Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 255 (2008) 686–696
Forest Ecology and Management
www.elsevier.com/locate/foreco

Rapid mortality of *Populus tremuloides* in southwestern Colorado, USA

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Received 9 March 2007; received in revised form 3 June 2007; accepted 6 September 2007

Abstract

Concentrated patches of recent trembling aspen (*Populus tremuloides*) mortality covered 56,091 ha of Colorado forests in 2006. Mortality has progressed rapidly. Area affected increased 58% between 2005 and 2006 on the Mancos-Dolores Ranger District, San Juan National Forest, where it equaled nearly 10% of the aspen cover type. In four stands that were measured twice, incidence of mortality increased from 7–9% in 2002/2003 to 31–60% in 2006. Mortality generally decreased with increasing elevation over the primary elevation range of aspen and occurred on less steep slopes than healthy aspen. Slope-weighted mean aspects of aspen cover type were northern at low elevations and generally southern at high elevations. Relative frequency of mortality was generally highest on southern to western aspects. In 31 stands measured in detail, mortality ranged from 0 to 100% (mean 32%) and was negatively correlated with stand density ($P = 0.033$). Size of trees affected was strongly correlated with amount of current mortality ($P < 0.001$), and current mortality was skewed toward larger diameter classes. Density of regeneration was in a low range typical of undisturbed stands and did not increase with overstory mortality.

Agents that typically kill mature trees in aspen stands were unimportant in this mortality. Instead, a group of interchangeable, usually secondary agents was most commonly associated with mortality, including Cytospora canker (usually caused by *Valsa sordida*), aspen bark beetles (*Trypophloeus populi* and *Procryphalus mucronatus*), poplar borer (*Saperda calcarata*), and bronze poplar borer (*Agrilus liragus*). The rapidity of mortality, mortality agents involved, and probably other causal factors distinguish this phenomenon from the long-term loss of aspen cover usually attributed to successional processes operating in an altered disturbance regime (and often exacerbated by ungulate browsing). Our data are consistent with a hypothesis that (a) predisposing factors include stand maturation, low density, southern aspects and low elevations; (b) a major inciting factor was the recent, acute drought accompanied by high temperatures, and; (c) contributing factors and proximate agents of mortality are the common biotic agents observed. On sites with poor regeneration and weak root systems, clones may die, resulting in the long-term loss of aspen forest cover.
Published by Elsevier B.V.

Keywords: Disturbance; Decline; Dieback

1. Introduction

Rapid mortality of trembling aspen (*Populus tremuloides*) has been reported from multiple locales in southwestern Colorado by varied observers since 2004. The suddenness and synchronicity of the phenomenon are striking in the context of stand-level mortality processes that are typically observed in aspen. Adding to the concern, regeneration appears to be sparse in many stands with heavy overstory mortality.

Studies of unusual aspen mortality in the past have revealed varied patterns and have been attributed to a number of causes. During the 1970s, widespread deterioration of aspen in the Great Lakes region was primarily attributed to high mean annual temperature (Shields and Bockheim, 1981). Stands with open canopy often deteriorated rapidly because they had increased exposure of the forest floor to sun and wind and increased moisture loss (Fralish, 1975). Most stands had established in the early 20th century due to widespread cutting and fire, so many stands were mature and thus susceptible to such damage. Clonal

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0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2007.09.071

differences were also implicated in susceptibility (Shields and Bockheim, 1981). Deterioration was interpreted by some as part of a successional process, returning composition to shade-tolerant, presettlement species (Fralish, 1975).

Also in the early 1970s, widespread deterioration of aspen was noted in the inland west, particularly in Utah and western Wyoming (Krebill, 1972; Loope and Gruell, 1972; Schier, 1975). Causes were considered to be fire exclusion, which allowed maturation of aspen stands established at the time of settlement, along with increased susceptibility to diseases and insects that accompanies maturation. However, concern encompassed not only mortality of ramets, but poor suckering. Suckering beneath deteriorating overstories was a fraction of that in healthy stands and was often insufficient to replace the mortality. Deteriorating aspen clones were often replaced by conifers or meadows. Heavy browsing by elk hastened the transition in some areas (Loope and Gruell, 1972; Ripple and Larsen, 2000). Root systems regressed in deteriorating stands, surviving primarily near the residual live stems (Schier, 1975). In southern Utah, deteriorating aspen stands had lower root densities than adjoining healthy stands (Shepperd et al., 2001), and suckering was suppressed by apical dominance of residual stems over the smaller root systems (Schier, 1975; Schier and Campbell, 1980). As in the Great Lakes region, observations suggested that genotype was an important factor determining which clones deteriorated. This ongoing deterioration of aspen stands and decrease in area of the cover type, due to vegetation succession under altered disturbance regimes and often exacerbated by ungulate browsing, has been termed ‘‘aspen decline’’ (e.g., Ripple and Larsen, 2000; Kulakowski et al., 2004; Kaye et al., 2005).

More recently, similar dieback, growth loss and mortality of aspen began in the 1980s or early 1990s in the prairie provinces of Canada, especially the aspen parkland and southern boreal forest of Alberta and Saskatchewan (Brandt et al., 2003; Frey et al., 2004; Hogg et al., 2005). Mortality is associated with dual stresses of drought and insect defoliation followed by secondary wood-boring insects and diseases. Continuing degradation of those aspen forests is anticipated under a warmer and drier climate. Unusually high rates of aspen mortality have also been observed recently in northern Arizona (M.L. Fairweather, personal communication) and in southern Utah and Montana (W.D. Shepperd, unpublished observations).

Our purpose in this report is to describe recent aspen mortality in southwestern Colorado, assess related landscape-scale and stand-level characteristics, and to develop a hypothesis as to the cause.

The southern Rocky Mountains of Colorado rise from arid, treeless deserts and plains at 1500–1700 m to peaks as high as 4400 m. Due to orographic and adiabatic processes, precipitation generally increases and mean temperature decreases as elevation increases. Most tree species have a broad band of elevation where these and related conditions are suitable for growth. Aspen occurs generally in the range 2100–3300 m in southwestern Colorado. Annual precipitation in the aspen forests ranges from approximately 38 to 110 cm, depending on elevation and local weather patterns. Because a species' lower elevation range may be determined by moisture limitation, periods of drought and warm temperature may have their greatest impact at low elevations. Moisture availability and tree distribution also vary with aspect, because intense solar radiation on southern and southwestern aspects greatly increases temperature and evapotranspiration.

2. Materials and methods

2.1. Aerial survey

Aerial survey, also known as aerial sketch-mapping, is a remote sensing technique of observing forest damage events from an aircraft and documenting them manually onto a base map. Aerial surveys were conducted over most forested areas of Colorado in high-winged aircraft flying between 150 and 600 m above ground. Aerial observers delineated declining aspen polygons onto computer touch screens incorporating a moving map display, which is referenced to the aircraft's location using global positioning system data. Base maps included United States Geological Survey (USGS) 1:100,000 scale topographic series digital raster graphs and USGS digital orthographic quarter quadrangles. The 2006 aerial survey of Colorado was conducted from 10 July through 26 September. The southwestern part of the state, where our analysis was focussed, was surveyed mostly in September, but the Gunnison National Forest was surveyed in late July.

The aerial signature of ‘‘aspen decline’’ ranges from a general lack of foliage representing groups of dead trees to areas with considerable dieback of tree branches. Because observers look for generally foliage-free aspen stands, it is fairly easy to discern this signature from other aspen stressors such as insect defoliation or frost damage, where foliage is often thin yet still present.

2.2. Analysis of geographic data

Within the boundaries of four national forests of southwestern Colorado, we generated a healthy aspen layer by clipping an aspen cover type layer with the damage polygons from the aerial survey. We used these layers to calculate the percentage of the cover type affected on these national forests and to compare Digital Elevation Model (DEM) and other data between healthy and damaged aspen. Aspen cover type is defined as forest in which aspen is the leading species in crown cover (*Picea engelmannii* and *Abies bifolia* are lumped together for this calculation).

Elevation, slope and aspect were calculated using DEM data with resolution of 3 arc-seconds (approximately 72 m × 92 m). A 30 m × 30 m grid of points was created, associated with data of the DEM cell in which they occurred, and the points that fell within polygons of interest were used as variates for analysis and frequency distributions. Slope was calculated as a simple mean and standard error of percent slope. Cover-type elevation was represented as means with frequency diagrams to indicate the distribution around the mean. Proportion of cover type affected was calculated in the same elevation classes. Aspect