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**ENVIRONMENTAL CONDITIONS AND ASPEN
REGENERATION FAILURE**

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Environmental Conditions and Aspen Regeneration Failure

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Executive Summary

Seven study sites were established on the San Juan, Grand Mesa, Uncompahgre and Gunnison National Forests and State lands near the Routt National Forest to determine what environmental conditions predisposed aspen sprouts to infection by two canker causing fungi (*Cytospora chrysosperma*, *Dothiora polyspora*). Each site was located where >95% aspen sprout mortality occurred in 1983, 1987 or 1990 and consisted of whole stands or portion of stands that ranged from 2-10 acres. At each site, a plot with >95% sprout mortality was paired with a plot within the stand or within 2 miles where at least 50% of the sprouts survived. Measurements of past meteorological conditions, current soil conditions, soil hydrologic factors, and current and previous stand conditions were taken during the summers of 1990-93.

Two scenarios explain the aspen regeneration failure at the seven study sites. On wet sites, excess soil moisture resulting from deep and late spring snow packs on poorly drained soils, predisposed aspen trees to infection by canker pathogens. Root mortality from soil flooding and drought in mid summer may have caused drought stress. On dry sites, drought conditions from low spring snow packs and reduced summer precipitation on soils with poor water holding capacity predisposed aspen trees to infection by canker pathogens. In addition, shallow rooting induced by a high water table appears to be related to potential drought on dry sites.

Predicting where mortality will occur is difficult because previous stand characteristics were not different between areas with or without sprout mortality and soil differences were specific to a site and thus the soil conditions were not similar on all sites.

Predicting when mortality will occur may be feasible with additional research that relates sprout health to the amount of water in spring snow packs, summer precipitation and Palmer Drought Index data. Failure of aspen regeneration will probably continue to occur. Based on 8-60 years of meteorological data, deep May snow packs occur about 26% and shallow snow packs occur 8% of the years at the study sites.

Introduction

Aspen (*Populus tremuloides* Michx.) is the most widely distributed tree species native to North America (Little 1971). Colorado and Utah contain most of the aspen in the west where the tree acreage comprises more than 25% of all commercial forests in these states. In Colorado, aspen forests comprise almost 3 million acres and are most prominent west of the Front Range and in the Sangre de Cristo Mountains (DeByle and Winokur 1985).

Water management, wildlife habitat, timber production, recreation, and scenic beauty are important uses of aspen in the Rocky Mountain Region (DeByle and Winokur 1985). A diversity of age and size classes is required to provide for this range of demands on the aspen resource. Clear felling is the preferred harvest method used to regenerate aspen and provide age and size diversity. Aspen regenerates in clearcut stands primarily by root suckering. Normally, suckering is prolific and dense sprout stands persist until competition, diseases and insects reduce the density. However, in some stands in the Rocky Mountain Region, 90-100% of the sprouts die from diseases within two to eight years after harvest (Crouch 1983, 1986, Hildebrand and Jacobi 1990, Hinds and Shepperd 1987). This extensive mortality results in regeneration failure. Regeneration has not occurred in affected areas even after 10 years, leaving large treeless patches (Crouch 1986, Hildebrand and Jacobi 1990). The treeless areas may encompass an entire harvest area or more commonly affect a portion of the area.

Studies in other regions of North America found various biotic and abiotic agents cause considerable mortality in aspen stands (Basham and Navartil, 1975, Bloomberg 1962, Gross and Basham 1981, Perala 1984, Pollard 1971, Stanoz and Patton 1984).

A recent survey of understory plant species on failed sprout stands in Colorado and Wyoming showed little difference in vegetation between stands with adequate or inadequate regeneration (Hildebrand and Jacobi 1990). Inadequately stocked stands had more yarrow (*Achillea lanulosa* Nutt.), dandelion (*Taraxacum officinale* Wiggers), strawberry (*Fragaria* sp.), and corn husk lily (*Veratrum tenuipetalum* Heller).

Adequately stocked stands had more *Osmorhiza* sp., snowberry (*Symphoricarpos* sp.), and meadow rue (*Thalictrum* sp.). Because the vegetation data were collected after most of the sprouts had died, subsequent changes in soil moisture and solarization may have influenced vegetative composition. In a few sites, where the slopes differed between adequate and poorly stocked stands, the poor stands were on level or low slope positions. However, there were too few samples of this condition to make any significant inferences.

Studies in Colorado to determine diseases related to aspen sprout mortality (Hinds and Shepperd 1987, Jacobi and Shepperd 1991) revealed various maladies. Two canker-inducing fungi were found responsible for many of the failed sprout stands in Colorado. *Dothiora polyspora* Shear & Davidson and *Cytospora chrysosperma* (Pers.) Fr. rapidly kill aspen sprouts within a few months after infection (Guyon, 1990, Jacobi and

Shepperd, 1991, Ramaley et al. 1987). Although both fungi are thought to be more damaging to stressed trees, *C. chrysosperma* is the predominant pathogen.

The overall objective of this project was to identify the interacting environmental conditions that predisposed aspen sprouts to infection by these canker fungi. Forest managers may then predict when and where this problem will occur and possibly avoid or prevent regeneration failure. Thus, the specific objectives were to determine: (1) the weather conditions related to the occurrence of aspen mortality; (2) the site, soil characteristics, and soil moisture factors related to the spatial occurrence of aspen mortality; 3) and any stand condition that could predict the occurrence of canker-induced mortality. This project was a cooperative effort among the USDA Forest Service, Colorado State University and USDA Natural Resource Conservation Service.

Materials and Methods

Seven study sites were established on the San Juan, Grand Mesa, Uncompahgre and Gunnison National Forests and State lands near the Routt National Forest (Fig. 1 and Table 1). Each site was located where >95% aspen sprout mortality occurred in 1983, 1987 or 1990 and consisted of whole stands or portions of stands that ranged from 2-10 acres. A plot with >95% sprout mortality (poor plot) was paired with a plot within the stand or within 2 miles where at least 50% of the sprouts survived (good plot). Plots were established one to eight years after mortality was observed. Three 10 X 10 m subplots were randomly placed within each plot. Measurements of various factors that could be related to canker occurrence were taken during the summers of 1990-93.

Colorado

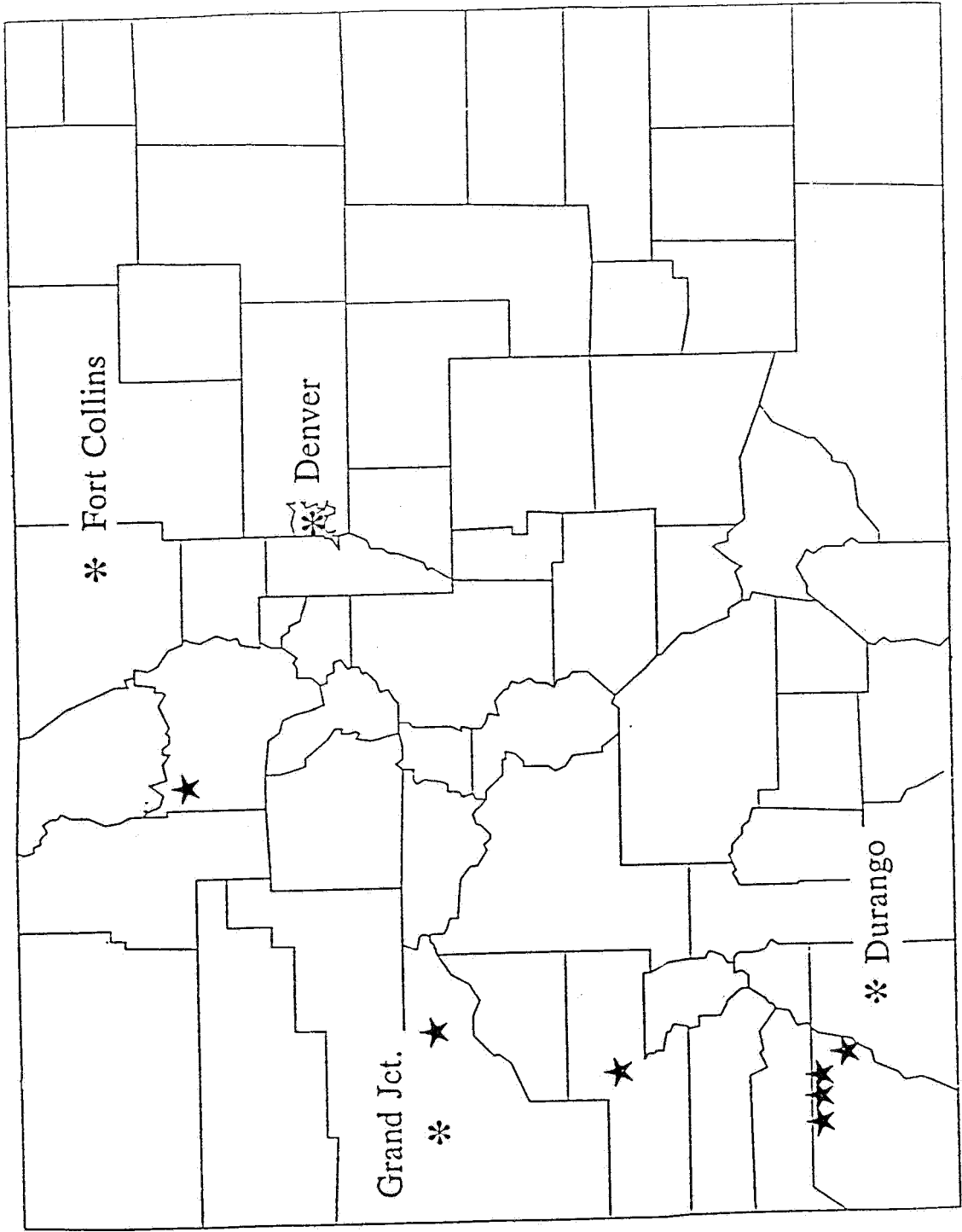


Figure 1. Aspen regeneration failure study site locations.

Table 1. Aspen regeneration failure study site location information.

Site ^a	Elevation (m)	Topo-map/ ^b Location	Slope	Aspect
San Juan Mancos Good	2877	Rampart Hills 12W37N9	10%	West
San Juan Mancos Poor	2987	Rampart Hills 12W37N10	8%	West
San Juan Stoner Mesa 64 Good	2853	Clyde Lake 12W40N36	14%	West
San Juan Stoner Mesa 64 Poor	2853	Clyde Lake 12W40N36	12%	North
San Juan Stoner Mesa 48 Good	2902	Clyde Lake 12W40N30	9%	Northwest
San Juan Stoner Mesa 48 Poor	2902	Clyde Lake 12W40N30	6%	Northwest
San Juan Stoner Mesa 45 Good	2926	Clyde Lake 12W40N29	4%	West
San Juan Stoner Mesa 45 Poor	2926	Clyde Lake 12W40N29	10%	Northwest
Uncompahgre Long Creek Good	2902	Ute 13W48N36	6%	Northeast
Uncompahgre Long Creek Poor	2902	Ute 13W48N36	3%	Northeast
Grand Mesa Cow camp Good	2955	Grand Mesa 94W11S9	18%	West
Grand Mesa Cow Camp Poor	2987	Grand Mesa 94W11S9	0%	N/A
Routt Carter Mountain Good	2816	Whiteley Peak 81W4N24	25%	East
Routt Carter Mountain Poor	2804	Whiteley Peak 81W4N24	10%	Southeast

^a Site - National forest, site name and aspen regeneration condition ^b Topo - map/location = name of 7.5 minute topographic map and range, township and section of plot location

Meteorological Factors: Meteorological data from National Weather Service stations near the research sites were analyzed to determine what environmental conditions occurred at the time of aspen sprout mortality. Meteorological data included April and May snow pack depths and water equivalent for 10 years prior to and including the year of aspen mortality, monthly mean, maximum and minimum temperatures, monthly total precipitation, 10 year moving average of mean monthly temperature and monthly Palmer drought index.

Soil Factors: One randomly located pit in each plot was used to describe the soil. Measurements included; depth of various horizons, depth to > 1% carbon, depth to maximum clay content, root size and distribution, percent pore space, percent clay, available water content, percent of particles > 2mm in diameter, and percent organic carbon.

To determine if one soil pit represented the variation in soil conditions across an entire plot, additional soil samples were collected by hand auger or tile spade. Two randomly located holes were sampled on each of the three subplots per plot. Samples were collected at 6 inch intervals to a 18-24 inch depth depending on where rocks interfered with digging. Particle fractionation was achieved by the Hydrometer Method (Klute, 1986). Percent sand, silt and clay along with the ratio of sand and silt to sand were analyzed at each location with a repeated measures analysis of variance, with subsampling.

To determine the degree of compaction, density readings of surface soil were taken on all study locations in 1990-91 using a CPN Corporation (CPN Corp 1985) Model MC-3 nuclear density/moisture meter. Areas affected by logging operations such as skidder tracks were avoided because they would not be representative of the site. Dry density values were calculated using one-minute gamma penetration and neutron back scatter counts taken at a depth of 0.3 m at three locations within 1.5 m of soil access tubes on all subplots.

Soil Hydrology: Neutron probes determined soil moisture at each subplot throughout two growing seasons (1991-92) at 15 cm intervals to a depth of 1.8 m. Nine soil-moisture access tubes were used on each plot with three per subplot. The data are best used as a means to look at changes over time and at differences between sites and not for absolute moisture values because no gravimetric standardizations were performed.

To determine if the water potential (drought stress) of currently growing trees differed between good and poor plots at a study site, predawn water potentials were obtained with a pressure bomb two to four times during the summer of 1991. Two aspen trees were used in each subplot for a total of 6 per plot. One leaf from two different branches of each tree was sampled for a total of 12 readings per plot.

Current Stand Conditions: To determine current health and status of aspen stands, three transects, 1 m wide were placed so they divided subplots into equal quarters. Data recorded in 1991 included numbers of trees. On the first 10 trees of each transect; height, diameter at 1.4 m, form, canker incidence, insect damage, physical damage including browsing, snow damage, trampling and mechanical wounds, foliar diseases, and root diseases were recorded. Age was determined at the ground line by ring counts of two trees. Two to 10 trees were cut near the subplots on each plot to provide samples for laboratory determination of radial growth patterns associated with the year of aspen mortality. Two radial measurements at right angles were used to produce average ring widths. Habitat types were assigned to each plot based on published keys (Hoffman and Alexander 1980, and Komarkova et al. 1988).

Previous Stand Conditions: To determine preharvest stand conditions, we recorded tree size, density and basal area on two-1 X 50 m transects placed at right angles to each other and intersecting at plot center. Stump numbers, species and diameters were recorded on each transect if half or more of the stump was within the 1 m wide strip. Twenty five aspen trees that remained of the original clone were measured for age at 1.4 m, and for diameters at stump height (15 cm) and at 1.4 m. These two diameters were used to develop a regression equation to estimate diameters at 1.4 m for stumps.

Results and Discussion

The occurrence of canker-induced aspen mortality was apparently related to excess soil moisture at four "wet" sites, drought stress at two "dry" sites and a combination of the two stresses at the Grand Mesa site. Predisposing stress at the four "wet" sites (three at the Stoner Mesa sites and one at Mancos), was probably caused by excess soil moisture from a late melting spring snow pack and cool temperatures the year of mortality. At the "dry" Uncompahgre and Carter Mountain sites, stress apparently resulted from a low spring snow pack that may not have fully charged the soil profile, followed by a summer drought the year of mortality. These meteorological events, mediated by subtle soil differences, predisposed aspen sprouts to infection by one or both canker fungi (*Dothiora polyspora* and *Cytospora chrysosperma*). Based on observation and isolation studies (Jacobi and Shepperd, 1991), two canker fungi (*Dothiora polyspora* and *Cytospora chrysosperma*) were the cause of mortality at three sites (Carter Mountain, Grand Mesa, Uncompahgre) and *Cytospora* canker was observed by other workers at the other four locations when mortality occurred. The following information supports these findings.

Meteorological: Snow pack (water equivalents) data provided the best measure of soil moisture status at the beginning of the growing season. A deep snow pack did not melt until early summer the year trees died at four "wet" sites because of an abnormally deep snow pack in May and below normal May- June temperatures (Table 2). The deep snow pack probably caused flooding and mortality of deeper roots, while trees

were leafing out. This root mortality probably resulted in drought stress later in the summer when roots were needed to extract moisture from deep within the soil profile. Drought stress predisposes trees to infection by canker fungi.

At the "dry" sites, April and May snow packs were low (Table 2) and summer droughts, as determined by Palmer Drought Index and precipitation data, probably stressed the aspen at the Carter Mountain and Uncompahgre sites. These stressed trees were predisposed to infection by the canker fungi.

Mortality at Grand Mesa appears to be related to wet conditions based on snow pack and Palmer Drought Index data and possibly drought stress based on reduced precipitation in July-September. Because mortality occurred here in 1987, the same year of drought stress at Carter Mt., we suspect wet conditions (high water table in the spring) followed by a late summer drought may be involved at Grand Mesa. Because of oxygen deprivation to roots, wet conditions at lower depths may have caused a shallow root system that could not provide moisture during the drought conditions of mid summer.

Table 2. Snow pack data for aspen regeneration failure study locations.

Location/Snow Stations ^a	Snow Pack Water Equivalents ^b in Year of Mortality			Average Water Equivalent			Years ^c
	April Inches	Probability %	May Inches	April Inches	May Inches	Years ^c	
Carter Mtn. (1987) Dry - Columbine Lodge - Willow Creek	15.7 9.4	5.9 13.0	1.7 4.9	24.8 12.8	22.6 11.6	60 58	
Grand Mesa (1987) - Park Reservoir	31.4	27.7	28.7	27.0	30.7	35	
Uncompahgre (1990) Dry - Columbine Pass	8.8	5.0	2.4	17.7	18.8	8	
Stoner Mesa (1983) Wet - Rico	9.8	25.0	5.9	7.3	1.3	57	
Mancos (1983) Wet - Mancos T-Down	26.6	31.0	N/A	21.5	15.7	11	

^a Site name and snow pack recording station names, year of sprout mortality and wet or dry site.

N/A = Data not available.

^b Snow pack water equivalents = amount of water in snow pack in April and May the year aspen mortality occurred. Probability is percent chance of this amount or greater amount of snow pack water equivalent occurring at the wet sites in any one year. For dry sites it is the percent chance of this amount of water equivalents or less in any one year.

^c years = number of years data available

Soil Factors: Each location had different soil conditions and soil hydrology. Thus, there were no consistent soil feature(s) that could explain all situations. In general, there were no major soil classification differences between good or poor areas with healthy or dead trees (Table 3). Subtle differences in soil conditions contributed to moisture excess or deficiency, though the entire stand was exposed to the same meteorological conditions. Soil parameters that indicated these subtle differences included, available water capacity, percent pore space, percent clay and percentage of particles greater than 2 mm (Table 3).

In general, at the four wet sites, areas with extensive tree mortality had soils with more clay (fewer macro pores) and less total pore space resulting in poor drainage compared to areas with limited mortality. Available water capacity did not seem to be related to the stress on these sites.

On dry sites (with drought-induced stress), extensive tree mortality occurred on soils with poor moisture holding capacity, or soils that were better drained based on percent pore space, percent clay, and percentage of particles greater than 2mm in diameter (Table 3). On the poor plot at Carter Mt., the reduced drainage at 2-4 ft (caused by lower pore space and higher clay content) combined with its position at the foot of a slope may have resulted in high water table. This high water table could cause root mortality and thus a shallow root system.

Table 3. Soil properties at aspen regeneration failure sites.

Study Location/ Meteorological Cond.	Shoot blight occurrence on both good and poor sites	Soil Type	Soil physical properties of poor site compared to good site.	Topographic features of poor site compared to good site
Carter Mountain Dry	Yes	Cryboroll	Less water holding capacity in upper layers	Bottom of slope vs mid slope
Uncompangre Dry	Yes	Cryboroll Poor had mottling	Slightly better drained	Similar
Grand Mesa Wet/Dry?	Yes	Poor=Cryboroll Good=Paleboroll	Slightly better drained	On top of bench vs mid slope
Stoner 45 Wet	Yes	Cryboroll	Slightly better drained. Has lateral water flow	Bottom of slope of large slump vs mid slope
Stoner 48 Wet	Yes	Poor=Cryboroll Good=Paleboroll	Slightly better drained. Has lateral water flow	No differences
Stoner 64 Wet	Yes	Poor=Paleboroll Good=Pachic Paleboroll	Less drainage in upper layers. Has lateral water flow.	No differences
Mancos Wet	Yes	Pachic Paleboroll	Less drainage in upper layers	Similar two miles apart

Topography also helped explain the stress on some sites such as Carter Mountain and Stoner 45 where the bottom slope location may have accentuated high soil moisture (Table 3).

We did not find any differences or relationships between the areas with or without mortality for the following factors; root size and vertical distribution, root depth, depth to 1% carbon, percent organic carbon and depth to maximum clay.

Soil Particle size: Soil texture was fairly uniform on each site, so the soil descriptions based on the one soil pit represented each site well. In only 6 of 42 cases were there significant differences between subplots within a plot in regard to percent sand, silt and clay.

Soil Hydrology: Each site had unique soil hydrology features, but in general the soil hydrology information supported the drought, flooding or combination theories of predisposing stresses (Table 4). On wet sites, percent soil moisture was significantly higher on the poor plots in the early season in the upper 24 inches of soil and throughout the season in the 25-48 inch profile. The wetter soils seem to support the idea that trees were flooded during a year of late melting snow pack. Soil moisture depletion rates (the rate soils dry out during the growing season) were significantly lower on the poor portions of wet sites for several weeks in early summer. rates on poor Depletion plots were unrelated to tree biomass, so the low depletion rates were apparently soil driven and not vegetation driven.

Table 4. Soil hydrology information from two growing seasons at aspen regeneration failure sites.

Study Location/ Meteorological Cond.	Percent Moisture 6-24 inch soil layer	Percent Moisture 25-48 inch soil layer	Depletion Rate 6-24 inch soil layer	Depletion Rate 25-48 inch soil layer
Carter Mountain Dry	No differences	No differences	No differences	Poor; significantly lower throughout season
Uncompahgre Dry	No differences	Poor; significantly higher throughout season	No differences	No differences
Grand Mesa Dry/Wet	No differences	No differences	No differences	No differences
Stoner 45 Wet	Poor; significantly higher in early season	Poor; significantly higher throughout season	Poor; significant. lower throughout season	Poor; significantly lower throughout season
Stoner 48 Wet	Poor; significantly higher in late season	Poor; significantly higher throughout season	Poor; significantly lower throughout season	Poor; significantly lower throughout season
Stoner 64 Wet	Poor; significantly higher in early season	Poor; significantly higher throughout season	No differences	Poor; significantly lower throughout season
Mancos Wet	Poor; significantly higher in early season	Poor; significantly higher throughout season	Poor; significantly lower throughout season	No differences

Previous Stand Condition: Unfortunately, it was not possible to predict which sites would have sprout mortality from previous stand characteristics. No significant differences occurred between good and poor plots on any site with regard to previous stand stem density, tree diameter or basal area. On all sites, shoot blight (*Pollaccia radiosa*) damage was noted in the year of mortality or the previous year so this damage may have produced infection sites for *Cytospora* and *Dothiora* fungi.

Current Tree/Stand Condition: No significant differences occurred between good and poor plots concerning habitat types, and water potentials of surviving trees. Habitat types at the study sites were *Abies bifolia*/*Carix geyeri*; *Populus tremuloides*/*Symphoricarpus oreophilus*; or *Populus tremuloides*/*Thalictrum fenderli*. All pressure bomb readings of current aspen trees were below 90 megapascals (Mpa) with most readings between 30 and 60 Mpa. Aspen trees are not predisposed to *Cytospora* infection below 100 Mpa (Guyon, 1993) so no currently growing trees were drought stressed.

Growth was significantly impacted in trees that survived on sites affected by late snow packs or droughts. Ring widths on surviving trees were significantly smaller the year mortality occurred. Trees on the poor sites at Stoner Mesa and Carter Mountain did not return to their premortality growth rate. Thus, two types of meteorological extremes apparently reduce growth and increase susceptibility to *C. chrysosperma*. Reduced

radial growth could result from root damage because of the drought or excess soil moisture conditions.

The average number of sprouts per square meter was 2.4 on good sites and 0.2 on poor sites. There were no significant differences in tree diameters, and heights between good and poor plots. Roots of the surviving sprouts on both good and poor plots were healthy and did not show root disease symptoms or signs.

Conclusions

We believe the following two scenarios explain the aspen regeneration failure at the seven study sites:

1. On wet sites, excess soil moisture from deep and late spring snow packs on poorly drained soils led to root mortality from the soil flooding, followed by drought in mid summer predisposing aspen trees to infection by canker pathogens.
2. On dry sites, drought conditions from low spring snow packs and reduced summer precipitation on soils with poor water holding capacity predisposed aspen to infection by canker pathogens. Additionally, at both the Carter Mountain and Uncompahgre sites, poor portions of the sites had soils with poor drainage at lower depths. At these latter two sites, shallow rooting induced by high water table combined with poor water holding capacity in the upper soil layer contributed to mid summer drought stress.

Predicting where mortality will occur is difficult. Previous stand characteristics and slope and site characteristics were not predictive and soil differences were only relative within a site. For example, there is no specific value of available water content of a soil that indicates the potential for drought. Forest managers are advised to avoid areas that are obviously at risk of having a high water table, such as at the bottom of slopes, wet swampy areas, or shallow soils in drought prone areas such as south facing slopes and low elevation sites.

Mortality of aspen regeneration will continue to occur in the region since late deep and low snow packs occur periodically. Based on 8-60 years of data near these seven study sites (Table 2) drought conditions occur at about 8% of the years and high and late snow packs occur about 26% of the years. Mortality predictions may be more feasible following extensive study of more sites with aspen regeneration failure and related meteorological data.

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