Encyclopedia of Scientific Dating Methods
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Dendrochronology, Fire Regimes

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Definition

Use of tree-ring data and methods to reconstruct past fire timing, fire regimes, and fire effects on individuals, communities, and ecosystems.

Introduction

Fire directly or indirectly affects woody plants in many ways, some of which will leave evidence in age or growth patterns in individual trees or community structure that can be cross-dated using dendrochronological methods. This evidence can be used to reconstruct past fire dates, fire regimes, and fire effects on individuals, communities, and ecosystems ("pyrodendroecology"). Fire regimes are defined as the combination of fire frequency, severity, size, seasonality, and relationships with forcing factors such as climate or changes in human land use.

Fire Evidence in Trees and Community Structure

A common type of fire evidence is from severe fire that kills all or most trees in an area which opens up space for new trees to establish. Even-aged forest structure is often used as evidence of past lethal fire, also referred to as "stand-replacing" fire. Such evidence provides a minimum date for the fire (i.e., the fire occurred sometime before the innermost dates of the oldest trees), and, by sampling multiple stands in an area, estimates of the fire size can be made based on broader-scale patterns of tree ages. Conversely, multiaged structure is considered to be evidence of less severe fires or other patchy mortality and recruitment events. Note that a dating limitation to age structure studies is that rarely are total tree ages able to be reconstructed. Tree ages are usually derived from increment cores or cross sections collected at a height above and several years after the date of seedling germination. Often cores or sections for age structure studies are collected low on the tree bole (e.g., 10–30 cm above ground level), and some studies have applied a correction factor to estimate germination dates from sample-height pith dates. However, regardless of these methods, generally age structure data are not accurate to exact years of tree germination.

Another commonly used line of evidence of past fire is from fire scars (Fig. 1). Fire scars are areas of cambial mortality resulting mainly from lower intensity fires that burn through surface fuels such as leaf litter, grasses and other herbaceous plants, or shrubs. If the cambium is killed all the way around the tree circumference, the tree is girdled and dies. However, if only a portion of the cambium is killed, a fire scar is formed and the tree continues to live. The formation of a fire scar is

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Fig. 1 (*Left*) A *Pinus ponderosa* stump with a fire-created “catface” facing to the right. The catface was formed from repeated fire scars (visible as distinct ridges inside the catface). Bark and sapwood have eroded from the outside of the stump, and only the heartwood is left. The stump was cut with a crosscut saw, placing the date of cutting likely in the late nineteenth or early twentieth century before widespread use of motorized chainsaws. (*Right*) Cross-section sample cut with a chainsaw from a fire-scarred *P. ponderosa* snag (standing dead tree). Dates of fire scars are marked on the section. The tree died in 1916 from a bark beetle attack as evidenced by blue stain in the small remnant of sapwood visible at the top of the photograph. Most of the sapwood has decayed since the tree died, limiting the amount of time that a death date could be established (Photograph credits: P. M. Brown)

a function of both bark thickness (thicker bark helps to insulate the cambium) and the intensity of the fire (a certain temperature is necessary to kill the cambium through the bark). After scar formation, circumferential growth will continue from the margins of the dead cambial zone, often completely regrowing over the scar unless the area is burned again in a subsequent fire (Smith and Sutherland 2001). After a tree has been scarred once, rapidly growing woundwood on the scar margins tends to have thinner bark making it more susceptible to subsequent fires. Because of this susceptibility, long sequences of multiple fire scars are often found on trees in forested ecosystems that experienced frequent, episodic, low intensity fires, such as many dry *Pinus* ecosystems around the world (Falk et al. 2011; Fig. 1 right).

Fire scars can usually be dated to their exact year of formation within a cross-dated ring series. Fire frequency is derived from sequences of composited fire-scar records found on multiple trees in a stand or study area. Seasonality of burning also can be estimated from the position of the scar within the annual ring and knowledge of the general seasonal timing of cambial growth for a species and location. The presence of a fire scar on a tree implies that the fire that formed it was relatively low intensity and nonlethal, at least at the scale of the individual tree. By compiling dates of fire scars from multiple trees or plots across a landscape, the relative sizes and severities of past fires can be estimated with a great deal of accuracy (Farris et al. 2010). Increasingly, fire history studies use both tree age structure and fire-scar data to develop more complete estimates of the frequency and patterns of lethal and nonlethal burning across a study area (Brown et al. 2008). Furthermore, the accuracy of annual fire dates provided through dendrochronological cross-dating permits comparison of fire timing between sites, mountain ranges, and regions and with independently derived tree-ring reconstructions of climate variables (Swetnam and Brown 2010).

Important insights into historical fire climatology have been made owing to the accuracy of fire dates provided through regional networks of fire-scar records (Falk et al. 2011).

Other evidence of fires recorded by trees includes tree death dates and tree growth responses. Trees killed by fire can be dated by cross-dating with living trees. However, sapwood typically does not last very long after a tree is dead (even on standing dead trees, sapwood lasts at most a few decades; Fig. 1 left), which limits the length of time that this line of evidence can be used to reconstruct fire-caused mortality. Growth responses include abrupt growth suppressions or releases. For example, a growth suppression may occur after a fire as a result of severe scorching of a tree canopy. A growth release may occur as a result of neighboring trees being killed with a subsequent loss of competitive pressure on the surviving tree. Other responses include traumatic resin ducts or other ring features that indicate injury to the tree (Brown and Swetnam 1994).

A note of caution is warranted here, in that many other environmental factors may leave similar evidence in trees as those resulting from the effects of fire. For example, lighting and other injury events may partially kill the cambium and leave a scar in the ring series. The approach used by most studies has been to composite potential fire evidence from multiple trees in a stand or study area and depend on synchronous patterns as indications of fire timing and effects. For example, lightning will result in a scar on only a single tree in any given year, whereas fire scars will be recorded on several trees in the same year due to the spreading nature of fire within a stand of trees. Conversely, not all fires that burn at the base of a tree will leave a fire scar or other fire-caused evidence, and again compositing evidence from multiple trees is a usual step to compile more complete spatio-temporal fire histories (e.g., Farris et al. 2010). Dendrochronological cross-dating is, of course, crucial in these studies to provide absolute calendrical dates for fire evidence to assess synchronous or asynchronous patterns within and between trees, sites, or regions.

Application of Dendrochronological Fire Regime Studies

Studies using pyrodendroecological data have generally had three broad and often overlapping goals: (1) to document and characterize past fire effects on ecosystem processes, structure, and function across spatiotemporal scales; (2) to understand how fire regimes have been affected by forcing factors such as temporal or spatial changes in climate, human land use, and vegetation (fuel) structure; and (3) to develop historical information used in forest and ecosystem management. Pyrodendroecological data provide understanding of fire as an ecological process over periods longer than those available from typical ecological studies or even instrumental or observational records. For example, a major focus of many pyrodendroecological studies has been to examine longer-term (multi-decadal to multi-centennial) variation in fire climatology (Swetnam and Brown 2010; Falk et al. 2011). Fire history and other dendroecological data also provide "historical ranges of variability" in disturbance regimes and forest structure for ecological restoration efforts intended to restore ecological processes in degraded, damaged, or mismanaged forested ecosystems (Brown et al. 2008). This is especially the case in western North America where fire suppression efforts over the past century have led to profound changes in forest and fuel structure and fire regimes in many "fire-adapted" dry conifer ecosystems (e.g., Friederici 2003).

Conclusion

Dendrochronological methods are useful for dating, reconstructing, and interpreting past fires, fire regimes, and fire effects on individuals, communities, and ecosystems. Multiple lines of evidence of fire and its effects are recorded in tree-ring series, and many of these can be dated to the exact year and even season of formation. Pyrodendroecological data are useful not only for dating of fires but, more importantly, for understanding the role of fire in ecosystem structure and function; for understanding the role of climate, human land use, and vegetation structure on variations in fire regimes; and for current and future management of ecosystems around the world.

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