USING INVENTORY DATA TO DETERMINE THE IMPACT OF DROUGHT ON TREE MORTALITY

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ABSTRACT

Drought has been the subject of numerous recent studies that hint at an acceleration of tree mortality due to climate change. In particular, a recent global survey of tree mortality events implicates drought as the cause of quaking aspen mortality in Minnesota, USA in 2007. In this study, data from the Forest Inventory and Analysis program of the USDA Forest Service were analyzed for the period 2000-2009. The fate of individual trees was tracked on a 5-year return interval and the proportion of trees that died was examined in relation to the Palmer Drought Severity Index for the same time period. Quaking aspen mortality increased in northeastern Minnesota over the study period but was stable in north-central Minnesota. The rate of quaking aspen mortality was found to be significantly higher than the mortality rate of all tree species combined in northeastern Minnesota in recent remeasurement periods. Aspen mortality cannot be conclusively attributed to drought without further analysis of contributing factors. While anecdotal observations of small-scale mortality have been cited as evidence of climate-change-induced mortality in other studies, the results of this study suggest further exploration of statistical models for apportionment of inciting, predisposing, and contributing tree mortality factors.

INTRODUCTION

Coincident with the growing concern of climate change effects on ecosystems, the impact of drought on tree mortality has become a topic of interest in both popular and academic literature. Moisture deficiency and increased temperature were linked by van Mantgem et al. (2009) to substantial increases in tree mortality across the western United States, and the story was subsequently reported in popular media outlets (e.g., Boxall 2009). Rapid mortality of quaking aspen (*Populus tremuloides*) has been reported in the western United States (Worrall et al. 2008) and Canada (Hogg et al. 2008) with drought implicated as the cause.

While the aforementioned studies relied on direct observation of mortality at a small number of field sites, some alternative approaches have been pursued. Rehfeldt et al. (2009) used presence/absence data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program to construct a bioclimatic model for the distribution of aspen. The model predicted the current range with only 4.5 percent error for 15,500 observations and allowed for predictions of range shifts (via mortality) under climate change scenarios. A self-identified first global survey of drought-induced tree mortality was developed by analyzing reports from around the world that link tree die-off to local drought conditions (Allen et al. 2010); the implication of this global drought survey is that mortality is increasing in response to global warming.

One of the mortality events attributed to drought by Allen et al. (2010) is the die-off of quaking aspen in northern Minnesota as reported by the Minnesota Department of Natural Resources (2007). It should be noted the report actually states the cause is "unknown," and later reports stated 30,000 acres of quaking aspen had perished from 2004 to 2009 indicating drought likely predisposed trees to attacks by secondary pests (Minnesota Department of Natural Resources 2009). The observations of mortality were derived partly from on-the-ground anecdotal observations and partly from aerial sketch mapping. Given emerging studies that suggest large-scale tree mortality events may be climate-change related, the purpose of this study was to objectively examine the evidence for drought-induced aspen mortality in northern Minnesota using FIA data.

METHODS

The area of investigation was limited to north-central (Climate Division 2) and northeastern (Climate Division 3) Minnesota in which severe drought occurred in 2006 and 2007. Climate Divisions in Minnesota are aggregations of counties with similar weather conditions (www.esrl.noaa.gov/psd/data/usclimate/map.html).

Individual tree data collected by FIA from 2000 to 2008 were analyzed. Because FIA revisited locations in Minnesota on a 5-year remeasurement interval, the status of individual trees was tracked over time (survived, died, or harvested). For the period analyzed, this approach resulted in six unique re-measurement intervals (2000-2004, 2001-

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2005, 2002-2006, 2003-2007, 2004-2008, 2005-2009). The FIA database contained information for 1,764 quaking aspen trees and 3,494 total trees in the study area. In addition to the status of individual trees, other attributes were examined such as diameter at breast height (d.b.h.) and age.

Monthly averages of Palmer Drought Severity Index (PDSI) data were acquired from the National Oceanic Atmospheric Administration's National Climatic Data Center. Data are available from 1895 to the present and are reported by climate division. Hurst rescaling was applied to time series of PDSI using the method of Outcalt et al. (1997). The rescaled PDSI simplifies interpretation and provides additional information regarding long-term drought trends.

RESULTS AND DISCUSSION

For north-central Minnesota (Climate Division 2), no statistically significant difference was found in the proportion of quaking aspen trees that experienced mortality across the six overlapping time intervals (Figure 1). For northeastern Minnesota (Climate Division 3), quaking aspen mortality observed for the 2005-2009 time period was significantly higher than the mortality observed in the 2001-2005 time period (Figure 2). Quaking aspen mortality was not significantly different than the mortality of all tree species combined for five out of six time periods in Climate Division 2, but was higher for the four most recent time periods in Climate Division 3. The drought experienced in Climate Division 3 was more prolonged than Climate Division 2 since 2001 (Figure 3) and could have contributed to the increase in aspen mortality with time. Without more information, it is impossible to determine whether quaking aspen trees have been disproportionately affected by drought in Climate Division 3 or if the higher mortality relative to other species is a natural result of successional trajectories and stand age. Given the history of forest harvest activities across the Minnesota, one might expect numerous stands in northern Minnesota to be in latter stages of stand development and predisposed to density and age-related tree mortality.

This study represents a preliminary examination of drought-induced mortality using FIA data, and a variety of challenges in linking drought to mortality were uncovered. Due to the 5-year FIA re measurement interval, it will be difficult to attribute a single-year drought event to an increase in mortality. That is, for each dead tree, the exact year of mortality cannot be determined. There are also scale issues that must be overcome. Many of the mortality events cataloged by Allen et al. (2010) were described as patchy, and the intensity of the FIA grid may not be well suited to such observations.

Perhaps the larger question is this: what is the correct way to link drought to tree mortality? There is a tendency in drought studies to use correspondence or correlation between the location of drought events and subsequent die off of trees as proof of causality. For example, if one examines Figure 2 and Figure 3 together, there appears to be a correspondence between increased aspen mortality and the prolonged drought of 2006-2007 in Climate Division 3. This correspondence does not prove causality, and it is generally accepted in the forestry community that drought is part of a complex that leads to mortality (as described by the decline spiral model, Manion 1991). At a minimum, an attempt should be made to eliminate other possible causes such as the age of the trees, other damage agents, or poor site quality. Future work should focus on development of statistical models to apportion the explanatory power of inciting, predisposing, and contributing factors that lead to mortality.

If establishing a causal link between a drought event and increased tree mortality requires more than correlation, the same standard should apply to attributing shifts in the drought/mortality cycle to climate change. Kampen (2010) elaborates on the shortfalls of correlational research and points out that models that verify or falsify can be misleading when feedback mechanisms exist and are not well understood.

CONCLUSIONS

Given extensive speculation that future climate change may result in widespread tree mortality, it may be ever more important to accurately establish causality between contemporary tree mortality and climatic events such as droughts. Erroneously attributing contemporary tree mortality to large-scale climatic events, rather than pursuing a better understanding of the host of factors involved, is likely to result in poor predictions for changing climatic conditions. This study found inconclusive evidence of increased quaking aspen tree mortality in Minnesota due to a long-term drought using large-scale inventory data, while anecdotal observations of small-scale mortality have been cited as evidence of climate-change-induced mortality. It is suggested that future studies explore statistical models for apportionment of inciting, predisposing, and contributing tree mortality factors.

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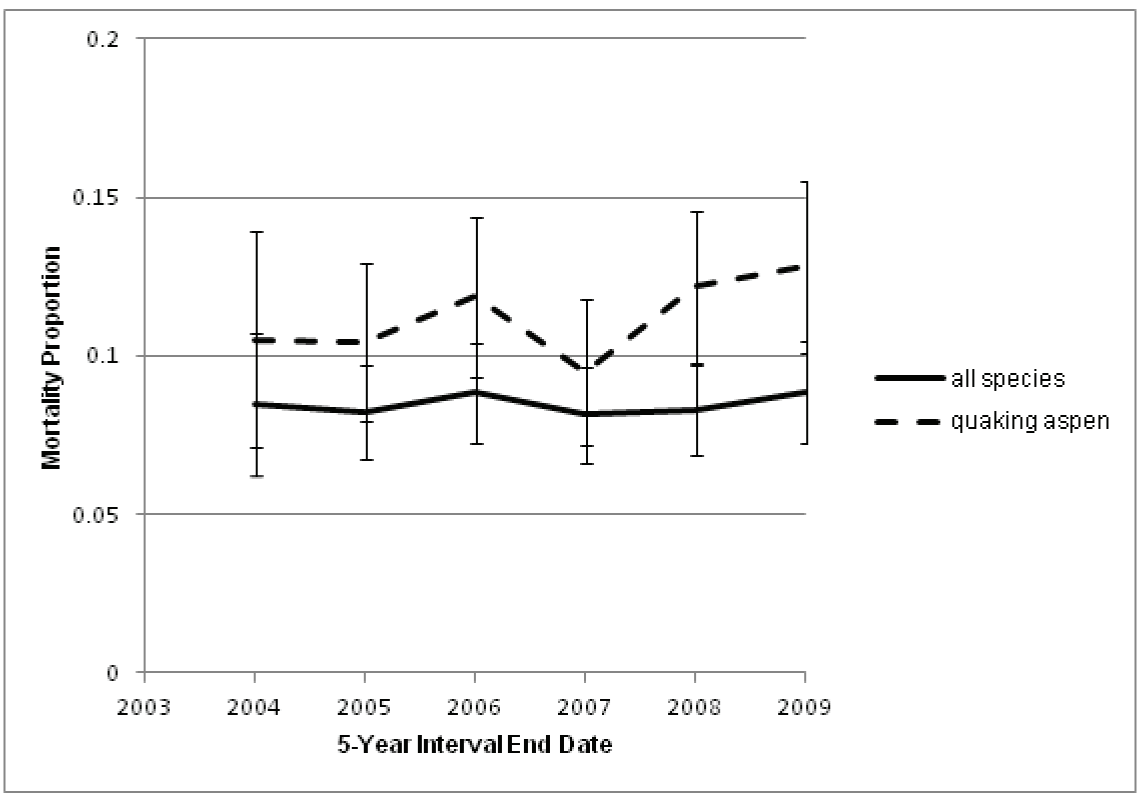

Figure 1—Proportion of trees that died in Climate Division 2 in Minnesota, USA. Trees were revisited on a 5-year interval, and the end year of the interval is depicted on the horizontal axis. Error bars represent the standard error for a sample proportion.

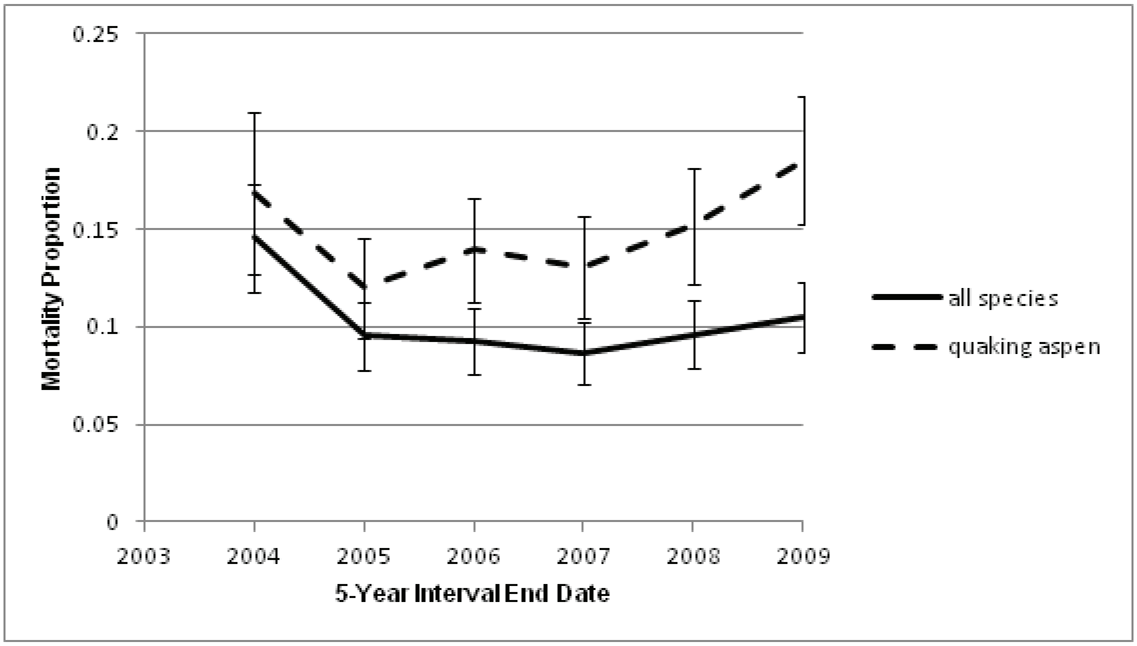

Figure 2—Proportion of trees that died in Climate Division 3 in Minnesota, USA. Trees were revisited on a 5-year interval, and the end year of the interval is depicted on the horizontal axis. Error bars represent the standard error for a sample proportion.

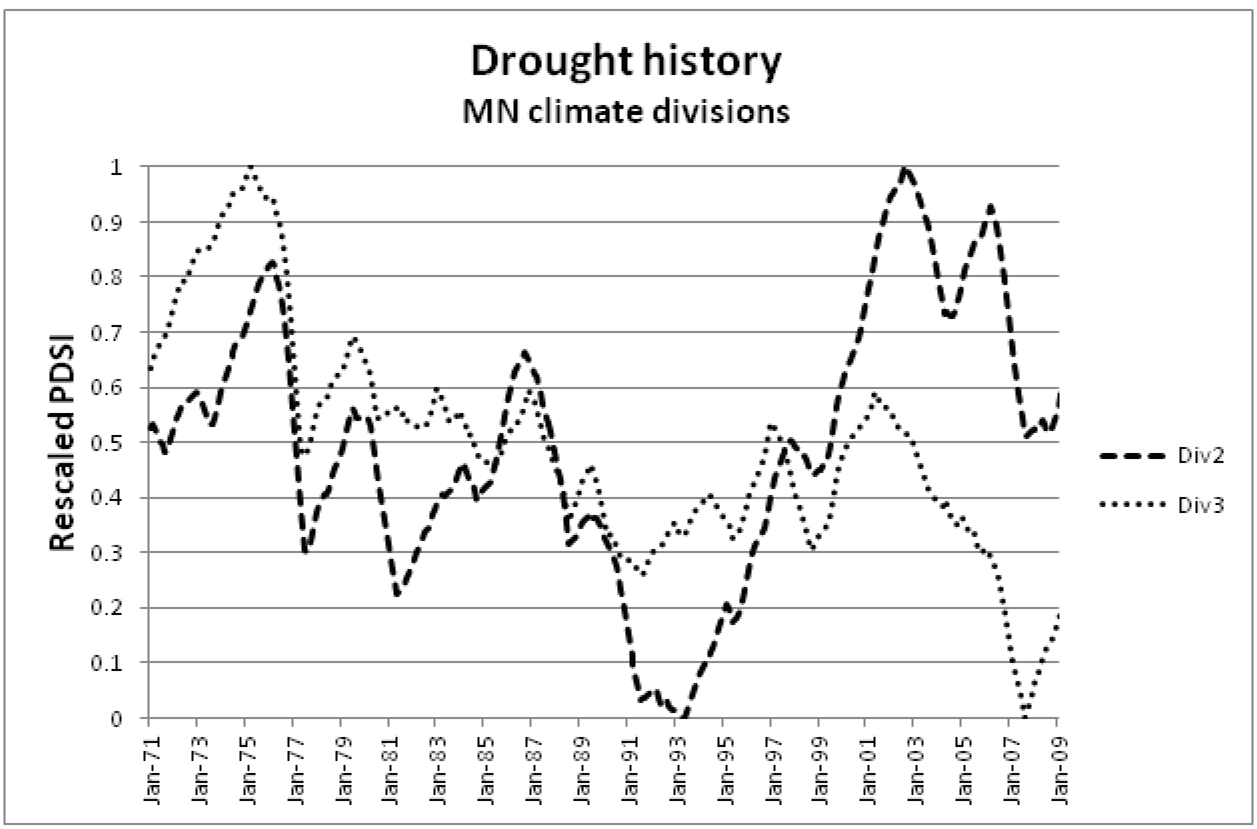

Figure 3—Drought as measured by the Palmer Drought Severity Index from 1971-2009 for Climate Divisions 2 and 3 in Minnesota, USA. Values have been transformed using Hurst rescaling such that positive slopes indicate a change from dryer to wetter conditions and negative slopes indicate a change from wetter to drier conditions. Climate Division 3 experienced its driest condition of the period in 2007 after a sustained shift toward drier conditions that began in 2001.