. Jacobi

Appendix 3. Soil Properties of Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands, Cont.

Plot #	SRI / musym #	Soil Complex Major Components		General Description						
		Name	%	Soil Texture	Slope %	Depth	Parent Material	Permeability	AWC	E.R.D (in.)
1115	860	Granath	55	loam	0 - 15	very deep	sandstone	moderately slow	high	60+
		Nortez	30	loam	0 - 15	moderately deep	sandstone	slow	low	20 - 40
1116	42	Gladel	45	sandy loam	3 - 9	shallow	sandstone	moderately rapid	very low	12-20
		Pulpit	35	loam	3 - 9	moderately deep	sandstone	moderately slow	moderate	20-40
1117	860	Granath	55	loam	0 - 15	very deep	sandstone	moderately slow	high	60+
		Nortez	30	loam	0 - 15	moderately deep	sandstone	slow	low	20 - 40
1118	860	Granath	55	loam	0 - 15	very deep	sandstone	moderately slow	high	60+
		Nortez	30	loam	0 - 15	moderately deep	sandstone	slow	low	20 - 40
1119	860	Granath	55	loam	0 - 15	very deep	sandstone	moderately slow	high	60+
		Nortez	30	loam	0 - 15	moderately deep	sandstone	slow	low	20 - 40
1120	527	Ormiston	50	loam	5 - 30	deep	sandstone	slow	low	60 +
		Beje	35	loam	5 - 30	shallow	sandstone	moderate	very low	10-20
1121	802	Argiustolls	30	stony clay loam	30 - 80	mod. deep to very deep	sandstone/shale	slow	very low to mod.	20 - 60
		Haplustalfs	30	stony clay loam	30 - 80	shallow to very deep	sandstone/shale	slow	very low to high	10 - 60
		Rock outcrop	25	exposed sandstone and shale ledges						
1122	527	Ormiston	50	loam	5 - 30	deep	sandstone	slow	low	60 +
		Beje	35	loam	5 - 30	shallow	sandstone	moderate	very low	10-20
2201	82	Zyme	50	clay loam	12 - 65	shallow	shale	slow	low	6 - 20
		Rock outcrop	30	exposed shale						
2202	82	Zyme	50	clay loam	12 - 65	shallow	shale	slow	low	6 - 20
		Rock outcrop	30	exposed shale						
2205	82	Zyme	50	clay loam	12 - 65	shallow	shale	slow	low	6 - 20
		Rock outcrop	30	exposed shale						
2207	82	Zyme	50	clay loam	12 - 65	shallow	shale	slow	low	6 - 20
		Rock outcrop	30	exposed shale						

Note: Plots 1101-1122 located near McPhee Reservoir and Plots 2201-2208 located near Ignacio
Note: No soils SSURGO data available for plots 2203, 2204, 2206, and 2208
AWC = available water capacity
ERD = effective rooting depth

Appendix 4. Directions to Plots at 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands

Plot #	Directions from Nearest Intersection	Directions to Plot Center
1101	Sagehen #1 bug traps are here from hwy 184 rt on 25 go 2 miles then rt at T toward reservoir park and walk around reservoir to sagehen point.	tagged tree small Pied 5.5 ft - 308° to P.C.
1102	from hwy 184 rt on 25 go 2 miles then rt at T toward reservoir 0.7 miles then left on FS500 1.6 miles rt on FS500A 0.9 miles to pullout (old road closed) on left	up the dirt road past tank traps towards old field from parking - ~480 ft to creek then ~ 2000 ft up road. Flagging on S side of road then ~ 100 ft S from road follow blue flagging - yellow rebar
1103	5.6 miles from FS 526 toward House Creek. Left into House Creek Campground. Park next to gate to group camp B	~ 425 ft from gate to group camp B at 164°. Dead tree tagged 21'9" at 20° to P.C.
1104	5.6 miles from FS 526 toward House Creek. Left into House Creek Campground. Pullout on left as road begins to turn rt, before loop A camp entrance	from pullout ~235 ft at 120°. Yellow rebar marks P.C. Tagged tree - 30' tall Pied 16' at 240° to P.C.
1105	FS526 from Dolores, left on FS529 for 2.2 miles, left on FS529D 1.35 miles, plot on right (west), visible dead and fading Pied Huge Pipo flagged with orange	From FS529D, P.C. ~375' at 232°, yellow rebar. Live Pipo tagged 88' at 280° to P.C.
1106	FS526 from Dolores, left on FS529 for 4.9 miles, plot on right (north side)	P.C. marked with yellow rebar next to old Pied stump. Juos tagged at 8'8" at 236° to P.C.
1107	from hwy 184 rt on 25 go 0.3 miles then rt toward campground/ marina1.6 miles, then rt 0.5 miles to overlook area.	From overlook parking lot head west over slight rise ~ 350'. P.C. is near oldest Pied snag, yellow rebar. Small, live Juos tagged 13'10" at 300° to P.C.
1108	from hwy 184 rt on 25 go 2 miles then rt at T toward reservoir 0.7 miles then left on FS500 1.6 miles then rt on FS500A 1.8 miles to orange painted TOPT tree on left	P.C. ~ 200' uphill from TOPT at 20°. P.C. marked with yellow rebar, live Pied tagged 15'10" at 242° to P.C.
1109	from hwy 184 rt on 25 go 0.6 miles. Pulloff on rt, across road from mailboxes and private road V6	Head along road toward 184 to green post over culvert (~200'). From post go ~ 675' at 280°. P.C. marked w/yellow rebar. Live Pied tagged 16' at 40° to P.C. P.C. very close to western edge of plot
1110	from hwy 184 rt on 25 go 0.3 miles then rt toward campground 1.6 mi then rt 0.3 miles toward overlook area. Plot is on right (south) side - dead trees visible. From culvert head 20' toward lookout	From road head ~ 250' at 170°. Large opening, many clumps of shrubs. P.C. marked w/yellow rebar. Class 9 Pied (6.4" DRC 9' tall) tagged at base - 5'1" at 193° to P.C.
1111	from 184 rt on 25 2 mi then rt at T toward reservoir 0.7 mi then left on FS500 1.6 mi then rt on FS500A 2.4 mi. Park north of road next to row of 5 hardwoods	From road head north (away from reservoir), follow tree line to west, meadow on rt, approx. 1000' then go ~ 100' at 270° into plot. P.C. marked w/ yellow rebar in large central grassy opening. Class 1 Pied tagged 18'4" at 316° to P.C.

Appendix 4. Directions to Plots at 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands, cont

Plot #	Directions from Nearest Intersection	Directions to Plot Center
1112	from 184 rt on 25 go 2 mi then rt at T toward reservoir 0.7 mi then left on FS500 1.6 mi then rt on FS500A 2.5 mi to end as road curves down to water.Park at entrance to old, closed road (left)	From end of FS500A follow closed road north (away from reservoir) ~ 500' then go east ~ 220' downslope toward water. P.C. marked w/yellow rebar. Live Jusc tagged 18'8" at 95° to P.C. Rebar next to base of Class 11B Pied
1113	from 184 rt on 25 2 mi then rt at T toward reservoir 0.7 mi then left on FS500 1.6 mi then rt on FS500A 1.9 mi. Large Pied on left painted w/2 orange bands and TOPT	From TOPT head toward reservoir on closed road approx. 400' at 198°. At double hump in road go 55' at 130° into mortality center. P.C. marked w/yellow rebar. Large Juos tagged at 15' at 324° to P.C.
1114	from 184 rt on 25 2 mi then rt at T toward reservoir 0.7 mi then left on FS500 1.6 mi then rt on FS500A 1.0 mi. Old road takes off to left(E)go 0.25 mi. Blue flagging on left (N) on old fence post	From old post head ~ 155' at 360°. P.C. marked w/yellow rebar next to (~5') a Class 9 Pied. Tagged tree is green Juos 40'8" at 98° to P.C. from center of base
1115	From Salter Y take FS514 1.5 mi, then stay to left onto FS521 (Ormiston Pt. Rd.) 2.2 mi, then left on FS520 1.8 mi, then take rt fork (FS475) 3.8 mi. Plot on SE side of road (left).	From road go ~ 95' at 150°. P.C. marked w/yellow rebar - right next to a 3' Class 9 Pied. Tagged tree is Pipo 26'5" at 16°° to P.C. Dead trees visible from road
1116	5.6 miles from FS 526 toward House Creek. Left into House Creek Campground. Park next to gate to group camp B	Plot is on FS plot House Creek Cut #5. P.C. marked w/yellow rebar next to tree #652, a Class 9 Pied that was a Class 5 in 1982. Tagged tree is a Class 1 Pied (tree #659) - 12'1" at 172° to P.C.
1117	From Salter Y take FS514 1.5 mi, then stay to left onto FS521 (Ormiston Pt. Rd.) 2.2 mi, then left on FS520 1.8 mi, then take rt fork (FS475) 3.5 mi. Plot on E side of road (left).	Head in from road ~ 50 ft. P.C. marked w/ yellow rebar next to the stump of a Class10 Pied. Tagged tree is a Class 8 Pied next to road - 18'7" at 130° to P.C. Dead trees visible from road
1118	From Salter Y take FS514 1.5 mi, then stay to left onto FS521 (Ormiston Pt. Rd.) 2.2 mi, then left on FS520 1.8 mi, then take rt fork (FS475) 3.2 mi, then take left fork onto old road 0.3 mi.	Plot is on west side of old road. Faders on road. From road head west. P.C. marked w/yellow rebar next to a 5' Class 11B Pied and snag. Tagged tree is a Class 8 Pied 9'5" to P.C.
1119	From Salter Y take FS514 1.5 mi, then stay to left onto FS521 (Ormiston Pt. Rd.) 2.2 mi, then left on FS520 1.8 mi, then take rt fork (FS475) 3.2 mi. Plot is on left (east of road).	From road head ~ 250' at 104° to P.C. - marked w/yellow rebar next to the stump of a Class 12 Pied. Tagged tree is a 10' tall Juos 17'10" at 176° to P.C.
1120	From Dolores head to House Creek on FS526. Turn left onto FS528 (House Creek Rd.) - go 5.35 mi. Park by road curves to right sign. Plot is uphill on east side of road	P.C. straight up slope from road sign ~100'. P.C. marked w/yellow rebar. Tagged tree is a green Juos 20'11" at 298°. Rebar is in center of several Class 11 Pieds.
1121	From Rt. 666 follow signs for San Juan NF & Dolores River access. From Bradfield Bridge go 0.4 mi then left onto FS504 toward Benchmark Lookout/Big Water Spring 0.4 mi to 1-lane bridge sign.	Park on left side.Plot is upslope on south side of road. P.C. marked w/yellow rebar next to a Class 8 and Class 11 Pied. Tagged tree is a green Juos 7'5" at 17° to P.C.

Appendix 4. Directions to Plots at 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands, cont.

Plot #	Directions from Nearest Intersection	Directions to Plot Center
1122	From Dolores head to House Creek on FS526. Turn left onto FS528 (House Creek Rd.) - go3.1 mi. Plot is on east side of road ~ 1000' upslope	From Road head at 130° for ~1000'. P.C. in large opening between 2 Class 11 Pieds. P.C. marked w/yellow rebar on eastern edge of mortality center. Tagged tree is a green Pied 14'10" at 252° to P.C.
2201	From Ignacio, 151 east to 333 east 2.4 mi to fork. Take left fork 0.4 mi. Wide shoulder on left. Plot is on right, south of road, uphill.	From pullout head upslope approx. 1000' at 176°. Yellow rebar next to old Pied snag 3' tall. Tagged tree is a live juniper 3'9" at 352° to P.C.
2202	From Ignacio, 151 east to 333 east 1.8 mi then rt towards oilwell 0.2 mi	From far end of oilwell platform head ~ 400' at 204°. P.C. marked w/yellow rebar. Live Pied w/ 50% dead branched tagged 8'9" at 110° to P.C.
2203	From Ignacio, 151 east to left on 334 north 2.5 mi then rt on FS537 (aka 335) 2.7 mi to pulloff on right side of road just before cattle guard	Follow fence line through gully, Quga, and meadow. Fence bends to left and goes uphill toward mortality center. At end of fence go ~ 100' at 82° to yellow rebar marking P.C. next to 2' Pied stump. Tagged Pied snag 8' at 8° to P.C.
2204	From Ignacio, 151 east to left on 334 north 2.5 mi then rt on FS537 (aka 335) 1.6 mi then left on FS123 0.4 mi. Park along road - near far end of corral	From road head ~ 330' at 92°. P.C. marked w/yellow rebar. Tagged green Pied 9'10" at 237° to P.C.
2205	From Ignacio, 151 east to left turn onto 333 east then 1.5 mi Park under 2 Juos and 2 Pied on left (north) side of road	From trees at roadside, head ~ 1100' at 72°. P.C. next to large green Pied and Class 11 Pied. P.C. marked w/yellow rebar. Large Juos (2 stems) tagged 18'9" at 327°
2206	From Ignacio, 151 east to Fosset Gulch access road. Take 1st left up Sheep canyon 0.25 mi. Plot is up slope on left.	Follow old logging road for ~ 200'. P.C. is ~ 50' upslope at 240° from logging road. P.C. marked w/yellow rebar. Small Jusc tagged 5'5" at 74° to P.C.
2207	From Ignacio, 151 east to left turn onto 333 east then 2.4 mi to fork. Take left fork, go 0.4 mi wide shoulder on left. Plot is on left, east of ridge	P.C. marked with yellow rebar next to Class 9 Pied . 11' tall Juos tagged upslope 13'3" at 10° to P.C.
2208	From Ignacio, 151 east to left on 334 north 2.5 mi then rt on FS537 2.4 mi pulloff on right. Plot is on slope south of road.	Head SSE upslope approx. 1083' to P.C. marked w/yellow rebar. Live Juos tagged slightly downslope from P.C. 14'11" at 170° to P.C.

Appendix 5. Transect Properties for 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands

Plot #	Date Sampled	Transect #	Transect Length (m)	Transect Width (m)	Transect Bearing	Transect Slope (%)
1101	5/25/1999	1	32.9	6.1	304	0
1101	5/25/1999	2	37.5	6.1	66	0
1101	5/25/1999	3	49.1	6.1	185	0
1102	5/20/1999	1	42.4	6.1	166	0
1102	5/20/1999	2	45.4	6.1	69	0
1102	6/7/1999	3	45.1	6.1	320	0
1103	5/26/1999	1	39.6	6.1	217	0
1103	5/26/1999	2	35.4	6.1	137	0
1103	5/26/1999	3	10.7	6.1	350	0
1104	5/27/1999	1	37.2	6.1	150	0
1104	5/27/1999	2	38.1	6.1	194	0
1104	5/27/1999	3	21.0	6.1	312	0
1105	5/29/1999	1	52.1	6.1	95	0
1105	5/29/1999	2	34.1	6.1	192	0
1105	5/29/1999	3	31.4	6.1	345	0
1106	5/30/1999	1	25.9	6.1	192	0
1106	5/30/1999	2	21.9	6.1	312	0
1106	5/30/1999	3	10.7	6.1	72	0
1107	7/6/1999	1	19.2	6.1	317	17
1107	7/6/1999	2	17.1	6.1	242	12
1107	7/6/1999	3	21.3	6.1	90	18
1108	6/8/1999	1	40.8	6.1	210	0
1108	6/8/1999	2	28.0	6.1	345	0
1108	6/8/1999	3	12.2	6.1	82	0
1109	6/9/1999	1	34.4	6.1	144	0
1109	6/9/1999	2	41.1	6.1	32	0
1109	6/9/1999	3	7.9	6.1	268	0
1110	7/7/1999	1	50.0	6.1	296	19
1110	7/7/1999	2	36.0	6.1	155	8
1110	7/7/1999	3	33.8	6.1	46	12
1111	7/8/1999	1	50.0	6.1	180	5
1111	7/8/1999	2	60.4	6.1	300	2
1111	7/8/1999	3	33.5	6.1	60	2
1112	7/9/1999	1	42.1	6.1	14	0
1112	7/9/1999	2	15.5	6.1	134	0
1112	7/9/1999	3	18.3	6.1	254	15
1113	7/10/1999	1	35.1	6.1	70	0
1113	7/10/1999	2	29.6	6.1	190	8
1113	7/10/1999	3	18.9	6.1	310	2
1114	7/22/1999	1	43.6	6.1	156	8
1114	7/22/1999	2	48.2	6.1	290	0
1114	7/22/1999	3	41.8	6.1	68	1
1115	7/28/1999	1	32.3	6.1	54	3
1115	7/28/1999	2	33.5	6.1	114	2
1115	7/28/1999	3	49.7	6.1	264	5

Appendix 5. Transect Properties for 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands, Cont.

Plot #	Date Sampled	Transect #	Transect Length (m)	Transect Width (m)	Transect Bearing	Transect Slope (%)
1116	7/29/1999	1	43.6	6.1	268	14
1116	7/29/1999	2	25.9	6.1	28	8
1116	7/29/1999	3	74.4	6.1	148	2
1117	7/30/1999	1	34.4	6.1	55	0
1117	7/30/1999	2	22.6	6.1	113	3
1117	7/30/1999	3	14.6	6.1	221	2
1118	7/31/1999	1	36.6	6.1	114	2
1118	7/31/1999	2	38.7	6.1	12	1
1118	7/31/1999	3	36.3	6.1	243	2
1119	8/1/1999	1	48.8	6.1	99	1
1119	8/1/1999	2	30.5	6.1	10	4
1119	8/1/1999	3	36.3	6.1	251	6
1120	8/9/1999	1	15.2	6.1	334	2
1120	8/9/1999	2	32.0	6.1	55	31
1120	8/9/1999	3	19.5	6.1	192	28
1121	8/10/1999	1	32.6	6.1	160	30
1121	8/10/1999	2	17.7	6.1	21	32
1121	8/10/1999	3	24.7	6.1	272	16
1122	8/11/1999	1	33.5	6.1	338	7
1122	8/11/1999	2	61.9	6.1	242	19
1122	8/11/1999	3	22.3	6.1	110	8
2201	6/15/1999	1	50.6	6.1	100	0
2201	6/15/1999	2	24.4	6.1	210	34
2201	6/15/1999	3	20.1	6.1	326	40
2202	6/16/1999	1	40.8	6.1	100	0
2202	6/16/1999	2	31.1	6.1	245	0
2202	6/16/1999	3	20.7	6.1	6	0
2203	6/17/1999	1	47.2	6.1	302	34
2203	6/17/1999	2	62.2	6.1	70	0
2203	6/17/1999	3	29.0	6.1	176	53
2204	6/19/1999	1	17.1	6.1	136	27
2204	6/19/1999	2	50.3	6.1	26	0
2204	6/19/1999	3	12.5	6.1	258	28
2205	6/28/1999	1	39.6	6.1	36	8
2205	6/28/1999	2	21.9	6.1	168	25
2205	6/28/1999	3	32.0	6.1	230	8
2206	6/21/1999	1	25.9	6.1	180	25
2206	6/21/1999	2	24.4	6.1	264	32
2206	07/02/199	3	9.8	6.1	42	43
2207	6/29/1999	1	55.2	6.1	22	26
2207	6/29/1999	2	32.0	6.1	261	5
2207	6/29/1999	3	38.1	6.1	145	41
2208	7/1/1999	1	20.1	6.1	36	12
2208	7/1/1999	2	31.1	6.1	158	14
2208	7/1/1999	3	49.1	6.1	278	26

Appendix 6. Shrub Layer Species at 30 Black Stain Root Disease Centers in Pinyon-Juniper Woodlands

woody plants > 30.48 cm tall
0.004 ha plot = 3.59 m radius

Species Code	Scientific Name	Common Name
AMSPP	*Amelanchier Species (A. alnifolia, A. utahensis)*	Serviceberry
ARTR	*Artemisia tridentata*	Sagebrush
CEMO	*Cercocarpus montanus*	Mountain Mahogany
CHNA	*Chrysothamnus nauseosus*	Common Rabbitbrush
FERU	*Fendlera rupicola*	Fendlerbush
PERA	*Peraphyllum ramosissimum*	Squaw Apple
PRVI	*Prunus virginiana*	Chokecherry
PUTR	*Purshia tridentata*	Bitterbrush
QUGA	*Quercus gambelii*	Gambel's Oak
RHTR	*Rhus trilobata var. trilobata*	Skunkbush
RILE	*Ribes leptanthum*	Western Gooseberry
RIMO	*Ribes montigenum*	Alpine Prickly Current
SYAL	*Symphoricarpos albus*	Snowberry
YUBA	*Yucca baccata*	Indian banana

Appendix 7. Herbaceous Layer Species at 30 Black Stain Root Disease Centers in Pinyon-Juniper Woodlands

all non-woody plants plus woody plants < 30.48 cm tall
20 cm X 50 cm plot

Species Code	Scientific Name	Common Name
ACLA	*Achillea lanulosa*	Yarrow
ADLE	*Adelolinum lewisii*	Wild Blue Flax
AGSPP	*Agoseris Species*	False-dandelion
ALMI	*Alisma minus*	Waterplantain
ALSPP	*Allium Species*	Wild Onion
AMSPP	*Amelanchier Species*	Serviceberry
ANOC	*Androsace occidentalis*	Western Rock Jasmine
ANTE	*Anisantha tectorum (Bromus tectorum)*	Cheatgrass
ANSPP	*Antennaria Species*	Pussytoes
APPE	*Apumila petradoria*	
ARFR	*Artemisia frigida*	Prairie Sagewort
ARLU	*Artemisia ludoviciana*	Louisiana Sagewort
ARTR	*Artemisia tridentata*	Sagebrush
ASDR	*Astragalus drummondii*	Drummond's Milk Vetch
ASFL	*Astragalus flexuosus*	Flexile Milk Vetch
ASSPP	*Astragalus Species*	Milk Vetch
BADI	*Bahia disecta*	Bahia
CACA	*Carum carvi*	Caraway
CANU	*Carduus nutans*	Musk Thistle
CASPP	*Castilleja Species*	Paintbrush
CEOR	*Ceratocephala orthoceras*	Hornhead (Ranunculus)
CEMO	*Cercocarpus montanus*	Mountain Mahogany
CHAL	*Chenopodium album*	Lamb's Quarters
CHDE	*Chrysothamnus depressus*	Rabbitbrush
COPA	*Collinsia parviflora*	Blue-eyed-Mary
COUM	*Comandra umbellata*	Bastard Toadflax
CYAC	*Cymopterus acaulis*	Plains Spring Parsley
DEIN	*Descurainia incisa*	Tansy Mustard
ERCO	*Erigeron compositus*	Fleabane
ERDI	*Erigeron divergens*	Diffuse Fleabane
ERFL	*Erigeron flagellaris*	Trailing Fleabane
ERRA	*Eriogonum racemosum*	Redroot Buckwheat
ERSPP	*Eriogonum Species*	Wild Buckwheat
ERUM	*Eriogonum umbellatum*	Sulphur Flower Buckwheat
GUSA	*Gutierrezia sarothrae*	Broom Snakeweed
HEVI	*Heterotheca villosa*	Hairy Golden Aster
KOMA	*Koeleria macrantha*	Prairie Junegrass
LASE	*Lactuca serriola*	Prickly Lettuce
LASPP	*Lathyrus Species*	Peavine
LERE	*Lesquerella rectipes*	Straight Bladderpod
LEER	*Leucelene ericoides*	Sand Aster
LISPP	*Lithospermum Species (incisum)*	Gromwell
LOTR	*Lomatium triternatum*	Desert Parsley
LOWR	*Lotus wrightii*	Wright's Deervetch

Appendix 7. Herbaceous Layer Species at 30 Black Stain Root Disease Centers in Pinyon-Juniper Woodlands, Cont.

Species Code	Scientific Name	Common Name
LUAR	*Lupinus argenteus*	Silvery Lupine
MARE	*Mahonia repens*	Oregon Grape
MASPP	*Machaeranthera Species*	Tansy Aster
MESA	*Medicago sativa*	Alfalfa
MEBR	*Mertensia brevistyla*	Short Style Bluebells
MELA	*Mertensia lanceolata*	Prairie Bluebells
MIGR	*Microsteris gracilis*	Microsteris
MOSS	Mosses incl. Selaginella Species	Moss
OPFR	*Opuntia fragilis*	Brittle Prickly Pear
OPSPP	*Opuntia Species*	Prickly Pear
OXDI	*Oxalis dillenii*	Dillen's Woodsorrel
PESI	*Pediocactus simpsonii*	Ball Cactus
PELI	*Penstemon linarioides subsp. coloradoensis*	Toadflax Penstemon
PESPP	*Penstemon Species*	Penstemon
PEST	*Penstemon strictus*	Rocky Mountain Penstemon
PERA	*Peraphyllum ramosissimum*	Squaw Apple
PEPU	*Petradoria pumila*	Grassy Rock Goldenrod
PHLO	*Phlox longifolia*	Longleaf Phlox
POACEAE	Poaceae, any member of grass family	Grasses
PRVI	*Prunus virginiana*	Chokecherry
PTAL	*Pterogonum alatum*	Winged Buckwheat
PUTR	*Purshia tridentata*	Bitterbrush
QUGA	*Quercus gambelii*	Gambel's Oak
SESPP	*Senecio Species*	Groundsel
SETR	*Senecio tridenticulatus*	Groundsel
SORO	*Solanum rostratum*	Buffalo Bur
SPCO	*Sphaeralcea coccinea*	Scarlet Globemallow
SYAL	*Symphoricarpos albus*	Snowberry
TAOF	*Taraxacum officinale*	Common Dandelion
TECA	*Tetradymia canescens*	Spineless Horsebrush
TEIV	*Tetraneuris ivesiana*	Ive's Four Nerved Daisy
TRSPP	*Trifolium Species*	Clover
VIAM	*Vicia americana*	American Vetch
YUBA	*Yucca baccata*	Yucca banana

Appendix 9. Pinyon Ages and Years Dead by Tree Status on 30 Black Stain Root Disease Centers in Pinyon

Status [a]	Core # [b]	Age	Last Ring	Years Dead
2	1104-11	82	1998	1
2	1107-12	81	1997	2
2	1107-14	126	1998	1
2	1107-6	143	1998	1
2	1108-5	61	1998	1
2	1108-7	81	1997	2
2	1109-1	134	1998	1
2	1110-5	92	1998	1
2	1111-1	86	1999	0
2	1111-12	177	1998	1
2	1111-17	122	1999	0
2	1111-3	56	1998	1
2	1115-10	68	1997	2
2	1121-10	374	1997	2
2	1122-4	125	1999	0
2	2201-5	126	1998	1
2	2202-9	n/a	1997	2
2	2205-3	91	1998	1
2	2206-2	65	1998	1
2	2207-4	226	1998	1
3	1101-4	59	1998	1
3	1102-8	45	1998	1
3	1104-2	102	1998	1
3	1105-5	78	1995	4
3	1106-2	n/a	1999	0
3	1109-3	123	1998	1
3	1111-10	154	1998	1
3	1119-1	93	1996	3
3	2202-6	112	1998	1
3	2204-2	121	1998	1
3	2206-1	66	1997	2
3	2206-6	64	1998	1
3	2207-6	160	1998	1
3	2207-7	151	1997	2
3	2208-2	n/a	1997	2
4	1110-12	117	1997	2
4	1111-4	83	1998	1
4	1112-4	240	1998	1
4	1113-10	75	1998	1
4	1113-7		1999	0
4	1114-2	77	1997	2
4	1115-12	74	1998	1
4	1118-3	47	1998	1
4	1120-7	303	1998	1
4	2201-9	175	1998	1
4	2203-13	71	1998	1
4	2203-2	105	1998	1
4	2203-8	88	1998	1

Appendix 9. Pinyon Ages and Years Dead by Tree Status, cont.

Status	Core #	Age	Last Ring	Years Dead
4	2205-11	367	1998	1
5	1102-6	31	1998	1
5	1103-4	82	1997	2
5	1103-7	26	1998	1
5	1103-8	74	1998	1
5	1103-9	47	1998	1
5	1104-9	48	1997	2
5	1107-8	84	1997	2
5	1109-5	85	n/a	n/a
5	1110-11	127	1996	3
5	1111-5	51	1998	1
5	1112-6		1998	1
5	1114-4		1998	1
5	1114-5	49	1997	2
5	1115-4	58	1998	1
5	1115-8	68	1997	2
5	1116-10	63	1998	1
5	1116-6	29	1998	1
5	1117-10	30	1998	1
5	1117-13	35	1998	1
5	1117-15	51	n/a	n/a
5	1118-4	n/a	1998	1
5	1118-6	39	1997	2
5	1119-13	63	1997	2
5	1119-9	55	1995	4
5	1121-3	130	1998	1
5	1121-8	127	1998	1
5	1122-3	117	1998	1
5	2204-6	113	1998	1
5	2205-12	220	1997	2
5	2205-13	76	1998	1
5	2205-5	168	1998	1
6	1101-3	62	1995	4
6	1104-5	90	1997	2
6	1104-6	92	1997	2
6	1105-1	52	1998	1
6	1105-2	74	1996	3
6	1109-6	94	1996	3
6	1111-6	54	1997	2
6	1111-7	47	1998	1
6	1112-1	268	1994	5
6	1112-2	223	1998	1
6	1113-9		1996	3
6	1114-1	65	1998	1
6	1114-9	66	1998	1
6	1115-13	52	1997	2
6	1115-2	54	1993	6
6	1116-11	106	1998	1
6	1116-12	n/a	1998	1
6	1116-9	89	1998	1

Appendix 9. Pinyon Ages and Years Dead by Tree Status, cont.

Status	Core #	Age	Last Ring	Years Dead
6	1117-3	62	1998	1
6	1117-4	74	1996	3
6	1117-7	71	1994	5
6	1118-7	74	1998	1
6	1118-8		1998	1
6	1118-9	45	1996	3
6	1120-1	80	1996	3
6	1121-5	153	1995	4
6	1121-7	87	1997	2
6	2203-14	101	1998	1
6	2203-17	125	1998	1
6	2203-4	116	1996	3
6	2204-4	97	1995	4
6	2204-8	77	1998	1
6	2206-10	55	1998	1
6	2206-3	62	1998	1
6	2206-8	64	1998	1
7	1101-6	34	n/a	n/a
7	1101-7	51	1992	7
7	1101-8	57	n/a	n/a
7	1102-4		1992	7
7	1102-7	71	n/a	n/a
7	1103-1		1993	6
7	1103-2	45	1995	4
7	1103-5	142	1988	11
7	1104-8	63	1994	5
7	1105-3	81	1995	4
7	1106-4	91	1996	3
7	1107-10	64	1995	4
7	1107-11	84	n/a	n/a
7	1107-15	88	1996	3
7	1107-3	85	1994	5
7	1108-4	78	n/a	n/a
7	1108-8	92	1997	2
7	1110-2	n/a	1991	8
7	1110-8	90	1993	6
7	1111-14	n/a	1994	5
7	1111-8	48	1997	2
7	1111-9	43	1994	5
7	1113-1	57	1991	8
7	1114-10	36	1997	2
7	1114-7	64	1997	2
7	1115-15	71	1993	6
7	1115-6	35	1996	3
7	1115-7	140	1996	3
7	1116-5	52	1994	5
7	1117-1	51	1993	6
7	1117-8	61	1994	5
7	1118-1	64	1994	5
7	1118-2	52	1994	5

Appendix 9. Pinyon Ages and Years Dead by Tree Status, cont.

Status	Core #	Age	Last Ring	Years Dead
7	1119-14	71	1993	6
7	1119-4	40	1996	3
7	1119-5	60	n/a	n/a
7	1121-2	142	1997	2
7	1122-2	172	n/a	n/a
7	2201-3	136	1995	4
7	2201-8	174	1995	4
7	2202-7	78	1993	6
7	2203-10	100	1994	5
7	2204-10	89	1995	4
7	2204-5	83	1996	3
7	2204-9	121	1997	2
7	2205-1	257	1993	6
7	2205-2	108	1996	3
7	2205-9	195	1991	8
7	2206-5	78	1996	3
7	2206-9	65	1991	8
7	2207-8	200	1993	6
7	2207-9	153	1993	6
8a	1107-1	70	1990	9
8a	1107-2	53	1994	5
8a	1108-10	63	1994	5
8a	1110-1	50	1990	9
8a	1110-10	130	1995	4
8a	1110-14	111	1990	9
8a	1110-7	47	1991	8
8a	1111-11	96	1995	4
8a	1111-15	146	n/a	n/a
8a	1113-11	75	1989	10
8a	1113-3	56	1994	5
8a	1113-5	63	1990	9
8d	1117-6	49	1993	6
8a	1117-9	n/a	1995	4
8a	1119-3	72	n/a	n/a
8a	1119-6	84	1995	4
8a	1119-8	65	1984	15
8a	1121-11	175	1988	11
8a	1121-4	155	1992	7
8a	2201-4	169	1995	4
8a	2202-3	127	1989	10
8a	2203-1	51	1992	7
8A	2203-16	79	1985	14
8a	2203-5	200	1987	12
8a	2207-3	71	1994	5
9	1101 C9	78	1991	8
9	1103 C9A	133	1989	10
9	1103 C9B	133	1975	24
9	1103 C9C	144	1983	16
9	1104 C9	149	1990	9
9a	1108-9	70	1992	7

Appendix 9. Pinyon Ages and Years Dead by Tree Status, cont.

Status	Sample #	Age	Last Ring	Years Dead
9	1109 C9	72	1988	11
9a	1110-16	122	1985	14
9	1110 C9	61	1985	14
9	1111 C9	165	1991	8
9	1112 C9A	99	1986	13
9	1112 C9B	112	1974	25
9	1114 C9	85	1974	25
9	1115 C9	47	1987	12
9a	1116-4	48	1987	12
9	1118 C9	46	1991	8
9	1119 C9	59	1986	13
9	1120 C9	73	1988	11
9a	2202-2	92	1989	10
9A	2203-12	102	1987	12
9a	2203-6	98	1984	15
9a	2207-1	42	1984	15
9a	2208-4	n/a	1987	12
9a	2208-6	n/a	1983	16
10	1101 C10	n/a	1989	10
10	1103 C10	135	1990	9
10	1103 C10B	135	1990	9
10	1104 C10	111	1991	8
10a	1104-4	140	n/a	n/a
10	1105 C10	123	1988	11
10a	1107-4	69	n/a	n/a
10	1107-9	64	1994	5
10	1108 C10	80	1993	6
10	1108 C10	81	1980	19
10a	1108-3	52	1990	9
10	1109 C10	126	1983	16
10	1111 C10	90	1992	7
10	1112 C-10	150	1988	11
10	1113 C10	126	1986	13
10a	1113-13	57	1989	10
10a	1113-15	107	1988	11
10a	1113-4	n/a	1988	11
10a	1116-1	34	1990	9
10	1119 C10	85	1991	8
10	1120 C10	84	1986	13
10	1120 C10B	353	1981	18
10	1122 C10	129	1994	5
10	2201 C10	97	1991	8
10	2201 C10B	93	1991	8
10	2201	210	n/a	n/a
10a	2201-2	147	1992	7
10	2205 C10	209	1981	18
10	2205 C10B	211	1992	7
10	2205	253	1993	6
10	2205	251	1993	6
11	1101 C11	66	1984	15

Appendix 9. Pinyon Ages and Years Dead by Tree Status, cont.

Status	Sample #	Age	Last Ring	Years Dead
11	1103 C11	144	1981	18
11	1103 C11B	149	1980	19
11	1108 C11	70	1989	10
11	1109 C11	122	1973	26
11	1109 C11B	124	1973	26
11	1111 C11	70	1984	15
11	1113 C11	94	1983	16
11	1122 C11	123	1994	5
11	2201 C11	277	1981	18
11a	2201-1	162	1984	15
11	2205 C11	204	1987	12
11	2205 C11B	193	1983	16
11a	2205-7	173	1984	15
11	2207 C11	177	1989	10
14a	1112-3	193	n/a	n/a

a: Status refers to the 14 class system applied to all trees within transects, see Table 1.1 for full description

b : First 4 digits of core/sample # represent the plot from which it was obtained, the following number represents the number of the core. Stem cross sections are denoted by "C". Ex. 1109 C11B is the second stem cross section obtained from a status 11 pinyon on plot 1109

Appendix 10. Mean Age of Pinyon within 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands

Plot #	Mean Age	St. Dev.	N
1101	58.1	13.6	7
1102	49.0	20.3	3
1103	106.8	45.1	13
1104	100.7	32.6	10
1105	77.7	25.0	6
1106	91.0	n/a	1
1107	85.8	25.4	14
1108	72.8	11.9	10
1109	109.8	21.4	9
1110	94.7	32.0	10
1111	90.8	43.7	18
1112	180.2	55.4	10
1113	77.8	23.8	10
1114	61.3	17.0	9
1115	65.7	27.2	11
1116	60.1	28.3	7
1117	57.3	18.3	11
1118	52.4	12.3	7
1119	70.5	17.1	12
1120	224.6	138.6	7
1121	162.0	83.5	9
1122	113.4	41.1	7
2201	166.4	53.6	12
2202	96.7	20.0	6
2203	102.1	35.2	14
2204	103.7	17.6	9
2205	198.4	73.0	15
2206	65.5	5.8	10
2207	145.4	58.4	9
2208	102.0	n/a	1

Note: Plots 1101-1122 located near McPhee Reservoir and Plots 2201-2208 located near Ignacio

Appendix 11. Mean Expansion Rates of 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands

	Mean Rate of Expansion	
Plot #	meters/year	S. E.
1101	1	0.42
1102	1.62	0.35
1103	1.32	0.36
1104	2.01	0.35
1105	1.58	0.48
1106	0	n/a
1107	1.87	1.33
1108	1.57	0.27
1109	1.18	0.48
1110	0.51	0.43
1111	1.59	0.22
1112	-1.22	2.61
1113	0.84	0.34
1114	1.02	0.23
1115	0.39	0.37
1116	0.04	0.34
1117	0.71	0.88
1118	1.28	0.24
1119	1.64	0.31
1120	0.43	0.39
1121	0.47	0.51
1122	0.62	1.17
2201	-0.01	0.33
2202	1.42	0.51
2203	1.29	0.36
2204	1.31	0.94
2205	1.27	0.37
2206	0.42	0.54
2207	1.96	0.34
2208	-0.6	0.83

Note: Plots 1101-1122 located near McPhee Reservoir and Plots 2201-2208 located near Ignacio

Appendix 12. Data Forms and Codes for 30 Black Stain Root Disease Mortality Centers in Pinyon Juniper Woodlands

Data Codes

Plot #: McPhee 11-(01-22)
Ignacio 22-(01-8)
Date: Month/Day/Year
Legal: Township/Range/Section
Quad.: Title of Quad. Map
Aspect: in degrees
Slope: % slope
Slope Position: 1= Ridge, 2= Top 1/3, 3= Middle 1/3, 4= Bottom 1/3, 5= Valley
Topography: 1 = convex 2 = concave 3 = even

Transect Length: horizontal distance in feet
Transect Width: horizontal distance in feet
Transect Bearing: in degrees

Tree species: PIED = Pinus edulis; JUSC = Juniperus scopulorum, PIPO = Pinus ponderosae
JUUT = Juniperus utahensis = Juniperus osteosperma

Black Stain / Ips / Other D.A.
0 = none
1 = present
2 = suspected, but not confirmed / unknown

Decline Agents
10 = Animal Damage
11 = Sapsucker Damage
22 = Unknown Bark Beetles
23 = Pedioptera twig beetles
24 = Wood Borers
25 = Ants
26 = Termites
31 = Phoradendron mistletoe on junipers
32 = Arceuthobium dwarf mistletoe on pinyon
33 = Gymnosporagium rust galls on junipers
40 = Brown cubical rot
41 = Sapwood decay
42 = Heartwood decay
51 = Resinosis – unknown cause
52 = Wound – unknown cause
53 = Broken top
54 = Many dead branches, but no chlorotic needles

55 = Crown thin

Appendix 12. Data Forms for 30 Black Stain Root Disease Mortality Centers in Pinyon-Juniper Woodlands, cont.

PLOT INFORMATION

Plot # : _____
Date: _ _/ _ _/ _ _
Legal (T/R/S): _ _ _/_ _ _/_ _
Quad.: _____

Directions:
Nearest Intersection: _____

To Plot Center: _____

Aspect: _____
Slope: _____
Topography: _____
Slope Position: _____
Soil Type: _____

UTM Coordinates
Plot Center: Rover File #: _____

Boundary: Rover File #: _____

Transect 1	Length: _____	Width: _____	Slope %: _____	Bearing: _____
Transect 2	Length: _____	Width: _____	Slope %: _____	Bearing: _____
Transect 3	Length: _____	Width: _____	Slope %: _____	Bearing: _____

Comments: _____

FINAL REPORT
ON THE

LARGE SCALE APPROACHES TO INVESTIGATING PINYON MORTALITY IN SOUTHWEST COLORADO

SAMUEL F. HARRISON AND WILLIAM R. JACOBI

DEPARTMENT OF BIOAGRICULTURAL SCIENCES AND PEST MANAGEMENT,
COLORADO STATE UNIVERSITY, FORT COLLINS, CO

Black Stain Root Disease of Pinyon Pine: Landscape Assessments

Samuel F. Harrison and William R. Jacobi
Department of Bioagricultural Sciences and Pest Management, Colorado State University
Fort Collins, CO 80523

Introduction

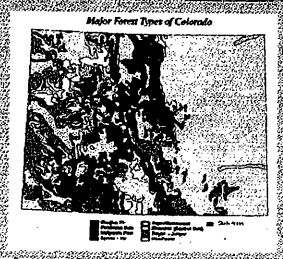
Project Objective: To produce a GIS-based landscape scale prediction system for incidence of pinyon decline in Southwest Colorado. The general principles of the hazard-rating model will be applicable, with local modifications, to pinyon/juniper forests throughout the Intermountain West.

Project Description: Using aerial photography and site visits by field personnel, mortality and stress in pinyon pine forests located in the San Juan National Forest and the Southern Ute Reservation in Colorado are being identified and entered into a GIS database. Along with soil and site characteristics and locations of disturbed areas. Analyzing the data using spatial statistics, a hazard rating system will be developed for pinyon decline in the Southwest.

Justification: In recent years, there have been reports of pinyon pine dying in unprecedented numbers in areas of the Southwest. The chief agents of mortality in these stands have been identified as Black Stain Root Disease (*Leptographium wagneri*) (Fig. 1), pinyon ips (*Ips confusus*), but factors contributing to the susceptibility of pinyon stands to these agents is largely unknown. This hazard-rating system will enable managers of public forests, National Parks and Monuments, county lands and private holdings to identify high risk areas for pinyon decline and to thereby implement practices to reduce the damage caused by the disease. Pinyon mortality has become a major problem in pinyon/juniper forests of the intermountain West. It creates areas of mortality which affect wildlife and biodiversity as well as detract from the value of forested land for recreational and aesthetic purposes. Currently, no tools exist to provide managers with information regarding which areas are at risk.

Fig. 1. A few years after this picture was taken Dolores Co., all of the pinyon began to fade and die. Each year a few more trees were killed. The stream in the foreground, removal of affected trees has failed to slow it down.

Fig. 2. Visitors at Mesa Verde National Park take a break in the middle of affected pinyon pine. Dead and dying trees in highly used recreation areas of forests result in real land managers.



Forest types of Colorado shown along with the two study regions. Pinyon and its associates account for a full 20% of the forested land in the state of Colorado. Reproduced with permission from the Colorado state Forest Service.

Summer 1998 Field Survey

During the 1998 field season, field personnel recorded data for 50 transects located throughout the two study areas. There were two purposes to this phase of the study; first, incidence of the decline previously unknown, could be determined based upon the data collected. Second, relationships between pinyon mortality and various stand attributes and site characteristics could be determined from this survey, providing the basis for a preliminary model.

These transects were placed so that each would fall within a different section, as determined using 7.5 minute USGS quads. The sections sampled were chosen so as to cover the maximum area within the area for which aerial photography was to be obtained.

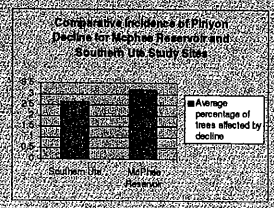
Each transect was 66' wide and was comprised of 8 intervals 264' (4 chains) long. All pinyon mortality and causal factors were recorded within each interval, along with site characteristics such as slope, aspect, and cover type. Additionally, a 20th acre plot was established in each interval to record detailed measurements of trees, both live and dead, including diameter, height, crown radius, and damaging agents.

Summer 1998 Transects Western Shore of McPhee Reservoir

An area of McPhee Reservoir, north of Dolores, Colorado showing the locations of sampled transects against a digital photo base.

Results of Field Survey

The data collected in the field study were analyzed to test for significant differences between the observable characteristics of affected and unaffected areas. Additionally, total incidence of mortality as a percentage of the total pinyon component of affected forests was estimated for the two study areas.



Overall incidence of pinyon mortality was found to be between 2.5 and 3.5 percent of all trees affected for the two study sites.

Statistical Results of Field Survey

Variable	Diseased	Mean	Prob > |t|
diameter (in.)	Y	4.68	0.0452
	N	5.36	
height (ft)	Y	11.1	0.3490
	N	11.5	
density (trees/acre)	Y	209	0.0081
	N	182	
crown area (sq ft/acre)	Y	11764	0.1174
	N	10961	
Pinyon BA (sq ft/acre)	Y	49.8	0.0001
	N	33.8	
slope (%)	Y	17.8	0.3970
	N	16.7	
gambel oak (% cover)	Y	7.0	0.0251
	N	9.35	
forbs (% cover)	Y	1.6	0.0579
	N	3.0	

Results of analysis of the data from the 1998 field season. Statistics for indicated intervals containing affected trees were compared to those of unaffected intervals.

Italicized significance at the 95% level

Characterizing affected stands

Based upon the results of the ground survey performed in 1998, we can infer that affected stands are most likely to contain larger numbers of small diameter trees, have higher total basal area, and have a lower proportion of ground cover comprised of Gambel Oak, and varied forbs than unaffected stands.

Analyzing Patterns of Mortality from Aerial Photography

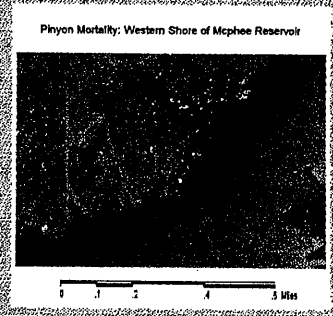
Infrared photo at 1 : 4000 scale

During the summer of 1998, infrared photography at the 1:4000 scale was obtained for both study areas. The images have been manually interpreted by means of a hand lens and/or stereoscope to demark areas of mortality. Interpretation of the photos is performed on a transparency placed over the photo. The transparency is then removed from the photo to be digitized directly via heads-up/on-screen digitizing. Each of these interpreted raster images is geo-referenced using a digital orthophoto quad, converted to a vector image using GIS software and joined with adjacent images.

Interpreted photo, showing areas of mortality in blue, and digitization points for geo-referencing (in red).

Areas of mortality digitized into vector format.

Aerial view of pinyon mortality near Cortez, Colorado.



A completed mosaic of the pattern of mortality for a small area on the western shore of McPhee Reservoir, derived from 4.1 : 6000 scale infrared photos. In this diagram, the pattern of mortality is displayed atop the digital orthographic quad that was used to georeference the data. The polygons are stored in GIS vector coverage format. Each polygon is associated with a set of entries in the database representing the number of dead, dying, and live crowns within. These spatially explicit data are being used to test for autocorrelation between mortality and the underlying site conditions.

Work remaining

Once all mortality for both study areas has been converted to GIS coverages, we can test for spatial autocorrelation between pinyon mortality and underlying site characteristics derived from existing databases. USDA Forest Service and BIA Forestry have provided GIS data for both study areas including:

- 30M Lynes
- Vegetation, including both vegetation type and percentage cover
- Digital Elevation Models (DEM) to examine elevation, slope, aspect, and hydrological characteristics of the landscape

Cooperators

Forest Health Specialists:
Dr. Phil Mask, Entomologist / Forest Health Management Specialist, CO
Dr. Tom Eager, Entomologist, Forest Health Management Specialist, CO
Dr. Jim Worrall, Pathologist / Forest Health Management Specialist, CO

Forest Health Monitoring:
Jennifer Fidel, Entomologist, Lakewood, CO

Forest Health / Ecological Evaluations Team:
Mr. Bill Smith, Ecological Statistician

Colorado State University Personnel:
Dr. William R. Jacobi, Professor of Forest and Shade Tree Pathology
Samuel F. Harrison, Graduate Student
Josh Hanna, Graduate Student

Cortez Ranger District:
Mike Schneider, Forest Ranger
Dan Dallabetta, District Forester
Teri Hubbard, Intern

Southern Ute BIA
Jim Fielder, BIA Forester

San Juan National Forest
Tom Cooke, Forester, Dolores Ranger District
Bob Kelly, Assistant Forester, Dolores Ranger District
Eric Lindman, Soil Scientist, Dolores Ranger District

Large Scale Spatial Approaches to Investigating Pinyon Mortality in Southwest Colorado

Samuel F. Harrison and William B. Jacobi
Colorado State University, Fort Collins CO

Abstract: A study was begun in 1997 in order to examine patterns of mortality of pinyon pine (*Pinus edulis*) due to various agents, most notably black stain root disease (*Leptographium wageneri*), Ips bark beetles (*Ips sp.*) and human perturbation of the environment by means of road building, home construction, and recreational use. This study was undertaken using both conventional forest sampling techniques, and also remote sensing techniques, including aerial photography and geographic information systems (GIS). Mortality was sampled for two areas in southwest Colorado, totaling approximately 115 square miles in size. Along each of 50 transects, all pinyon mortality was recorded, and periodic plots were established to record the characteristics of both live and killed trees, as well as other underlying site characteristics such as topography, vegetative cover, and sources of anthropogenic disturbance. Analysis of the data suggests that incidence of mortality is highest in pinyon stands characterized by high densities of small diameter trees with below average amounts of non-pinyon vegetative cover. Relationships between mortality and topography were inconclusive, as were relationships between mortality and site disturbance by humans. At the same time, infrared aerial photography at the 1:6000 scale was obtained for both areas. These photographs were manually interpreted to detect all recognizable pinyon mortality on the landscape. Interpreted images are being converted to GIS coverages for the purpose of spatial autocorrelation analysis between pinyon mortality and underlying site factors such as slope, aspect, elevation, soil type, vegetative cover, and land use. When completed, the study will provide a model for pinyon mortality in the region, as well as a much-needed comparison of the accuracy and utility of technology-based sampling and analysis, as opposed to conventional sampling, of patterns of forest disease.

A thesis-based report is not available for this project because of personnel issues. The following is a synopsis of the project progress. We assume in cooperation with cooperators who funded this project we will publish a manuscript based on this work in the future.

Project Objectives: To: 1) produce a GIS-based landscape scale prediction system for incidence of pinyon mortality from Ips bark beetles and black stain root disease in Southwest Colorado and 2) determine the impact of the mortality on the pinyon/juniper plant communities. The general principles of the hazard-rating model will be applicable, with local modifications, to pinyon/juniper forests throughout the Intermountain West.

Project Description: Using aerial photography and site visits by field personnel, mortality centers in pinyon pine forests located in the San Juan National Forest and the Southern Ute Reservation in Colorado will be identified and entered into a GIS database along with soil and site characteristics and locations of disturbed areas. Analyzing the data using spatial statistics, a hazard rating system will be developed for pinyon mortality in the Southwest. Mortality centers will be assessed in detail to determine their size, rapidity of mortality, impacts on regeneration and vegetation diversity.

Justification: The hazard-rating system will enable managers of public forests, National Parks and Monuments, state and county lands, and private holdings to identify high risk areas for pinyon mortality and to thereby implement practices to reduce the damage caused by the disease. It will also enable land managers to better determine the most appropriate land management emphasis for a given area and aid in the development of Forest Plans. Pinyon mortality has become a major problem in pinyon/juniper forests of the Intermountain West. It creates areas of mortality, which affect wildlife and biodiversity as well as detract from the value of forested land for recreational and aesthetic purposes. We have two primary mortality agents (black stain and Ips bark beetles) working at different rates and possibly different locations and forest conditions. Both organisms create many dead trees that greatly increase the risk of wild fires. Currently, no tools exist to provide managers with information regarding which areas are at risk.

Urgency:

Reports of pinyon dying in unprecedented numbers has made pinyon mortality one of the top priorities for the Forest Health Management Service Center in Gunnison. Forest Health personnel in Utah, Arizona, and New Mexico has voiced similar concerns. Continued high mortality of pinyon could potentially shift the species composition of these forests towards juniper only. Dramatic increases in use of pinyon/juniper woodlands for housing and recreation in recent years has turned this problem into a regional issue. Interest in the project has been sufficiently great that several agencies at the local, state and federal level have funded the first year of field work in order to get the project started as soon as possible. Those contributing in 1998 were Colorado State Forest Service, San Juan National Forest, BIA, Forest Health Monitoring, and Colorado State University.

Work Completed

1. Gather existing data. Published literature, soil and vegetation maps, disturbance data, meteorological data, and other spatial data existing for the San Juan National Forest, Southern Ute Reservation and surrounding areas has been compiled. These areas were used because there was available GIS data on a variety of parameters.

2. Obtain aerial photos. During the summer of 1998, infrared photographs were taken of areas on the San Juan National Forest and the Southern Ute Reservation totaling 110 square miles in area. The photos are at a scale of 1:6000, which allows us easily to pick out areas of mortality in most cases to the single tree level.

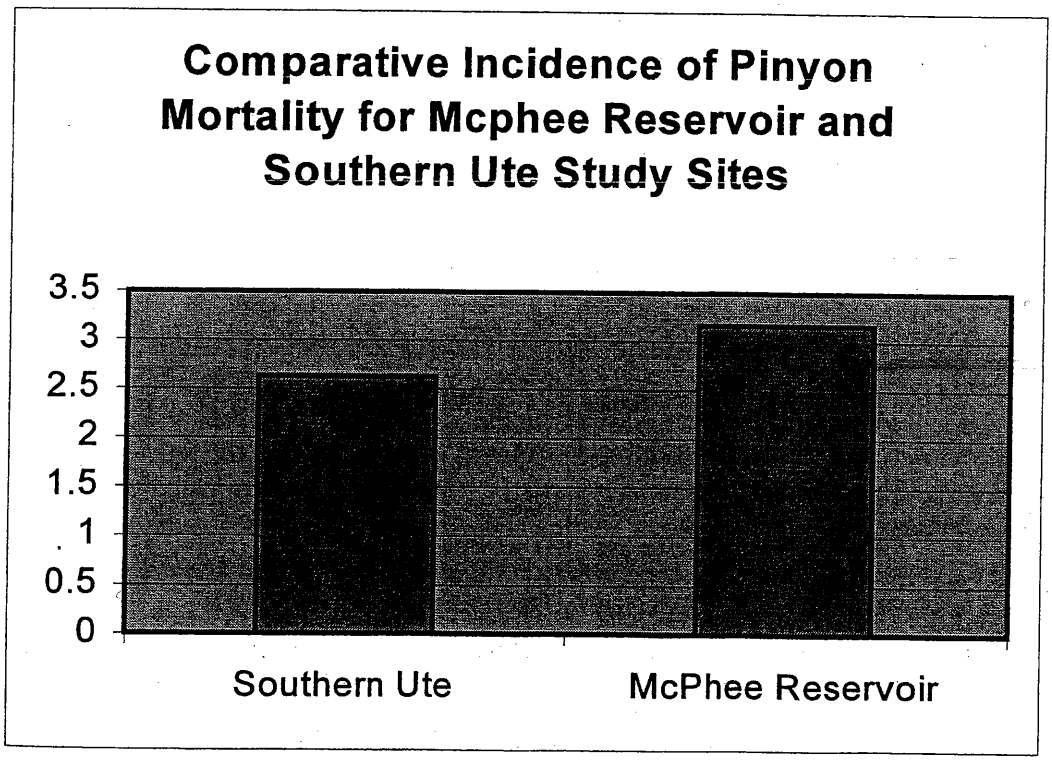
3. Obtain field data. Also during the summer of 1998, field personnel recorded data for 50 half-mile transects located throughout the two areas for which photos were obtained. There were two purposes to this phase of the study: first, incidence of the decline, previously unknown, could be determined based upon the data collected. Second, the locations of mortality sites found in this sample provide the preliminary basis for the model. These transects were placed so that each would fall within a different section, as determined using 7.5 minute USGS quads. The sections sampled were chosen so as to cover the maximum area within the flight zones. The status of the pinyon trees and normal forestry measurements were taken along the transects.

4. Analyze field data. The data from the 1998 field season was compiled and preliminary analysis completed. The data will be entered into a GIS database so that it can be merged with the spatial data relating to site characteristics. This will make possible a preliminary analysis to test for correlation between mortality observed on the ground and underlying site factors.

5. Digitize photos. Over 850 photos were analyzed to identify pinyon mortality by circling with a pen one or more dead trees. Then, photos are being digitized and referenced to lat-long coordinates so they may be overlaid with existing GIS coverages. This process will create GIS coverages that contain spatial data for the entire study area and the associated site data for all sample points.

6. 1999 Field Season. During the 1999 field season, a field crew sampled over 40 mortality sites identified from the infrared photographs. The boundary was traversed with a GPS unit to obtain accurate areas. All dead trees were counted within these mortality sites to determine the relationships between photo interpreted mortality incidence and area affected and the on site determinations.

Results of Field Survey: Figure one.



1. Incidence of pinyon pine mortality was 2-3.5 % of all trees in the sampled areas (Figure 1)
2. Only stem density and tree diameter were significantly related to incidence of Black Stain root disease. Plots where the disease occurred had smaller diameter trees and more of them (Table 1)

Table One: Relationship of tree and site factor and occurrence of black stain root disease in pinyon stands.

Variable	Disease in interval	Mean	Probability> |T|
Tree Diameter(inch)	no	5.36	0.04
	yes	4.86	0.04
Percent slope (%)	no	16.7	0.40
	yes	17.8	0.39
Tree Density (Stems /acre)	no	182.4	0.001
	yes	230.0	0.001

Spatial analysis:

1. The goal of this portion of the study was to determine if aerial photography could detect black stain root disease and Ips bark beetle mortality and distinguish them. This study was also supposed to determine if there were any site or physiographic factors related to the occurrence of mortality using GIS and spatial data analysis.

2. We succeeded in interpreting all photos for mortality by drawing polygons on the photos. Determining cause of death was not attempted since there were so many dead trees and there were no distinct differences noted.

3. We counted the number of green, dying or dead trees within the polygons.

4. We digitized these polygons and bound them together to form 3-4 photo's around each of the 50 field transects.

5. Because of personnel issues we have not had the opportunity to complete the next phases of the project. We plan to:

- Assess the spatial distribution of the polygons
- Determine if there any spatial relationships between slope, aspect, soil conditions, vegetation classification, precipitation and occurrence of the mortality.
- Determine the relationship between on the ground counts of dead trees and the counts taken from the aerial photos.