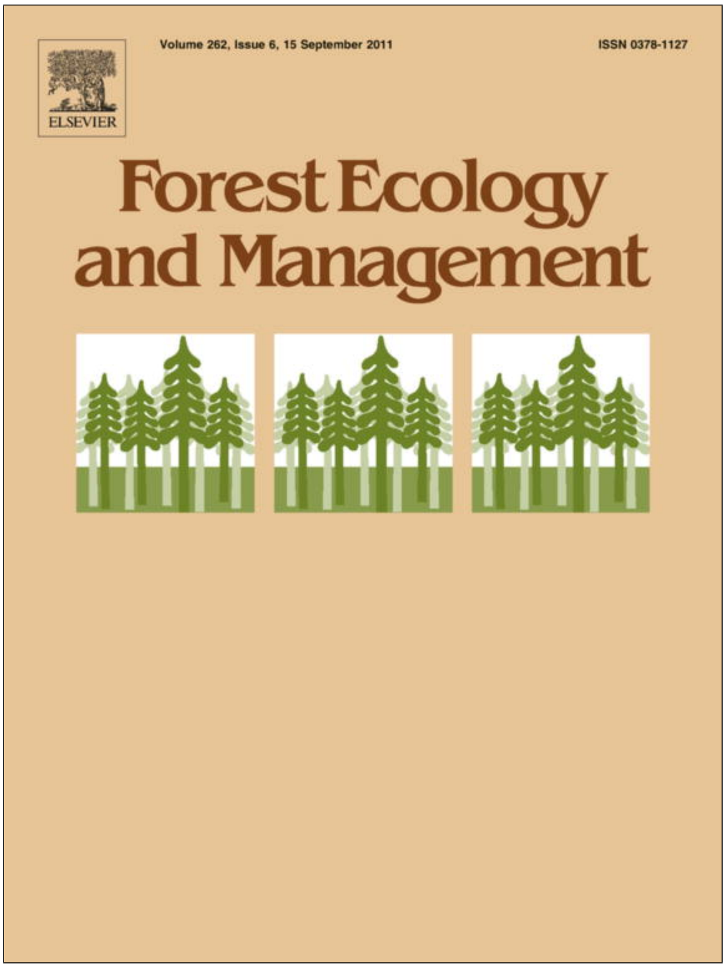
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Do partial cross sections from live trees for fire history analysis result in higher mortality 2 years after sampling?

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ABSTRACT

Although partial cross sections from live trees have been utilized in the development of fire history studies, few efforts have been made to examine the effects of this method on the individual trees that were sampled. We examined 115 red pine (*Pinus resinosa* Ait.), eastern white pine (*Pinus strobus* L.), and jack pine (*Pinus banksiana* Lamb.) trees from which partial cross sections had been removed 2 years earlier, and 209 similarly sized neighboring red pine and eastern white pine trees. Two years following the removal of partial cross sections, 22 sampled trees (19%) had died. When compared with neighboring trees, removing a partial cross section did not appear to increase the mortality rate for a given tree (*t*-test; $P = 0.150$). However, when we compared the characteristics of the trees with partial cross sections removed, we did observe some trends; i.e., those trees that died were primarily killed by wind-induced breakage at the level of the partial cross section. Almost all stems where partial cross sections were collected from a catface edge or had >30% of the total area removed were more susceptible to stem breakage and experienced an increased likelihood of mortality. While these results suggest that the collection of partial cross sections from live trees may be an effective method for fire-history sampling, the negative impacts of the sampling on individual trees may be reduced by ensuring that samples are collected from the center, rather than the catface edge, and <25% of the total stem area is removed.

1. Introduction

Mixed-pine forest ecosystems composed of mainly red pine (*Pinus resinosa* Ait.), eastern white pine (*Pinus strobus* L.), and jack pine (*Pinus banksiana* Lamb.) once dominated large portions of the pre-EuroAmerican landscape of the eastern Upper Peninsula of Michigan. Although these forests were maintained by low- to moderate-severity surface fires occurring once every 50–60 years (Drobyshev et al., 2008a), most of these forest ecosystems have been altered considerably since settlement. As a result, the original geographic extent of these forest ecosystems has greatly declined following late 19th and early 20th century logging, repeated slash fires following the logging, conversion to agriculture and plantation forests, and active fire suppression (Whitney, 1987; Losey, 2003; Schulte et al., 2007).

Efforts are currently underway to restore these forest ecosystems and resource managers are looking for guidance in these efforts (Corace et al., 2009). In particular, resource managers have begun using a combination of prescribed fire and mechanical treatments, such as thinning, to increase recruitment of red pine and eastern white pine seedlings, increase mean residual stem diameters, and reduce fuel loadings associated with the high densities of jack pine that developed following turn-of-the-century logging, and subsequent management (Drobyshev et al., 2008a). To assist in this effort, we examined the fire history in one area that is currently among the first conducting practices to restore mixed-pine forest ecosystems in the eastern Upper Peninsula of Michigan. Working with resource managers at Seney National Wildlife Refuge (SNWR), we developed a detailed record of fire history for SNWR using partial cross sections from both live and dead red pine, eastern white pine, and jack pine (Drobyshev et al., 2008b).

The use of cross sections and partial cross sections from live fire-scarred trees has been an accepted technique for developing long-term fire history records for many forest types. The use of partial cross section sampling for fire history analysis has been used in

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the western United States for almost 40 years (e.g., McBride and Laven, 1976; Baisan and Swetnam, 1990; Heyerdahl et al., 2001; Taylor and Skinner, 2003) and more recently in Europe (e.g., Drobyshev and Niklasson, 2004). The presence of basal scars caused by heat released during fires (a "catface"), indicates at least one past fire that wounded a portion of the cambium. This physical damage to a tree can then be dated using dendrochronological methods. The above methods are often preferred over samples collected using an increment borer for two main reasons: (1) difficulty in sampling visible scars due to narrow borer diameter, preventing the borer from meeting the scar tip ("scar face") during sampling, and (2) high probability of borer missing additional scars not clearly visible on the frontal view (including "hidden scars" or grown-over scars) (personal observations, Cochrane and Daniels, 2008). The result is that fire history studies based upon information obtained via increment borers are inherently imprecise (Barrett and Arno, 1988).

However, unlike complete cross-section samples that require felling a tree, or increment borer samples that may not provide useful or adequate information, partial cross sections can be extracted from live trees with a chain saw to remove a portion of a tree to age both visible and grown-over fire scars. This sampling technique leaves the sampled tree standing (Arno and Sneck, 1977), and allows for a more thorough and accurate dating of multiple fire scars than increment coring (Baisan and Swetnam, 1990). However, one primary drawback of the partial cross-section method is that it can also weaken the tree and make it more susceptible to insects, disease, windthrow, or stem breakage (Heyerdahl and McKay, 2001). Pine species also often extrude large amounts of resin to cover the wound caused by the removal of the partial cross section, which may increase the flammability of the affected wood when the next fire occurs and further decrease the stability and longevity of a live tree with a partial cross section removed (Feeney et al., 1998; Santoro et al., 2001).

Despite the widespread use of collecting partial cross sections for fire history studies, little information is available on the effects of this technique on the longevity of sampled trees (but see Heyerdahl and McKay, 2001, 2008). This situation presents a conundrum for resource managers and scientists who are interested in restoring fire-dependent forest ecosystems, especially in areas where little information is known about the characteristics of natural fire (e.g., fire return interval, seasonality of natural fires, fire size). Resource managers must balance the need for detailed fire history information to guide their management and restoration practices while considering that the acquisition of this information may result in damage to individual trees. Many of these trees are frequently the older individuals that provide important ecological services (Franklin et al., 1987), and provide the most complete information on the fire history for a specific site and landscape.

In some cases, sampling may need to be conducted in designated natural or wilderness areas where the impact of research must be carefully considered and limited. With this in mind, we examined the status of sampled trees 2 years following partial cross section removal as part of a fire history study for SNWR (Drobyshev et al., 2008b). Specifically, we addressed the following questions: (1) did the collection of partial cross sections increase the mortality of sampled trees when compared with control neighboring trees of similar diameter and condition? and (2) if there was an increase in mortality following partial cross section collection, what factors may have led to the mortality of sampled trees?

2. Materials and methods

2.1. Study area

Our study focused on mixed-pine forest ecosystems located at SNWR (46°16′59.988″N 85°57′00.0″W), a 38,540-ha refuge of the US Fish and Wildlife Service's National Wildlife Refuge System located in the eastern Upper Peninsula of Michigan (Fig. 1). SNWR is located within the Seney Sand Lake Plain Sub-Subsection (Albert, 1995). The climate of the study area is considered continental, although it is somewhat modified by the proximity to both Lake Superior and Lake Michigan. The long-term average temperature (1950–2000 recorded at SNWR) is 5.7 °C. Precipitation averages 81 cm annually, with an average of 302 cm of snowfall per year.

Although a large portion of SNWR has been altered to promote habitat for migratory waterfowl and other wildlife species primarily through the maintenance of a network of dikes and anthropogenic pools (Losey, 2003), approximately one-third of SNWR is a relatively unaltered Federally-designated Wilderness Area. The Seney Wilderness Area (SWA) is a 10,178-ha area containing the Strangmoor Bog National Natural Landmark, one of the largest patterned fen landscapes in the United States outside of Alaska. This landscape is characterized by a string of fen wetlands with raised sand ridges that support mixed-pine forest ecosystems (Heinselman, 1965; US Fish and Wildlife Service (USFWS), 2009).

2.2. Field methods

A total of 124 partial cross-section samples from live trees were collected in 2006 from 49 sites, with 15 of these sites located within the SWA. Each sample was collected using a chain saw, and the location of each sampled tree geo-referenced using a global positioning system. At each site, up to eight partial cross sections were collected from live trees. In 2008, 2 years after partial cross sections were collected, we re-located 115 sampled trees (51 trees in the SWA, 64 trees in the non-Wilderness portion of SNWR; we were unable to re-locate nine of the partial cross-section sampled trees). We determined that individual trees were living if they had green needles and were free standing. For each tree, we recorded the following information: species, dbh (diameter at breast height, 1.37 m) (cm), height (m), crown class (dominant, codominant, intermediate, or overtopped), presence of stem decay identified by examining the cut area of the stem for insect galleries, char, sawdust, or decay, distance to nearest tree (m), number of trees within 5 m, direction of fall (degree), if applicable, height of cut (m), distance to edge of sand ridge (m), position of cut on tree (middle or catface edge) (Fig. 2), presence of resin in cut, diameter at cut height (cm), horizontal width (cm), horizontal depth (cm), vertical depth (cm) and area of catface deeper than 5 cm.

The cross-sectional area (CSA) of the tree at the cut height (usually near the base of the tree) was determined using the following equation: $\pi(d/2)^2$ where d is the diameter (cm) of the bole of the tree at partial cross section height. The area of the partial cross section removed was subtracted from the total CSA by multiplying the horizontal width and depth. To account for CSA lost from previous fires, trees having a fire scar deeper than 5 cm (78% of samples) had this scar area removed from the total CSA. Since the fire scars were assumed to be triangular in shape, three measurements representing the sides of the fire scars were collected (a–c) and the following formula was used to calculate the total fire scar cross-sectional area based upon Heyerdahl and McKay (2001):

$$\sqrt{(s*(s-a)*(s-b)*(s-c))} \text{ where } s = 0.5*(a+b+c) \quad (1)$$

For trees containing multiple catfaces (17% of samples), each catface was treated as an individual scar and all were subtracted from the entire CSA. After the partial cross section and fire scar area were removed from the total CSA, the remaining area was determined to be the holding wood of the sampled trees.

To determine if the mortality associated with the sampling of partial cross sections was different from natural background mortality, neighboring, control red pine, eastern white pine, and jack

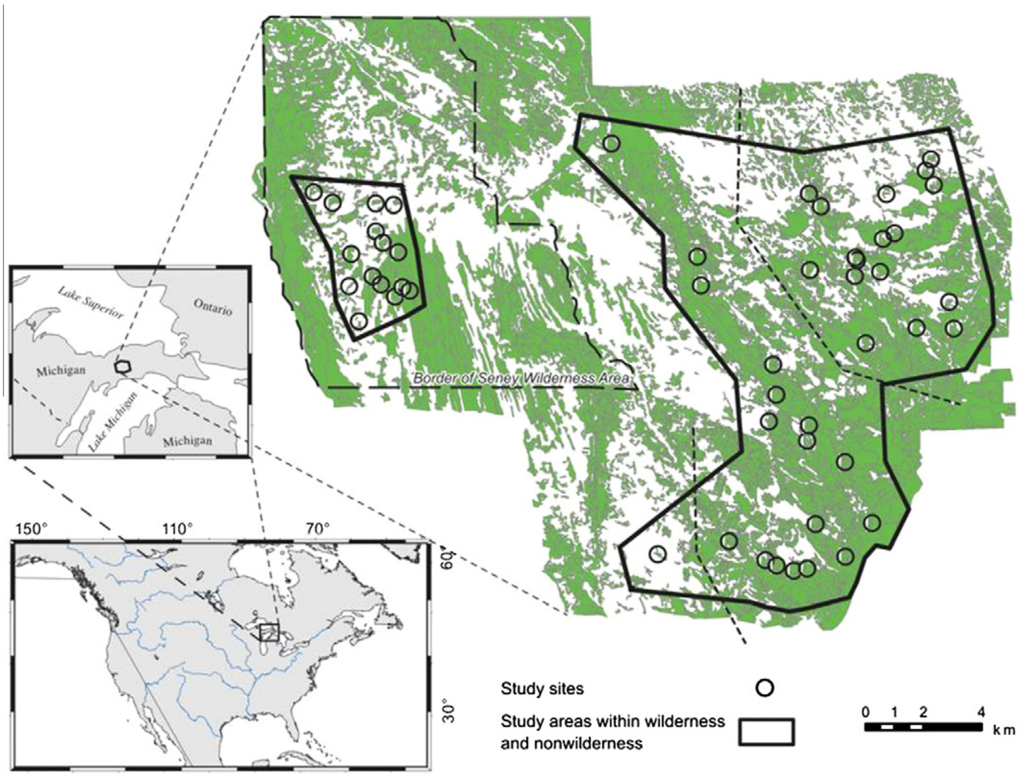

Fig. 1. Location of Seney National Wildlife Refuge (SNWR) in the Upper Peninsula of Michigan (inset) and map of SNWR highlighting the Seney Wilderness Area.

pine trees of similar dbh and condition (i.e., crown class) to the partial cross-section sampled trees were also sampled and assessed. Specifically, we paired 1–2 control trees that did not have a partial cross section collected in 2006 with each partial cross-section sampled tree. These control trees represented the closest neighboring trees (mean distance 15.7 m, range 0.9–68.0 m) to the partial cross-section sampled individual. Some of the control trees had a catface (40 of 122) as in some areas the only fire-scarred individual was sampled for the fire history analysis. The following measurements were collected from the control trees: species, dbh (cm), height (m), crown class, presence of decay identified by examining the cut area of the stem for insect galleries, char, sawdust, or decay, distance to nearest neighboring tree (m), trees within 5 m, direction of fall (degree), distance to edge of sand ridge (m), and status (live or dead). Dead trees were only included if suspected to have died in the past 2 years (determined visually based upon tight bark and dead needles present on the branches).

2.3. Statistical analyses

We used non-paired *t*-tests to determine if there were significant differences in the characteristics of partial cross-section sampled trees between the SWA and non-Wilderness portions of SNWR. Although the general partial cross section collection methods were similar in both areas, we were concerned that there might be an operational bias to collect smaller samples from trees in the SWA as these areas are old-growth mixed-pine forest ecosystems. We also used a non-paired *t*-test to test for differences in mortality associated with the characteristics between live and dead partial cross-section sampled trees, as well as to compare the characteristics of live and dead partial cross-section sampled trees and control neighboring trees. All statistical analyses were conducted using SAS software (ver. 9.2; Cary, NC).

3. Results

3.1. Characteristics of partial cross-sectioned stems

Red pine was the dominant species sampled (96%), with jack pine (3%) and eastern white pine (1%) sampled less frequently. Fifteen percent of partial cross-section sampled trees had more than one catface present and most (78%) of these catfaces were deeper than 5 cm. The tree diameter at the partial cross section cut height varied considerably, from 22.0 to 86.0 cm for partial cross sections collected from live trees and 11.0 to 78.0 cm for partial cross sections collected from dead trees (Fig. 3). The partial cross-section area removed (mean 857 cm^2, range 66–2107 cm^2) tended to be larger than the existing area of the fire scars (mean 95 cm^2, range 0–517 cm^2), suggesting considerably more wood was removed with the partial cross section relative to the area of the fire scar (Fig. 3). Three sampled trees could not have their partial cross-section areas measured due to prescribed fires that occurred between 2006–2008 and consumed part of the sampled cross-sectional area. Visual signs of decay and insect galleries were present in the center of trees and around fire scars in the majority (57%) of the sampled trees. However, we do not know if these are associated with pre-sampling or post-sampling conditions.

The measurements for the partial cross-section area (horizontal width and depth) and vertical depth were compared between the SWA and non-Wilderness portions of SNWR (Fig. 4). Non-paired *t*-tests did not show a significant difference in the sampling of the two locations based upon horizontal width ($P = 0.731$) and depth ($P = 0.196$). However, partial cross sections collected in the non-Wilderness areas of SNWR appeared to have a lower vertical depth than those partial cross sections collected in the SWA ($P = 0.108$). The height of cut (distance from ground level to lower portion of sampled partial cross-section area) was also the same

Fig. 2. Example of a center cut (top) and catface edge cut (bottom) partial cross sections collected from a red pine at Seney National Wildlife Refuge. Note pencil for scale (length 15 cm) and difference in fire scar (top nearly healed over, bottom open catface).

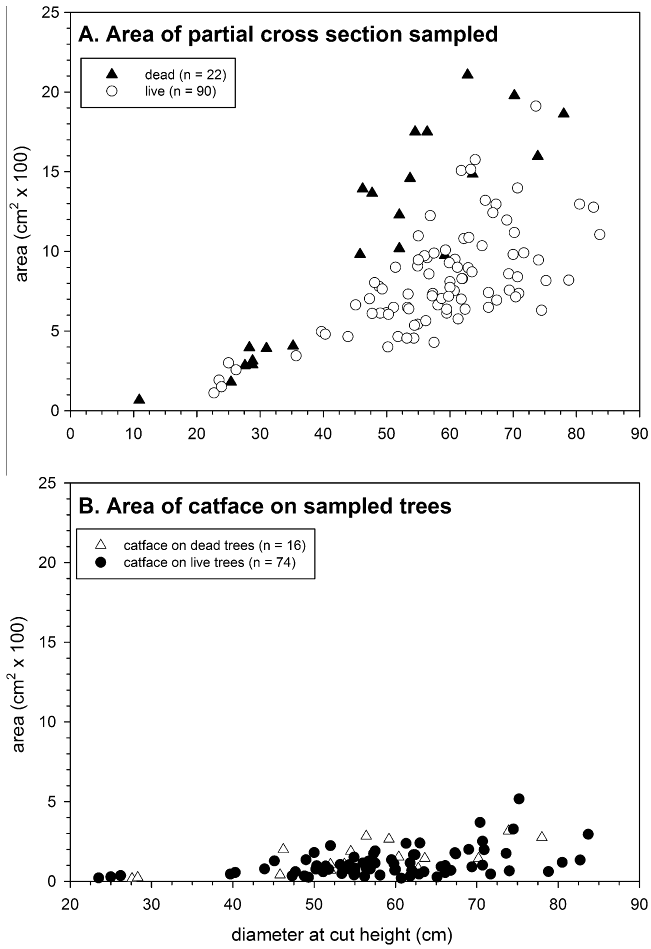

Fig. 3. Diameter at cut height (cm) and area (cm^2) of living and dead trees 2 years after sampling (A) and diameter at cut height (cm) and area (cm^2) of catface deeper than 5 cm of living and dead trees 2 years after sampling (B) at Seney National Wildlife Refuge. Note that area of partial cross section removed could not be determined from three sampled trees due to damage from a prescribed fire.

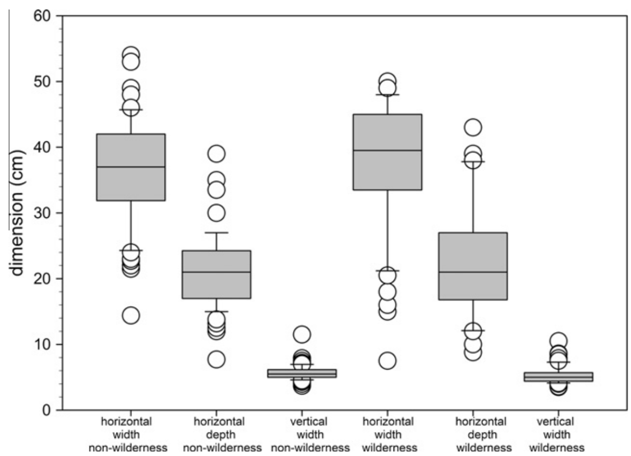

Fig. 4. Dimensions and height of the partial cross section removed in the non-Wilderness and Wilderness Area at Seney National Wildlife Refuge. The box encloses the 25th and 75th percentiles and the error bars enclose the 10th and 90th percentiles.

for the non-Wilderness (0.26 m) and SWA (0.25 m) areas ($P = 0.890$). Resin was present on all sampled trees (live and dead), except for the three that had been burned in the recent prescribed fires (all of which were still alive).

The dbh of partial cross-section sampled trees had a mean diameter of 46.1 cm and ranged from 8.5–70.6 cm (Fig. 5). The mean dbh values of the dead trees (non-Wilderness = 37.0 cm; SWA = 40.1 cm) were lower than the mean dbh values of the live trees (non-Wilderness = 48.1 cm; SWA = 47.7 cm) (Fig. 5), and we found that there were differences in the size of both live and dead sampled trees in the non-Wilderness ($P = 0.003$) and in the SWA ($P = 0.056$).

The area removed for the partial cross sections of the sampled trees was highly variable (Fig. 6), with live partial cross-section sampled trees having significantly less area removed than dead partial cross-section sampled trees (31% and 55% of area removed on average, respectively, $P = 0.001$; Fig. 7). The position of the cut on dead trees showed that sampled trees with catface edge cuts (96%) seemed more likely to fall over than catface center cuts (4%), with stem breakage being the most likely cause of mortality as evidence of the stems breaking above or at the location of the partial cross section. The position of cut on sampled trees was not similar, with 51% and 49% of the trees sampled in the non-Wilderness with catface edge and catface center cuts, respectively. In the SWA, most partial cross sections were removed from the catface edge of the trees (71%) rather than the catface center of the trees (29%).

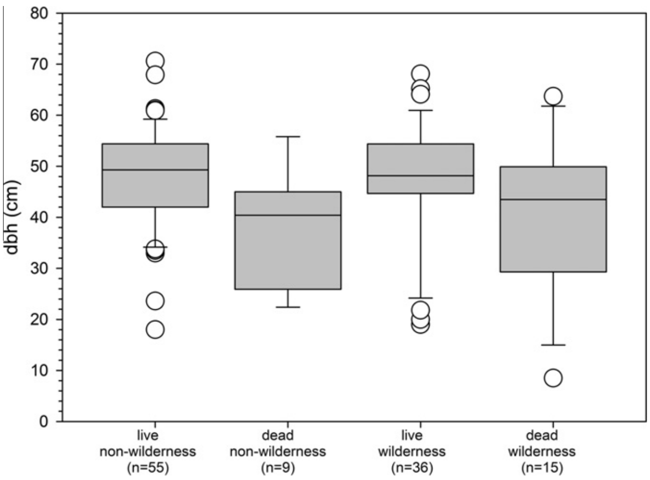

Fig. 5. Diameter of the live and dead partial cross-section sampled trees in the non-Wilderness and Wilderness Area at Seney National Wildlife Refuge. The box encloses the 25th and 75th percentiles and the error bars enclose the 10th and 90th percentiles.

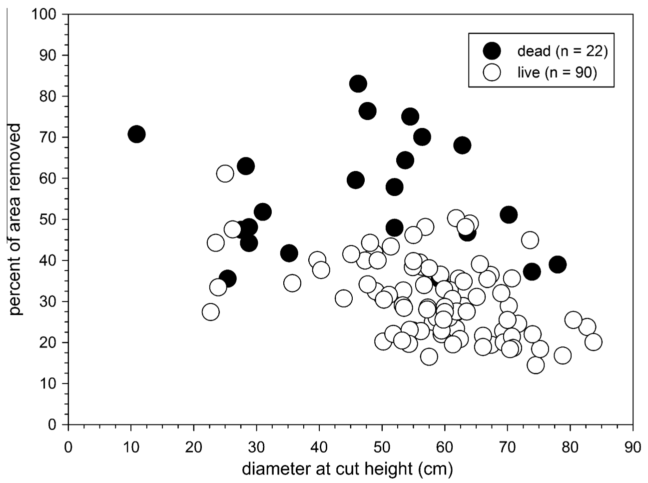

Fig. 6. Relationship between diameter at cut height and percent of area removed for each partial cross-section sampled tree at Seney National Wildlife Refuge.

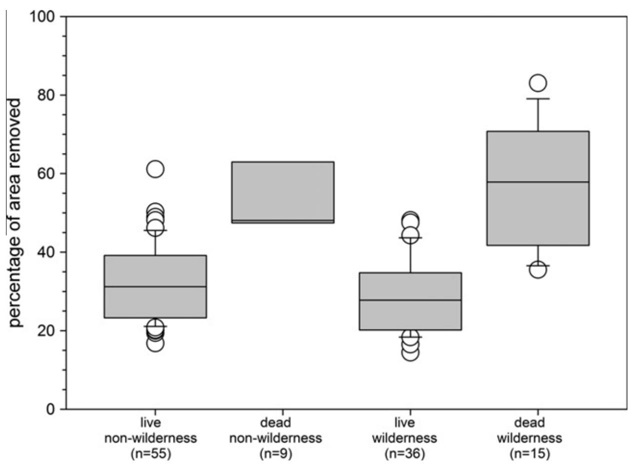

Fig. 7. Percentage of cross-sectional area removed for live and dead trees in the non-Wilderness and Wilderness Area at Seney National Wildlife Refuge. The box encloses the 25th and 75th percentiles and the error bars enclose the 10th and 90th percentiles.

3.2. Mortality and comparison with control neighboring trees

Two years following sampling, 22 of the live 115 partial cross-sectioned trees (19%) had died, most associated with stem breakage at the location of the cut. Eighty-three percent of the partial cross-section trees had two neighboring control trees measured within 70 m, while the remaining 17% of partial cross section sampled trees had one neighbor measured. The control trees (87 trees SWA; 122 trees non-Wilderness) were similar in diameter to the sampled trees (mean 44.5 cm, range 8.8–67.1 cm). A catface deeper than 5 cm was visible on 35% of the control trees. When we compared the mortality of the partial cross-section trees with the control neighbor trees 2 years after sampling, we found that the mortality rates were similar ($P = 0.15$).

4. Discussion

4.1. Factors influencing mortality of partial cross-sectioned trees

Overall, we did not observe a significant difference in the mortality of partial cross-section sampled red pine, eastern white pine, and jack pine trees when compared with neighboring non-sampled control trees after 2 years. This does not imply, however, that there is no mortality of partial cross-section sampled trees as we observed 22 sampled trees that had died 2 years after partial cross section sampling. As observed with partial cross-sectioned ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.) stems in Oregon and Washington (Heyerdahl and McKay, 2001), removing a partial cross section in red pine, eastern white pine, or jack pine did not appear to increase the likelihood that sectioned trees would be killed by insects or pathogens. While we observed insect activity in the majority of the sampled trees (57%), most of these signs (e.g., few insect galleries and small amounts of fine sawdust present within the sectioned area and along the base of the sampled tree) indicated minimal activity and impact. We did observe, however, that there are factors associated with the collection of the partial cross sections that may have resulted in the increased mortality of sampled trees. These factors include: (1) the location of the partial cross section within the catface, and (2) the amount of area removed with the partial cross section.

The position of the partial cross section removed from the stem appears to have strongly influenced the mortality of sampled trees. Although the characteristics of the partial cross sections removed were similar (e.g., there were no differences in the horizontal width and depth, and vertical depth, of the partial cross sections), our results showed that 96% of those trees with a catface edge removed during sampling process were dead 2 years after the collection of the partial cross section due to windthrow or stem breakage. This type of partial cross-section removal weakens one side of the holding wood and makes the tree more susceptible to breakage. Partial cross sections collected from the center of the catface edge leave the sides intact, allowing the tree to have better supporting holding wood.

In addition to the location of the cross section removal, we also found that the amount of area of the stem removed in the cross section increased the likelihood of mortality following sampling. As part of our fire history sampling, we specifically selected trees of a range of sizes so as to capture differences among age cohorts and stand development patterns. While the area of the fire scars on the sampled trees was relatively small when compared with the area removed, the total area of the partial cross section removed from the sampled trees was variable depending on the location of the pith relative to the fire scar(s) and the stem area that had healed and grown over older fire scars. Despite this variability associated with individual fire scars and trees, our results clearly show that when a larger proportion of stem area is removed there is an increased likelihood of mortality. Individual trees with <30% of the total area removed tended to remain alive following the cross section removal, while those with >50% of the total cross-sectional area removed were more likely to be dead due to stem breakage at the height of the partial cross section.

These estimates of survival based upon the area removed should be considered conservative in that the methods for measuring the total area removed may underestimate the proportion of the total area removed with the partial cross section. As with the studies of survival following partial cross section removal in ponderosa pine (Heyerdahl and McKay, 2001, 2008), fire scars were assumed to be triangular in shape. The fact that many fire scars are more concave in shape suggests that we may have underestimated the area of the catface. Furthermore, the partial cross section removed from the stem, assumed to be rectangular in shape, often included a curved edge on the bark side which would have overestimated the total area of the partial cross section removed from the tree.

It should also be noted that when collecting partial cross sections, we did not purposely set out to collect samples from the catface edges or collect larger partial cross section due to ease of collection. Rather, those trees with partial cross sections removed from the catface edges or those that were >50% of the total cross-sectional area were sampled in this manner because of the fire scar placement and amount of wood grown over the older, multiple fire scars. When developing a fire history study and attempting to have as little impact on the trees and the ecosystem as possible, trees that have multiple fire scars hold more information on the past fire history at that site. It is likely that these trees with multiple fire scars are less stable than trees with one or no fire scars. As a result, our estimate of the background mortality from the control trees is conservative as it included trees with and without fire scars (34% and 66%, respectively). While it would have been preferable to only select fire-scarred trees for our control group, there were not enough neighboring fire-scarred trees to effectively sample in this manner.

Once a partial cross section is removed from the tree, it is not the direct removal of the partial cross section that results in mortality of the tree. Rather, it is a combination of other secondary factors that leads to an increased likelihood of mortality of the partial cross section sampled trees. In the SWA, mixed-pine forest ecosystems are located on elevated long, narrow sand ridges within a patterned fen matrix. As frontal systems and winds move primarily from the west–northwest to the east–southeast perpendicular to the position of the long axis of these sand ridges, these forest ecosystems are relatively unprotected from high winds due to their higher elevation than the surrounding wetlands. We suggest our findings indicate wind patterns are associated with the observed stem breakage in the SWA. Previous studies in jack pine-dominated sites elsewhere in Michigan have also suggested that wind can be a major factor in stem breakage (Corace et al., 2010). There is also evidence that larger fires are driven by these climatic factors (Drobyshev et al., in press), with larger fires moving from the west–northwest and fire scar development most common on the east–southeast side of most stems (Drobyshev et al., 2008a). These factors, when combined with the fact that red pine is considered to be susceptible to wind throw (Rich et al., 2007), and that in some instances a large, catface edge portion of the stem was removed during sampling, increase the likelihood of mortality.

While the removal of a partial cross section did not appear to result in increased insect or pathogen activity shortly after collection, there is the possibility that these stems will be more susceptible to mortality following fire in the future. All stems (except those that had experienced a prescribed fire following collection) extruded high amounts of resin as a defense mechanism to insects and rot. Mechanical wounding of a tree will lead to an increase in resin flow into the wounded section (Lombardero et al., 2006). On three individual trees that were located within an area that experienced a prescribed fire following sampling, we observed that this increased resin of the section cavity was consumed by the fire. It is possible that future prescribed fires or wildfire could influence the mortality of sectioned trees by eroding away parts of the holding wood and further weakening the structural stability of the tree (Santoro et al., 2001). A similar study in Oregon and Washington found 11 years after collection, 70% of the partial cross section trees that had died following sampling could be attributed to multiple prescribed fires (Heyerdahl and McKay, 2008). However, the same study also noted that these prescribed fires also killed a large number of catfaced ponderosa pine that were not sampled. We intend to continue to monitor these sampled trees into the future in order to elucidate longer-term mortality patterns that may result from partial cross section sampling and future fires.

4.2. Management implications

Fire history studies usually focus on obtaining the longest and most inclusive record of fires possible, and as a result most trees that are sampled are the largest and oldest trees in a stand. Often, it is these trees that contribute significantly to the structure and function of forest ecosystems (Franklin et al., 1987; Hansen et al., 1991). While the collection of complete or partial cross sections from dead trees is a common procedure, partial cross sections from live trees may also be important data sources for developing a fire history especially in areas where there are not sufficient numbers of dead stems from which to collect partial or full cross sections. However, the collection of partial cross sections from live trees often conflicts with the conservation of large, old, fire-scarred trees, especially in natural areas. There may also be issues associated with 'standards of care' typically associated with the management of wildlife and danger trees that may be a liability to the natural resource organization (Cochrane and Daniels, 2008). For example, in areas that may be utilized for hunting or recreation, the increased risk these partial cross-section trees create may not be justifiable or permissible.

A primary issue that resource managers who are considering the removal of partial cross sections face is the increased likelihood of tree mortality that will result from partial cross section removal. While the overall decision whether or not to allow sampling will be driven by the specific needs and mandates of the resource organization with land management responsibility, there may be instances where the information gained from the use of partial cross sections outweighs the potential impact to the individual trees. If we assume a background natural mortality rate of 1–2% per year for mixed-pine forest stands that have mean stem densities of 100 stems ha^{-1}, as we have observed at SWA (Drobyshev et al., 2008b), and we consider an example where a total of five trees are sampled per stand and all die over a 5 year period, then we could assume an increase in the baseline annual mortality rate to only 2–3% over that time period. For the resource managers at SNWR, the information gained on fire history by obtaining cross sections of live trees outweighed the potential impacts and mortality caused to the sampled stems and has proved invaluable to the progressive management of fire dependent ecosystems at SNWR.

Our results suggest that if resource managers decide to allow the collection of partial cross sections from live trees, they should consider the following. First, resource managers should stipulate that no more than 20–25% of the total stem area be removed from the sampled tree, allowing for a 5–10% margin of error when extracting the partial cross section with a chain saw. This estimate can be determined by measuring the tree diameter at the sample height (subtracting the bark width which represents the support structure for the tree) and then by carefully considering the dimensions of the partial cross section (horizontal width and depth, and vertical depth) to be removed so that it optimizes the amount of information included on the sample. Once these dimensions are calculated, the total area of the partial cross section can be determined. If the extracted area exceeds 20–25%, then a decision should be made regarding whether the tree should be sampled, taking into consideration the availability of other potential recording trees in the area and other issues. Second, resource managers should stipulate that partial cross sections be, when possible, removed from the center of the catface rather than the catface edge. In cases where the catface edge is sampled, efforts should be made to reduce the total amount of area removed with the partial cross section. Finally, because our results, as well as those of Heyerdahl and McKay (2008), suggest that the resin in the sampling cavities may not remain after repeated fires, resource managers should understand that mortality from insects, rot, or windthrow is likely more probable as the structural support for the tree and its physiological state is negatively impacted due to sampling.

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