A case of extensive conifer needle browning in northwestern Ontario in 2012: Winter drying or freezing damage?

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ABSTRACT

In the spring of 2012, conifers in a large area in northwestern Ontario exhibited severe needle browning prior to budbreak, affecting more than 250 000 ha of forests north and west of Thunder Bay. Examination of weather data suggests that damage was caused by a combination of warm temperatures in March resulting in dehardening followed by freezing temperatures in April that were below a critical value. Damage was similar in nature to that observed in 2007 in northeastern Ontario, but in this case occurred earlier in the year and affected a larger area. Areas of northern Ontario where trees were affected were easily separated from those where no damage was observed using daily minimum temperature and cumulative growing degree day data. We suggest that a new term, *winter freezing damage*, be used to describe conifer needle and bud damage prior to budbreak when a period of warm temperatures in late winter/early spring followed by a period of sufficiently cold freezing temperatures causes damage to forest stands.

Keywords: conifer winter damage, mature needle and bud mortality, late March warming, early dehardening, freezing

RÉSUMÉ

Au printemps 2012, les conifères d'une grande partie du nord-ouest de l'Ontario montraient un brunissement important de leurs aiguilles avant le débourrement printanier, et ce sur plus de 250 000 ha de forêts situées au nord et à l'ouest de Thunder Bay. L'étude des données météorologiques indique que les dommages ont été provoqués par une combinaison de températures chaudes au cours du mois de mars qui ont interrompu la dormance, suivies de températures très froides en avril, inférieures au seuil critique. Les dommages étaient de même nature que ceux observés en 2007 dans le nord-est de l'Ontario, mais qui étaient survenus plus tôt dans la saison, affectant une plus grande étendue. Les secteurs du nord de l'Ontario où les arbres ont subi des dommages se distinguaient clairement de ceux sans dommage apparent sur la base des données de température minimale moyenne et des degrés-jours de croissance accumulés. Nous suggérons d'utiliser le néologisme « *dommage de gel hivernal* » pour décrire les dommages aux aiguilles et aux bourgeons de conifères survenant avant le débourrement lorsqu'un redoux suivi d'une période de températures sous le point de congélation survient à la fin de l'hiver ou au début du printemps, provoquant des dommages aux peuplements forestiers.

Mots clés : dommage de gel hivernal, aiguille mature et mortalité du bourgeon, réchauffement hâtif de mars, interruption hâtive de la dormance, gel

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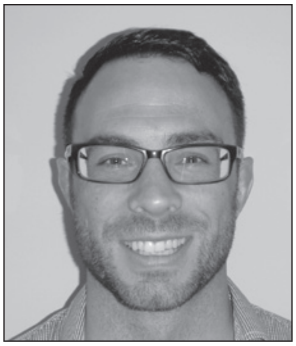

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Description of Conifer Browning

In the spring of 2012, severe needle browning (i.e., needle death) developed in jack pine (*Pinus banksiana* Lamb.) (Fig. 1, Fig. 2, and Fig. 3), white spruce (*Picea glauca* [Moench] Voss) (Fig. 4), balsam fir (*Abies balsamea* [L.] Mill.) (Fig. 5), and black spruce (*Picea mariana* [Mill.] BSP) stands in a large area of northwestern Ontario. Affected trees were mostly young conifers between 5 and 25 years old, but in some areas mature overstory trees were also damaged. Among species, white spruce and balsam fir sustained the most damage and black spruce the least. Damage was first noticed prior to budbreak during late April and early May 2012 by the discoloration of needles on affected trees. Obvious effects on deciduous trees were not observed, except on tamarack (*Larix laricina* [Du Roi] K. Loch) where buds only flushed on branches in the lower part of the trees (Fig. 6).

Aerial surveys conducted by Ontario Ministry of Natural Resources' Inventory, Monitoring, and Assessment staff in mid-May showed that damage occurred mostly in a 200 × 300 km area from Geraldton in the east, to Gull Bay in the north, and Ignace in the west (Fig. 7). About 60 000 ha of forest exhibited light damage, with 10% to 25% of the trees in the area affected, and about 190 000 ha had severe damage, with more than 25% (and up to 100%) of the trees damaged.

Fig. 1. Aerial view of damaged jack pine plantations established in 1998, 15 km west of Upsala, Ontario (photo taken by Dennis Bonner on May 10, 2012).

Fig. 2. Ground view of damaged jack pine planted in 1995, 13 km southwest of Upsala, Ontario (photo taken by Ricardo Velasquez on June 13, 2012).

Fig. 3. The branches and needles that remained unaffected (green) would have been under snow cover (photo taken on April 25, 2012).

Fig. 4. White spruce saplings showing signs of damage (photo taken by Tyler Straight on May 6, 2012 near Kaministiquia, Ontario).

Fig. 5. Affected balsam fir sapling (photo taken by Tyler Straight on May 22, 2012 at about 100 km north of Thunder Bay, Ontario).

Fig. 6. Affected tamarack in which only the buds in the lower crown flushed, possibly due to having been under snow cover during a late winter thaw-freezing (photo taken by Tyler Straight on May 9, 2012 near Pakashkan Lake, Ontario).

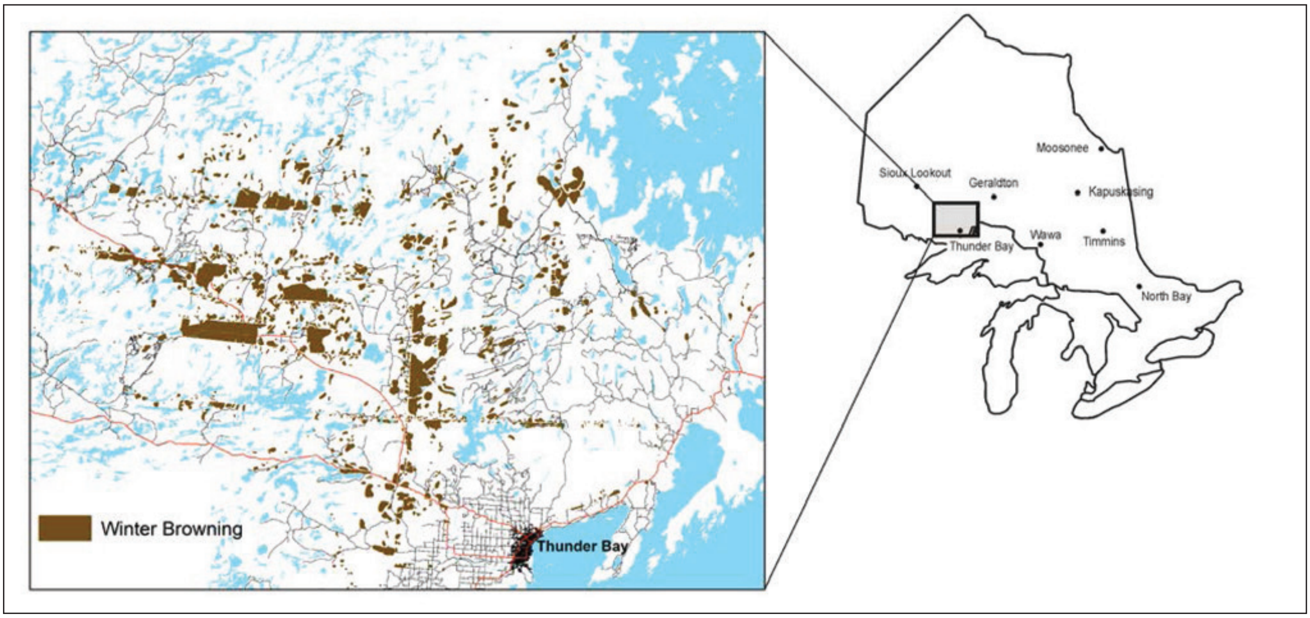

Fig. 7. Distribution of damaged conifer stands in northwestern Ontario based on an aerial survey conducted by Ontario Ministry of Natural Resources' Inventory, Monitoring, and Assessment staff in mid-May 2012. The red and black lines are primary and secondary highways and areas in blue are water. Isolated damage east to Geraldton was not included in the survey. The east–west and north–south patterns of mapped damage reflect the orientation of survey flight lines.

Needle damage symptoms were similar to those observed in spring 2007 near Kapuskasing, Ontario (Man *et al.* 2009). However, in the 2007 event, which occurred in mid-May before budbreak, 70% to 100% of conifer needles and 20% to 30% of buds on affected trees were damaged and did not flush (Man *et al.* 2009). In 2012, only 5% to 10% of the buds on affected trees were damaged and most buds flushed by early June, though with reduced level of vigour (Fig. 8). Due to the obvious abrupt transition height below which branches were undamaged, we assumed that snow cover at the time of the damaging event provided protection for the lower portions of the trees (Fig. 3 and Fig. 6). As the timing of needle discoloration was late April to early May prior to conifer budbreak, we suspect that the damage is similar to winter browning, a phenomenon that has been observed in many locations around the world, but whose cause(s) are not entirely understood (Bella and Navratil 1987).

Trees affected by winter browning may suffer substantial growth loss and even mortality (Belle and Navratil 1987). The general belief is that its cause is warm air temperatures in winter that desiccate conifer foliage when water cannot not be obtained to meet transpirational needs due to frozen soil (Hiratsuka and Zalasky 1993). Unseasonably warm weather, with sunny days, frozen soil, and strong winds are suggested as the main contributing factors (Belle and Navratil 1987, Hiratsuka and Zalasky 1993). Some researchers believe that the damage is associated with fluctuations of warm and freezing temperatures in winter months (Henson 1952, Cayford *et al.* 1959, Robin and Susut 1974). In the well-studied syndrome of red spruce winter injury

Fig. 8. Affected trees after buds had flushed and dead needles were shed (photo taken by Ricardo Velasquez on July 12, 2012 in a jack pine plantation established in 2000, 120 km north of Thunder Bay, Ontario).

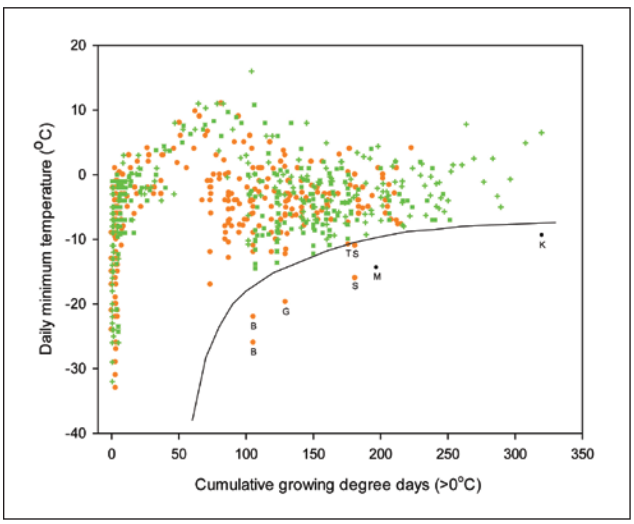

Fig. 9. Cumulative growing degree days above 0°C and daily minimum temperatures from January 1 to April 30, 2012 for the 10 locations across northern Ontario listed in Table 1. The symbol • represents the weather stations in the areas of observed conifer damage and + and ■ represent the stations on the western and eastern edges, respectively, of the areas where damage was observed. The curve represents the relationship between cumulative growing degree days and conifer cold hardiness derived from Glerum (1973). Symbols with letters are days that damage is believed to have occurred, T for Thunder Bay, S for Suomi, G for Geraldton, and B for Gull Bay. Temperature data from Environment Canada for conifer winter browning reported in 2007 near Kapuskasing, Ontario by Man et al. (2009) (represented by K using Environment Canada online archive for Kapuskasing) and in 1958 in Manitoba, Saskatchewan, and western Ontario by Cayford et al. (1959) (represented by M using Environment Canada online archive for Brandon) are presented for comparison (black dots).

in the northeastern United States, both winter desiccation (Curry and Church 1952, Herrick and Friedland 1991, Hadley *et al*. 1991) and dehardening/freezing damage (Peart *et al*. 1991; Perkins and Adams 1995; Strimbeck *et al*. 1995; Lazarus *et al*. 2004, 2006) have been suggested as causal factors. In this paper we examine the possible causes of widespread conifer damage in northern Ontario and identify next steps to improve our understanding of this recurring phenomenon.

Weather Conditions

Since the damage observed in northwestern Ontario was likely weather-related, we examined weather records from the period shortly before the damage symptoms appeared. We obtained weather data for areas where damage was and was not observed in northern Ontario in spring 2012. The primary data source was the Environment Canada online archive (http://climate.weatheroffice.gc.ca), with data for Suomi and Gull Bay obtained from Accuweather (http://www.accuweather.com/en/ca/canada-weather). In total, four weather stations from areas where damage occurred (Thunder Bay, Suomi, Gull Bay, and Geraldton) and six weather stations from undamaged areas, three from the east (Wawa, Kapuskasing, and Timmins) and three from the west (Dryden, Fort Frances, and Red Lake).

Were Warm Air Temperatures Responsible for the Damage?

Areas in which trees were affected were subject to abnormally high temperatures from mid to late March when daytime temperatures reached 20°C and in some areas exceeded 25°C (Table 1). However, daytime temperatures during the warm period were generally lower in the Suomi, Thunder Bay, Gull Bay, and Geraldton areas where damage was widespread compared to areas where damage did not occur. For example, greater warming occurred at Fort Frances and Timmins, where conifer damage was generally not observed. Warm temperatures that occur when soil is frozen can result in desiccation damage to conifers, but our data indicated that where warm temperatures occurred in March areas with unaffected trees greatly exceeded those where conifer needle browning occurred. Thus, we conclude that in this case the cause of damage was not winter desiccation.

Was Low Precipitation Responsible for the Damage?

Precipitation in the Thunder Bay area was considerably lower in autumn and winter relative to climate normals (Table 1). Drought in the autumn may reduce water storage in tree stems and leaves and increase vulnerability of conifers to winter desiccation caused by warm air temperatures when the soil is frozen (Hiratsuka and Zalasky 1993). In comparison, low precipitation levels in the winter can result in reduced snow cover and consequently deeper soil freezing. According to Environment Canada (see snow depth by locations at http://climate.weatheroffice.gc.ca), because of unseasonably warm weather across northern Ontario, snow cover had nearly disappeared by the end of March 2012. In mid-April approximately 20 cm of snow fell on areas where trees were affected; however, in areas where conifer damage was not observed, snowfall was much less or did not occur. Overall, we did not discern a clear difference in seasonal precipitation between the areas where damage did and did not occur, as some sites where trees sustained damage had more precipitation than those where no damage was observed (Table 1). We therefore conclude that low precipitation in autumn 2011 and winter 2012 did not predispose conifers to the damage observed in spring 2012.

Table 1. Selected weather data for northern Ontario from 2011 and 2012. Mean maximum temperature during the warm period (March 15 to 22, 2012); and summer (June 1 to August 31, 2011), fall (September 1 to November 30, 2011), and winter (December 1, 2011 to April 30, 2012) precipitation. Numbers in parentheses are percentage relative to 30-year normals (1971 to 2000). Weather stations located within the area of extensive conifer damage are shaded. All the data are from Environment Canada online archive, except for Suomi and Gull Bay during 2011 to 2012, which are from Accuweather (the 30-year normals for those locations are from Thunder Bay and Geraldton, respectively).

Weather station location	Mean maximum temperature (°C)	Summer precipitation (mm)	Fall precipitation (mm)	Winter precipitation (mm)
Red Lake	16.6	219 (80%)	227 (130%)	161 (118%)
Fort Frances	21.5	208 (70%)	95 (53%)	168 (105%)
Dryden	18.3	153 (50%)	146 (77%)	212 (151%)
Suomi	16.8	295 (113%)	129 (63%)	223 (126%)
Thunder Bay	14.8	243 (93%)	84 (41%)	122 (69%)
Gull Bay	16.1	163 (58%)	187 (78%)	148 (87%)
Geraldton	16.2	210 (75%)	183 (76%)	191 (112%)
Wawa	19.5	288 (100%)	235 (71%)	243 (79%)
Kapuskasing	19.8	214 (80%)	189 (77%)	324 (129%)
Timmins	21.5	109 (42%)	213 (91%)	191 (72%)

Were Freezing Temperatures Responsible for the Damage?

Although buds and shoots of boreal conifers may appear inactive in late winter/early spring, their physiological status is subject to change, that is, with exposure to increasing temperatures dormant shoots can gradually lose cold hardiness (Glerum 1973). If this occurs, freezing damage can occur at increasingly higher temperatures. The examination of temperature records showed that air temperatures returned to normal after the March warming episode, with nighttime temperatures generally falling below zero. Therefore, we plotted daily minimum temperatures versus cumulative growing degree days (calculated as a cumulative total of daily averages above base temperature 0°C as suggested by Man and Lu 2010). Three of the four stations within the areas where trees sustained damage had notably colder minimum temperatures after the sites had exceeded 100 growing degree days (Fig. 9). These cold nights occurred on April 16 and 17, with night temperatures falling to -22°C and -26°C at Gull Bay, -19.7°C at Geraldton, -11°C and -16°C at Suomi, and -10.8°C at Thunder Bay.

Quantitative relationships between cumulative growing degree days and conifer cold hardiness are not readily available from the literature. We therefore developed such a relationship for black spruce (solid line in Fig. 9) based on the cold hardiness measurements by Glerum (1973) and growing degree days estimated using weather records for the year of Glerum's study at Midhurst, Ontario. Since Glerum (1973) observed losses of cold hardiness prior to budbreak, we were able to correlate dormant season cold hardiness with accumulated growing degree days.

We observed that in areas where damage was later found night temperatures on April 16 and 17, 2012 were generally sufficiently cold to cause damage, as predicted based on our reinterpretation of Glerum (1973). Near Thunder Bay, only moderate to low levels of damage were found on isolated ornamental trees (Fig. 7), and based on accumulated growing degree days and freezing temperatures this location was considered borderline in susceptibility to damage (T in Fig. 9).

For these reasons, we concluded that it is likely that the warm episode in March caused early dehardening and loss of cold hardiness of trees (Zhu *et al.* 2002), which were subsequently damaged by freezing when more seasonal cold temperatures resumed. Minimum temperatures in areas damaged in April were either colder or occurred closer to the time of budbreak (i.e., had greater cumulative growing degree days) compared with sites that were outside the areas where tree sustained damage.

Implications for Research

We propose that two recent widespread incidents of extensive conifer damage in northern Ontario, one in 2007 in the northeast (Man *et al.* 2009) and the other in 2012 in the northwest, were caused by the same sequence of well-above-average late winter/early spring temperatures that dehardened conifers and made them more susceptible to freezing damage when more seasonal temperatures resumed, as was observed elsewhere (albeit at smaller scales) in 2012 (NDSU Agriculture Communication 2012, Vermont Forest Health 2012). Symptoms of damage in 2012 (present study) occurred about a month earlier than was observed in 2007 (April 17 vs. May 19), and with fewer accumulated growing degree days (cumulative growing degree days above 0°C were between 100 and 200 in 2012 versus about 320 in 2007).

Needle injury occurring to dormant trees during winter has been attributed to three main causes: foliage desiccation (Hiratsuka and Zalasky 1993), rapid freezing (Perkins and Adams 1995), and pre-budbreak dehardening/freezing (Man *et al.* 2009). In Canada, damage to dormant conifers has occurred mainly in the west, including Manitoba, Saskatchewan, and in the Rocky Mountains of Alberta and British Columbia (Cayford *et al.* 1959, Robin and Susut 1974; Hiratsuka and Zalasky 1993). The damage has been referred to using a variety of terms that indicate it is caused by desiccation, e.g., winter desiccation, winter drying, winter drought, winter frost drying, parch killing, or that do not allude to the cause of damage beyond it being associated with winter, e.g., winter killing, winter injury, winter browning, winter burn, or in one case describe the result, i.e., red belt (e.g., Cayford *et al.* 1959, Bella and Navratil 1987, Hiratsuka and Zalasky 1993, Berg and Chapin 1994). For the current event, weather records provide evidence that the observed conifer damage was due to later-winter/early spring freezing damage prior to budbreak. We suggest the term *winter freezing damage* be used to describe conifer bud and needle damage that occurs any time prior to budbreak when warm temperatures causing loss of cold hardiness are followed by damaging freezing conditions.

Further research is needed to confirm the winter freezing hypothesis and to determine the actual loss of cold hardiness following different levels of warming in late winter/early spring. Although desiccation has commonly been used to explain conifer needle and bud damage during the dormant season (Cayford *et al.* 1959, Robin and Susut 1974, Hiratsuka and Zalasky 1993), a direct link has yet to be established. In the event of future climatic conditions similar to those observed in northern Ontario in 2012, we suggest that controlled experiments be carried out to confirm our evaluation that winter freezing rather than desiccation is the primary causal factor.

We believe that large-scale winter damage to conifers in Ontario occurred at least once prior to the 2007 and 2012 events, with similar symptoms and weather conditions recorded in 1958 for Saskatchewan and Manitoba (Cayford *et al.* 1959) and northwestern Ontario (Buchan 1958). Since the 1958 incident occurred at least 50 years ago, ascribing present-day examples to climate change would require an increase in the frequency and severity of such events, as reported by Man *et al.* (2009) and Augspurger (2013) through phenology observations and temperature records. As the relationship between freezing conditions and warming climate likely varies by geographical region (Colombo 1998), monitoring forest health and reporting such climatically induced damage will be important to document climate change effects on forests in coming decades.

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