Journal of Environmental Management 149 (2015) 157–167

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Changes in winter conditions impact forest management in north temperate forests

Chadwick D. Rittenhouse [a], [b], [*], Adena R. Rissman [a]

[a] Department of Forest and Wildlife Ecology, University of Wisconsin–Madison, 1630 Linden Drive, Madison, WI 53706, USA
[b] Wildlife and Fisheries Conservation Center, Department of Natural Resources and the Environment, University of Connecticut, 1376 Storrs Road Unit 4087, Storrs, CT 06269-4087, USA

ARTICLE INFO

Article history:
Received 16 January 2014
Received in revised form
29 September 2014
Accepted 13 October 2014
Available online

Keywords:
Climate change impacts
Forestry
Adaptation
Multiple stressors

ABSTRACT

Climate change may impact forest management activities with important implications for forest ecosystems. However, most climate change research on forests has focused on climate-driven shifts in species ranges, forest carbon, and hydrology. To examine how climate change may alter timber harvesting and forest operations in north temperate forests, we asked: 1) How have winter conditions changed over the past 60 years? 2) Have changes in winter weather altered timber harvest patterns on public forestlands? 3) What are the implications of changes in winter weather conditions for timber harvest operations in the context of the economic, ecological, and social goals of forest management? Using meteorological information from Climate Data Online and Autoregressive Integrated Moving Average (ARIMA) models we document substantial changes in winter conditions in Wisconsin, including a two- to three-week shortening of frozen ground conditions from 1948 to 2012. Increases in minimum and mean soil temperatures were spatially heterogeneous. Analysis of timber harvest records identified a shift toward greater harvest of jack pine and red pine and less harvest of aspen, black spruce, hemlock, red maple, and white spruce in years with less frozen ground or snow duration. Interviews suggested that frozen ground is a mediating condition that enables low-impact timber harvesting. Climate change may alter frozen ground conditions with complex implications for forest management.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Based on global climate change models, studies at global and regional scales anticipate that changes in temperature and precipitation will affect supporting and regulating services of forest ecosystems, including carbon sequestration and storage potential (van Mantgem et al., 2009; Yvon-Durocher et al., 2010), climate regulation (Foley et al., 2007), and hydrology (Meyer et al., 1999; Stewart, 2013). Studies of provisioning services of forest ecosystems have largely focused on anticipated changes in timber supply through species range shifts (Iverson and Prasad, 1998) and changes in vegetation growth and length of growing seasons (Saxe et al., 2001; Tullus et al., 2012), atmospheric CO_2 concentrations (Norby et al., 1999; Hyvönen et al., 2007), disturbance regimes (Dale et al., 2001), and invasive plants, insect and disease dynamics Ayers and Lombardero 2000, Dukes et al., 2009). Less well studied are the impacts of climate change on forest operations, including changing access to stands, timing of harvest and transport, and selection of forests for harvest based on operability (Spittlehouse, 2005; Ogden and Innes, 2007; Gauthier et al., 2014). Changes in provisioning services due to climate change may also have interacting effects on supporting and regulating services (Alig et al., 2002). The dynamic interactions of humans and their environments, at local to global scales, produce these interrelated effects (Chapin et al., 2006).

Climate change portends changes in the timing, frequency, duration, and intensity of weather events. When assessing impacts, vulnerabilities, and adaptations, researchers often cannot discern a priori which climate change impacts produce vulnerabilities of greatest concern to communities of interest. Therefore a participatory process is needed to define vulnerabilities, narrow into the most relevant impacts and vulnerabilities, and examine related adaptations (Smit and Wandel, 2006). This process led us to focus on winter weather and frozen ground conditions, which are not widely discussed in the literature on forest management and

---

[*] Corresponding author. Wildlife and Fisheries Conservation Center, Department of Natural Resources and the Environment, University of Connecticut, 1376 Storrs Road Unit 4087, Storrs, CT 06269-4087, USA. Tel.: +1 860 4860335; fax: +1 860 4865408.

E-mail address: chadwick.rittenhouse@uconn.edu (C.D. Rittenhouse).

http://dx.doi.org/10.1016/j.jenvman.2014.10.010
0301-4797/© 2014 Elsevier Ltd. All rights reserved.

climate change (Spittlehouse, 2005) despite anticipated changes in winter temperatures, precipitation type, extent of snow cover, and snow depth.

The majority of temperate forests are managed for timber and non-timber forest products (Food and Agriculture Organization, 2010). In north-temperate regions, winter weather conditions are primary factors affecting forest operations, including the ability to access sites, harvest within sites, and transport equipment and products away from sites. Reduced access to timber on wet, unfrozen soils is expected to threaten the forest industry (Lindner et al., 2010). Forest operations conducted on partially frozen or thawed soils can cause rutting and soil compaction (Stone, 2002), which have long-term impacts on soil productivity (Corns, 1988; Grigal, 2000). While local meteorological records indicate a trend toward warmer winters in the north-central United States (Serbin and Kucharik, 2009; Kucharik et al., 2010; Sinha et al., 2010), the effects on frozen ground conditions depend on several factors. Snow insulates soils from cold air temperatures in winter, so reduced snow in the absence of temperature change can result in greater depth of frozen soil (Groffman et al., 2001, 2011). However, empirical observations from Canada indicate that warmer winters and reduced snow depth result in fewer soil freezing days (Henry, 2008; Sinha and Cherkauer, 2008). Reduction in albedo leads to increased absorption of solar energy and hence warming of exposed soils (Chapin et al., 2000), as does increases in winter temperatures (Mellander et al., 2007). We were particularly interested in trends over time in duration and variability in frozen ground conditions.

This research aims to document climate impacts on forest management and contextualize those impacts with an assessment of multiple goals and stressors. We asked: 1) How have winter conditions changed over the past 60 years? 2) Have changes in winter weather altered timber harvest patterns on public forestlands? 3) What are the implications of changes in winter weather conditions for timber harvest operations in the balance of economic, ecological, and social goals of forest management? To answer our questions we first quantified changes in winter conditions. We then associated changes in winter conditions with tree harvest amounts. Finally, we examined the context of climate change impacts based on document analysis and interviews with forest managers. We focus on Wisconsin, the United States' leading producer of paper products.

2. Methods

We used a mixed-methods approach to link quantitative evidence of trends with rich contextual description of the drivers and implications of these trends (Johnson and Onwuegbuzie, 2004). Our mixed-methods analysis combined historical analysis of climate data and timber harvesting trends with qualitative interviews that provided context and meaning for changes in winter conditions. Wisconsin's north and eastern temperate forests support a \$20 billion timber industry. Loggers secure contracts to harvest timber on public and private lands, and most contracts provide a two-year period for conducting harvests, so loggers have some flexibility in determining what to harvest at any time. Logs and chips are then transported to mills; one study in this region estimated a 240 km mean round trip distance, of which 3% was on private logging roads including unpaved forest roads, 16% was on minor county roads, and 81% was on major state roads (Stewart et al., 2012). Sustainable harvests are encouraged through government policy and nongovernmental certification programs. For instance, loggers are encouraged to follow Best Management Practices for water quality. County and state forests and private lands enrolled in the forest tax program are certified by the Sustainable Forestry Initiative (SFI) and/or Forest Stewardship Council (FSC).

2.1. Historical analysis of winter conditions, 1948–2012

We obtained meteorological records for eight weather stations in Wisconsin (Fig. 1; Supplementary material, Appendix 1) from Climate Data Online provided by the National Climatic Data Center, National Oceanic and Atmospheric Administration. All stations in the analysis had nearly complete daily records and at least 60 years of continuous observations. The meteorological records consisted of daily records of maximum air temperature (Tmax; °C), minimum air temperature (Tmin; °C), precipitation amount (Prec; mm), snowfall amount (Snow; mm), and snow depth (Snwd; mm). From those weather observations, we calculated the daily mean air temperatures:

$$T\text{mean}_i = \frac{(T\text{max}_i - T\text{min}_i)}{2} \tag{1}$$

for each day i. We then calculated an 11-day running mean (Trun) of the daily mean air temperatures for each day where the mean for day 11 was the mean value of daily mean air temperature for the 11 days from day (i−10) to day i. Values of Trun on the first 10 days were calculated using 1-day to 10-day running means respectively. We estimated daily soil temperature (Ts) at 10-cm depth (Zheng et al., 1993):

$$T\text{s} = 0.78 \times T\text{run}_i + 2.87 \tag{2}$$

where $T\text{run}_i$ was an 11-day mean of daily mean air temperature.

We considered the soil frozen if the soil temperature at 10-cm depth was ≤ 0 °C. This depth of soil freezing approximated the point between being able to operate lighter logging equipment ($\geq$7.5 cm frozen soil) vs. heavier logging equipment ($\geq$15 cm frozen soil; Stone, 2002). We then adjusted Ts based on presence (Snwd > 0 mm; Eq. (3)) or absence (Snwd $= 0$ mm; Eq. (4)) of snow cover:

$$T\text{sa} = [(T\text{avg}_i - T\text{avg}_{i-1}) \times M_1] + T\text{s}_{i-1} \tag{3}$$

$$T\text{sa} = [(T\text{avg}_i - T\text{avg}_{i-1}) \times M_2] + T\text{s}_i \tag{4}$$

where $M_1 = 0.1$ and $M_2 = 0.25$ were constant scalers derived from regressing Trun against observed soil temperatures (Zheng et al., 1993). We applied these equations to weather information obtained from airport locations with little or no topographic relief. Local forest soil conditions are influenced by soil type, topography, subsurface water dynamics, and vegetative cover, which can impact the onset, depth, and duration of frozen soil. Thus, we considered the soil temperatures obtained in Eqs. (3) and (4) as estimates of local forest soil conditions and not observed values.

We calculated several metrics of changes in winter conditions for each winter season, defined as November 1 to April 30 (Table 1). These metrics included frozen ground days (Tsa $\leq$ 0 C), thawed ground days (Tsa $>$ 0 C), soil temperature, and snow melt. To analyze each time series of winter conditions, we fit Autoregressive Integrated Moving Average (ARIMA) models (Box and Jenkins, 1976). ARIMA models decompose a time series into trend and irregular components, while accounting for potential correlations in the irregular component. Specifically, an ARIMA (p,d,q) model, specifies an autoregressive model of order p, a moving average model of order q, or a mixed model with p and q greater than 0. ARIMA models assume constant mean and variance over time (i.e., a stationary time series) so time series were differenced d times to

Download English Version:

https://daneshyari.com/en/article/7483211

Download Persian Version:

https://daneshyari.com/article/7483211

Daneshyari.com