Fire History of a Douglas-Fir-Oregon White Oak Woodland, Waldron Island, Washington

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Abstract

The last 100 years have seen a marked decline in Oregon white oak woodlands in the Puget Sound region. Efforts to restore the woodlands cannot hope to be successful unless the role fire has played in maintaining them in the past is understood. A fire scar chronology was constructed from a *Pseudotsuga menziesii–Quercus garryana* community within a 155 ha study site on southeast Waldron Island, Washington. Sixty-two scars were identified on 15 crossdated *Pseudotsuga* samples that documented fire events between 1530 and 1908. A master tree-ring chronology was created for the period 1685 to 2004. Composite fire intervals and individual-tree fire intervals were used to characterize the fire history. Seasons of past fires were determined by analyzing fire scar position within annual ring structure. For the historical period 1700-1879, the composite mean fire return interval (FRI) was 7.4 yrs, and the mean individual-tree FRI was 18.4 yrs. The historic period mean individual-tree FRI was 18.4 yrs. In contrast, only three fires were recorded during the settlement/modern period (1880-2004), resulting in a mean individual-tree FRI of 103.8 yrs. Seasonality of past fires indicates that most fires occurred during late summer and fall. No evidence of spring or early summer burning was detected. Our study of the fire history for a site on Waldron Island shows a marked reduction in fire frequency between the historical and settlement/modern period, which we interpret as reflecting declines in Native American population size and activity and the eventual cessation of deliberate ignitions by Native Americans.

Introduction

Fire has been an important agent of disturbance in *Quercus garryana* (Oregon white oak) and associated prairie ecosystems throughout the Willamette Valley-Puget Trough-Georgia Basin ecoregion (Habeck 1961, Taylor and Boss 1975, Kruckeberg 1991, Franklin and Dyrness 1988, Agee 1993). Ecologists and ethnobotanists generally consider these fires to have originated largely as the result of Native American activities (White 1980, Agee 1993, Boyd 1999a, Turner 1999). However, the precise nature of historical fire regimes—the frequency, severity, seasonality, and variability—remains poorly understood (Agee 1993, Fuchs 2001). Evidence of past fires in the form of fire-scarred trees is scarce, entirely lacking, or has not been studied. Further, much of the knowledge surrounding the historical use of fires by Native Americans in the ecoregion has been lost.

Q. garryana and prairie ecosystems in the region were significantly altered following Euro-American settlement in the mid-1800s. Extensive degradation and loss of these native plant communities resulted from urban development, livestock grazing, and conversion to agriculture (Dunn and Ewing 1997, Chappell et al. 2001, Fuchs 2001). Fire suppression and lack of deliberate ignitions in coastal *Q. garryana* communities over the last century has led to major structural and compositional changes, primarily in the form of conversion of woodlands and savannas to more closed, conifer-dominated forests (Franklin and Dyrness 1988, Kruckeberg 1991, Chappell and Crawford 1997, Ewing 1997). The encroachment of *Pseudotsuga menziesii* (Douglas-fir) and other woody vegetation in these areas has been widespread (Agee and Dunwiddie 1984, Kertis 1986, Agee 1987, Sugihara and Reed 1987b, Salstrom 1989, Gedalof et al. 2006). Along with introductions of non-native species such as *Cytisus scoparius* (Scots broom), *Hypochaeris radicata* (hairy cats-ear), and common pasture grasses (e.g., *Holcus lanatus, Agrostis capillaris, Dactylis glomerata, Bromus diandrus, Poa pratensis)*, encroachment-driven changes have led to the decline and/or local extirpation of flora and fauna associated with these ecosystems (Dunn and Ewing 1997, Fuchs 2001, Thyssel and Carey 2001).

The decline of *Q. garryana* and associated species has resulted in a growing interest in the restoration of ecosystem components and processes associated with

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oak and prairie communities (Agee 1996b, Larsen and Morgan 1998, Bayrakci et al. 2001, Fuchs 2001, GOERT 2002). Prescribed fire is one restoration tool that has been applied experimentally to limited areas of these ecosystems in Pacific Northwest (Sugihara and Reed 1987a, Schuller 1997, Tveten and Fonda 1999, Dunwiddie et al. 2001, Regan and Agee 2004, MacDougall 2005). However, uncertainties surrounding the historical role of fire add complexity to an already difficult conservation challenge (Agee 1996a).

Mixed oak–conifer woodlands often occur in Washington in the ecotone between open prairie and conifer forest (Stein 1990). Fragments of this community type can be found in the San Juan Islands of Puget Sound. Although heavily altered by extensive infilling of *P. menziesii*, one of the largest remnants occurs at the southern end of Waldron Island (Sprenger et al. 2005). Within this mixed oak–conifer woodland, we hypothesized that enough older *P. menziesii* remain with recoverable fire scars to allow reconstruction of a fire history using dendrochronological methods. Describing the historical nature of fire in *Q. garryana* communities has important implications for understanding ecological processes as well as informing management and conservation of these increasingly rare communities.

Dendrochronological tools, including the use of crossdated tree rings, have rarely been applied to *Q. garryana* communities or met with limited success in attempts to document past fire occurrences (e.g., Agee and Dunwiddie 1984, Kertis 1986, Agee 1987, Peterson and Hammer 2001, Spurbeck and Keenum 2003, Gedalof et al. 2006). Sites that are sufficiently large and also retain intact, mature trees are rare, many are managed as protected areas and do not allow the use of the instruments commonly used in fire history sampling (e.g., increment borers, chainsaws). Additionally, large, old *P. menziesii* trees on these sites that may have contained fire scars have been logged off, and the remaining oaks tend to be much less reliable recorders of fire occurrences (Agee 1993).

The primary objective of this study was to describe the fire history of mixed oak–conifer woodland along the southern portion of Waldron Island in the northern Puget Trough. The specific objectives were to: 1) Document the frequency and temporal variability of historical fires, 2) Evaluate seasonality of historical fires, and 3) Identify the likely source of historical fire ignitions.

Study Site

The 155-ha study site is located in the southeast portion of Waldron Island (48°41′ N, 123°02′ W), a 11.8 km^2 island in the San Juan archipelago (Figure 1). These islands fall within the rain shadow of the

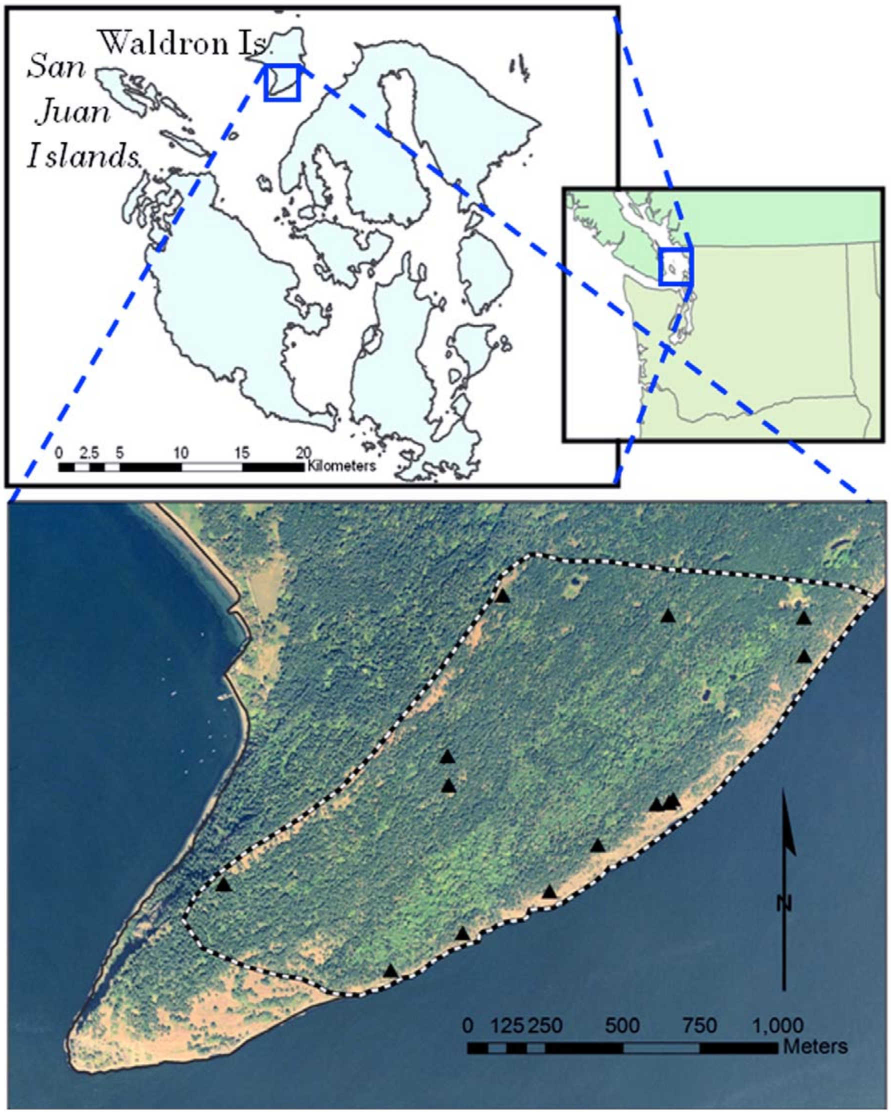

Figure 1. Location of the study site on Point Disney, Waldron Island, Washington. Aerial photograph shows study site boundary and includes locations of fire scar samples.

Olympic Peninsula. Mean annual rainfall is 72 cm, with roughly 70% falling between October and March (Olga, WA, 1971-2000; U.S. National Climatic Data Center, Asheville, North Carolina). The study site lies east of the northeast-southwest ridgeline of Point Disney and largely encompasses two preserves: the San Juan Preservation Trust's Waldron Preserve to the north, and The Nature Conservancy's Bitte Baer Preserve to the south. The site has moderate slopes (14°–19°) with a predominantly southeastern aspect.

The geology of the site is characterized by a raised and rocky terrain, composed mostly of fine-grained marine sandstone with underlying layers of conglomerates (Baichtal 1982). Considerable deformation is evident in the structure of the ridges of exposed rock, which diagonally cross the slopes. Soils are classified as the Roche-Rock outcrop complex and pure Rock land, and are typically thin and poorly developed (Schlots 1962). The extreme southern extent of the study site was quarried during 1906-1908, when substantial portions of the sandstone cliffs were removed through blasting (Ludwig 1972).

Currently, forest is the dominant vegetation of the study site, although small remnants of grassland and woodland exist as well (Sprenger et al. 2005). The principal tree species is *P. menziesii*, which is present over a wide range of age and size classes (up to 450 yrs, 140 cm DBH). *Arbutus menziesii* (Pacific madrone) and *Juniperus maritima* (seaside juniper) are scattered throughout. *Q. garryana* is rare but present within the densest stands of the study site, becoming more common toward the southern half, and along the narrow, open ridgeline that forms the northeast–southwest divide of the site. Oak and mature *P. menziesii* also occur in roughly equal mixtures on a 10 ha bench bordering the grasslands. Within the closed forest portions of the study site, remnants of the *P. menziesii/Symphoricarpos albus–Holidiscus discolor* association and the *P. menziesii/Arbutus menziesii/H. discolor–Lonicera hispidula* association can be found. Bordering these are intact examples of *P. menziesii/Q. garryana/S. albus* woodlands.

Two lines of evidence suggest historical stand structures were much more open than today. First, many of the mature *P. menziesii* have large, low-hanging limbs, characteristic of trees that had been growing in savannas. Second, a comparison of U. S. Geological Survey aerial photos (1965 vs. 2004) depicts an increase in tree density in woodlands, and encroachment into the open grasslands.

Native American settlement and land use activities have been documented as far back as 10,000 yr BP in the Puget Trough (Weiser and Lepofsky 2009). Considerable evidence exists for the widespread use of fire and other practices by Coast Salish and Lummi peoples to improve conditions for hunting and to promote growth of plants used for food, fiber, and other purposes (Suttles 1974; Turner 1975, 1999, 2001). Some of the important foodstuffs for local peoples living in and around the San Juan Islands have all been documented on Point Disney, including *Camassia quamash*, *Fritillaria lanceolata*, *Allium cernuum*, and *Brodiaea spp*. (Habegger, 1996).

There is considerable uncertainty regarding the pre-contact size of the Native American population in the San Juan Islands. However, the introduction of smallpox and other lethal diseases into the Puget Sound region in the 1770s began a period of rapid population decline in many of the villages. Within a century, it is estimated that the Coast Salish population had been reduced by 70-80% (Boyd 1999b). Euro-American settlement of the San Juan Islands began in the late 1850s, with settlement on Waldron Island beginning about a decade later (Ludwig 1972). By the early 1870s a small number of farmers were living on Waldron Island—all of them along the shore of Cowlitz Bay in the western portion of the island. Sheep grazing began in the late 1870s on Point Disney. Significant logging occurred on portions of Point Disney during the 1940s, 1950s, and 1968-1972 (Ludwig 1972; William Carlson, San Juan County logger, pers. comm.), but likely some cutting of trees coincided with quarry activities on the point during 1906-08.

Methods

We obtained twenty-nine samples in the spring of 2004 by removing either partial (live trees and snags) or complete (down logs and stumps) cross sections of *P. menziesii* (Arno and Sneck 1977) (Figure 2). Samples were selected based on highest number of visible fire scars and the relative soundness of wood. Because the objective of sampling was to obtain close to a complete inventory of fire dates (Swetnam and Baisan 1996), while restricting destructive sampling (< 30 live trees), a targeted sampling approach (Baker and Ehle 2001) was used as opposed to a stratified random design (Johnson and Gutsell 1994). Selecting trees with multiple scars, as long as they are well distributed across the landscape, should provide the most complete fire record (Swetnam and Baisan 1996, Fulé et al. 2003).

We collected increment cores for a master ring-width chronology from 20 dominant, non-scarred, and climatically sensitive *Pseudotsuga menziesii* trees (Stokes and Smiley 1968, Fritts 2001). Cores were mounted and

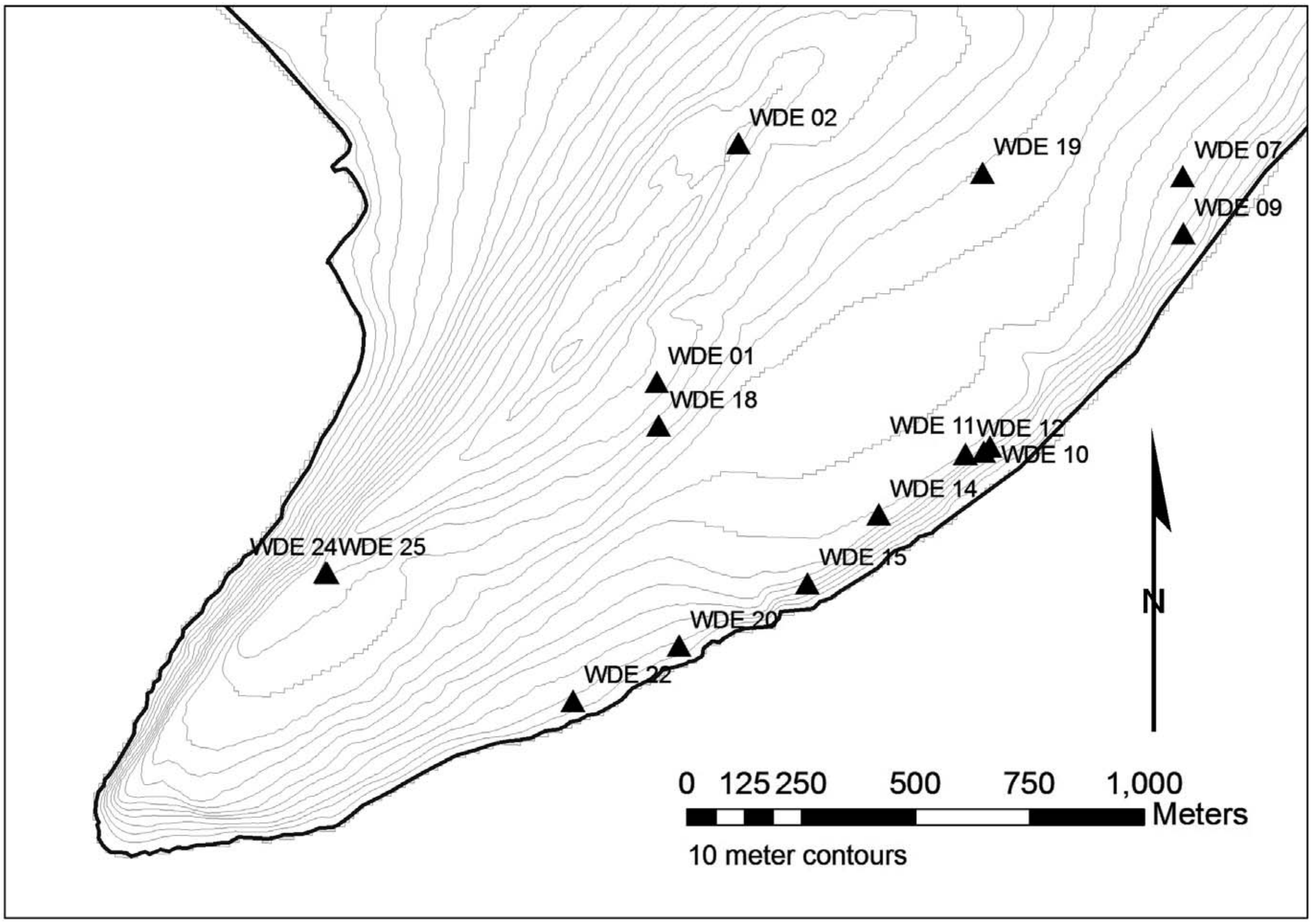

Figure 2. Locations of labeled fire scar samples on map of southeastern Waldron Island.

sanded until the growth rings were clearly visible. Ring widths were individually measured using a sliding stage measuring system to the nearest 0.01 mm (Robinson and Evans 1980). Rings were analyzed for measurement and crossdating errors using COFECHA (Holmes 1999; 20 series measured, allowing crossdating from 1685–2004; average mean sensitivity = 0.282, series intercorrelation = 0.618).

Fire scar cross sections were dried, mounted to backing boards, and sanded with progressively finer sandpaper until a smooth polish was achieved and individual cell walls were clearly visible. Fire scars were identified by the characteristic band of killed cambium tissue and the associated patterns of radial growth healing (McBride 1983). Scars were carefully examined to avoid confusion with other forms of tree injury (Gara et al. 1986). Ring counts on all samples were conducted prior to crossdating, noting year and intra-annual position of each fire scar. A scar's position within the annual ring (earlywood, latewood, or dormant) allows for a fire's seasonality to be determined (Baisan and Swetnam 1990). Ultimately, due to a combination of decay and insect damage, only 14 of the 29 cross sections were used to generate a fire chronology for the site.

Samples from live trees were crossdated using the site's master chronology (Stokes and Smiley 1968). Rings from samples originating on dead wood were measured and analyzed using COFECHA (Holmes 1999). After calendar years were assigned to samples, rings were visually d against the master chronology to insure that correct dates were applied.

Data Analysis

We analyzed fire return intervals (FRI) over two time periods: historical and settlement/modern. The historical period began with the first fire-year recorded by 20% or more (n = 4) of the total number of recording trees (n = 15) (Grissino-Mayer 2001) and ended on the last fire-year during the decade when direct influence from Euro-American settlers was light or not yet present (1870s). The settlement/modern period spans from 1880-2004.

For both time periods, FRI were analyzed using an individual-tree method and a composite method (Romme 1980). Individual-tree FRI were derived from individual sample locations in the following manner: ten sample locations represent individual samples; two locations combine 2 and 3 samples (WDE 25 and WDE 11, respectively). Samples were combined due to their close proximity to each other (mean distance apart = 29 m, range 3 - 56 m; Agee 1993). Individual-tree FRI will not account for every fire as trees are imperfect recorders of fire (Deiterich and Swetnam 1984) and not every fire will burn every tree. Fires can also consume the evidence left by previous fires (Brown and Swetnam 1994). Though the individual-tree FRI tends to overestimate the population fire return interval (Agee 1993), it provides greater comparisons with other studies using these methods.

Composite intervals were calculated from the combined record of fire dates, incorporating every fire from the entire study site and were analyzed using FHX2 software (Grissino-Mayer 2001). Statistical analysis of individual-tree and composite fire intervals using FHX2 (Grissino-Mayer 2001) included mean, median, and the Weibull median probability interval (WMPI). Intervals were tested to determine if a Weibull distribution modeled the data better than a normal distribution using a one-sample Kolmogorov-Smirnov Goodness-of-Fit Test (Grissino-Mayer 1995, Zar 1999). WMPI provides an improved measure of central tendency in skewed fire interval distributions (Grissino-Mayer 1995). WMPI can be interpreted similarly to the mean fire return interval (MFI) based on the normal distribution and has been applied to both low- and high-severity fire regimes (Agee 1993, Grissino-Mayer 1995, Fulé et al. 1997, Wright and Agee 2004).

Variability of fire intervals was measured using the following techniques: the range, the minimum and maximum fire-free interval; the standard deviation of the MFI; and the Weibull confidence interval (WCI), the theoretical fire intervals associated with the 87.5% and 12.5% exceedance probability levels for a given Weibull distribution. The WCI identifies the extreme 25% of all intervals and has been suggested as a guide for reintroducing fire to follow historical patterns (Grissino-Mayer 1999).

Results

We identified sixty-two crossdated fire scars from 15 samples (Figure 3). These scars represented 31 different fire-years from 1530 to 1908. Two samples recorded only a single fire occurrence, 13 samples recorded multiple scars, and one sample recorded 13 fire events (Figure 3). Widespread fires (≥ 4 scarred trees) occurred during the years 1807, 1817, and 1834. The first fire-year that represented 20% or more of recording trees was 1700. The last fire-year of the decade preceding direct influence on the site by Euro-American settlers was 1879.

The results of the Kolmogorov-Smirnov Goodness-of-Fit test show that the Weibull distribution is a better fit for the fire interval data than the normal distribution. These results are consistent for the individual-tree frequencies and the composite frequencies (Tables 1 and 2). The settlement/modern period (1879-2004) had too few intervals to test for a fit with the Weibull; these results are presented as mean and median values only (Tables 1 and 2). Historical period (1700-1879) fire frequency (WMPI) for composite intervals is 7.4 yr (range 2-31; Table 1). Individual-tree fire frequency (WMPI) for the same period averaged 18.4 yr (range 3-156; Table 2).

Settlement/modern period fire frequency (MFI) for composite intervals is 37 yr (range 5-96). The maximum length fire-free interval is 96 yr. The individual-tree MFI for the same period is 103.8 yr (range 96-111).

Thirteen of the 15 crossdated fire scar samples exhibited noticeable damage from past insect attacks in the form of frass-packed galleries. Galleries tended to be restricted to the fire damaged regions and in some cases obscured a large enough portion of the fire scar to make it undatable. Some samples contained regions so impacted by insect decay and resin saturated wood that it was impossible to determine whether a fire scar was present at all. Although no insect body parts were found, gallery shape and frass texture indicates that members of the *Buprestidae* family were the most active in colonizing the fire-scarred trees (Edmonds et al 2000).

The season of past fires, based on fire scar position within annual rings, was identifiable on 30 out of the 62 scars analyzed. Of these, 40% (12) were classified as dormant season scars and 60% (18) were classified as late season scars. No fires appear to have burned during earlywood formation.

Discussion

This study documents the fire history of a *Pseudotsuga menziesii—Quercus garryana* woodland in the Puget Trough using full and partial cross sections. The removal of cross sections allowed more thorough analysis and interpretation of the fire scars contained within the tree-ring samples. The 250-450 year old trees that contained this information are a fading resource not

TABLE 1. Summary of composite fire interval analysis. SD.: standard deviation; MFI: mean fire interval; WMPI: Weibull median probability interval; *P*: p-value for failing to reject the null hypothesis that the fire interval data can be modeled using a Weibull distribution; WCI: Weibull confidence interval, the theoretical fire intervals associated with the 87.5 and 12.5 percentiles, respectively.

Analysis Period	No. of intervals	Mean (MFI)	Med.	SD	Range	WMPI	*P*	WCI
Historical (1700-1879)								
All scars	21	8.5	6.0	6.8	2-3.1	7.4	0.77	2.4-15.8
Settlement / Modern (1880-2004)								
All scars	3	37†	10	51.2	5-96	-	-	-

† Because the settlement/modern period included calendar year 2004 and no fires were detected after 1908, this last interval is a *fire free interval*.

TABLE 2. Summary of individual-tree fire interval analysis. Individual-tree fire intervals were analyzed across the historical and the settlement/modern time periods. SD: standard deviation; MFI: mean fire interval; WMPI: Weibull median probability interval; *P*: p-value for failing to reject the null hypothesis that the fire interval data can be modeled using a Weibull distribution; WCI: Weibull confidence interval, the theoretical fire intervals associated with the 87.5 and 12.5 percentiles, respectively.

Analysis Period	No. of intervals	Mean (MFI)	Med.	SD	Range	WMPI	*P*	WCI
Historical (1700-1879)	33	25.7	17	32.9	3-156	18.4	0.469	3.7-53.1
Settlement / Modern (1880-2004)	7	103.8†	106	7.5	96-111	-	-	-

† Because the settlement/modern period included calendar year 2004 and no fires were detected after 1908, this last interval is a *fire free interval*.

likely to persist much beyond a century (Van Pelt and Swetnam 1990).

Analysis of fire scars from Point Disney shows that *P. menziesii* trees recorded numerous fire events from the early 16th century up through the early 20th century. However, for several reasons, this chronology likely does not include all fire scars on the sample trees, nor all fires that burned on Point Disney. First, it is reasonable to assume that not all fire scars were located in the portion of each tree trunk that was typically sampled for partial cross sections. This was made evident in sample WDE 11 (Figure 3), which was one of two samples (out of 15) to be removed as a complete, rather than partial, cross section. On this sample, only eight of the 13 identified scars were located on the face of the main fire scar on the tree, the region that is typically sampled for partial cross sections (Arno and Sneck 1977). If this tree is typical of the larger stand, nearly 40% of scar-forming fires may not be represented in the partial cross section samples. Second, portions of the fire record are obscured by damaged or missing wood (e.g., decay, beetle galleries, burned material). We cannot estimate what proportion of fire scars may have been missed because of this damage. However, since nearly half of the original 29 samples were undatable and not included in the chronology, it is likely that significant portions of the fire record were obscured. Third, trees are imperfect recorders of fires, and not all fires scar every tree. Many fires are patchy and do not thoroughly burn across all areas of a site (Morrison and Swanson 1990). Furthermore, historical fires burning in the short grass and shrub fuels underneath oak woodlands would typically be rapidly moving fires, and may not have produced enough sustained heat to produce scars on the thick-barked, fire resistant *P. menziesii* trees (Agee 1993). Therefore, the absence of a fire scar on a tree does not necessarily translate into the absence of fire. Considering the above, the results of the site's fire chronology should be interpreted as a conservative estimate of the true population fire history.

The distribution of fire scar samples obtained from the site is not uniform, even though ground surveys designed to detect the presence of fire scarred trees was thorough and systematic. A somewhat linear grouping of samples is conspicuously located along the southeastern shoreline and relatively few samples

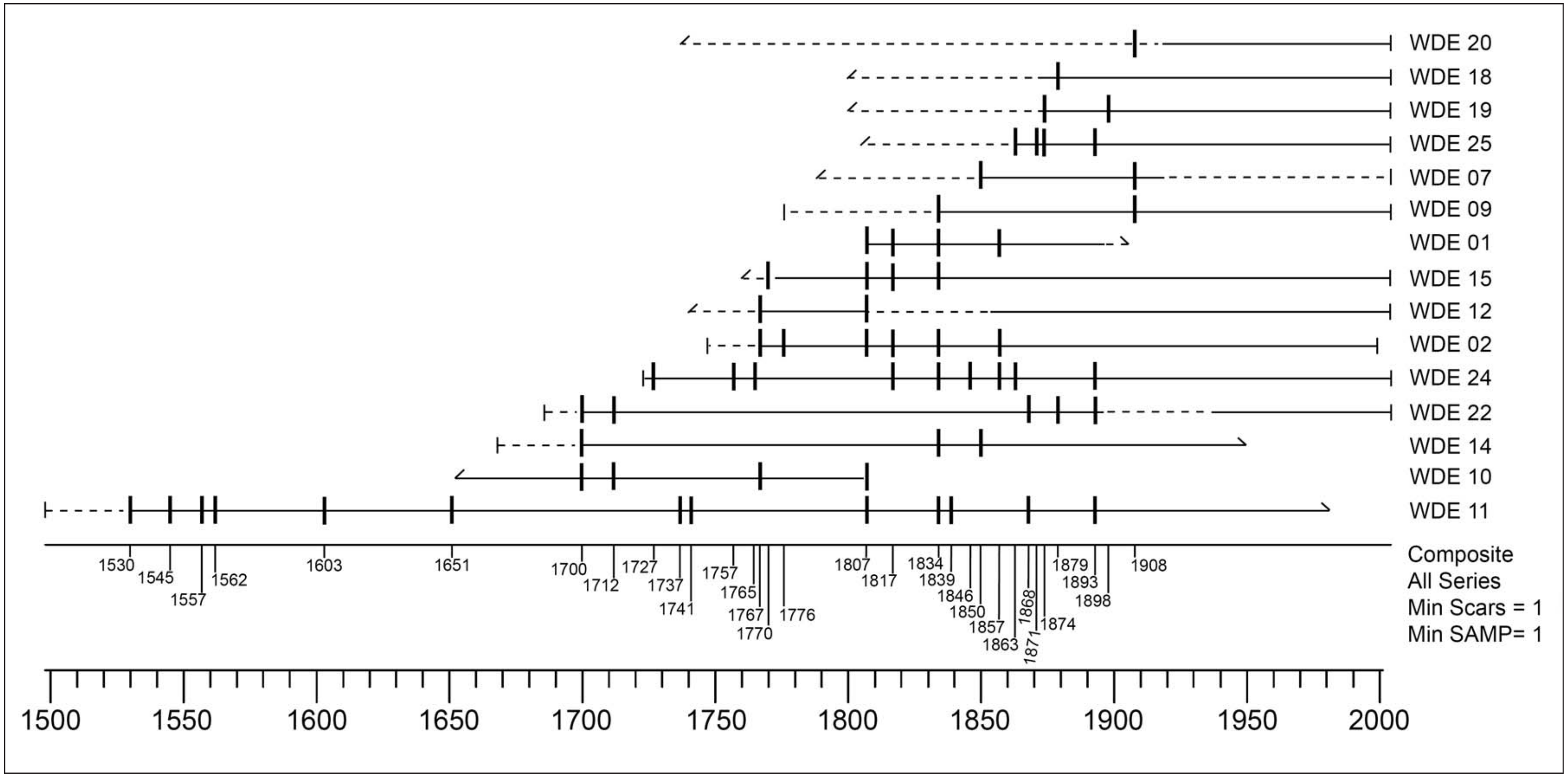

Figure 3. Complete fire history of *Pseudotsuga menziesii—Quercus garryana woodland*, Waldron Island, Washington. Horizontal lines represent each of the 15 crossdated samples collected from the site. Solid lines are recorder years, dashed lines represent null years (years that either preceded the first recorded fire scar or years that were later obscured by fire or other damaging agents). Bold vertical bars denote known fire-years; vertical endpoints are pith and bark years; and diagonal endpoints represent ring years.

are located throughout the interior (Figure 2). The most probable reason for this pattern relates to the history of logging; we conclude that the abundance of stumps observed in some areas reflects the intensity of prior timber harvest. Also noted was the apparent absence of stumps associated with steep and rocky terrain. In particular, the first 100-200 m of steep terrain abutting the shoreline contains relatively little evidence of past timber extraction. In the absence of logging the distribution of fire scars would likely be much more uniform.

The chronology of fire events reconstructed from southeastern Waldron Island shows that frequent, recurring fires have been a component of this site for at least four centuries. Fire history studies useful for comparison include those from Lopez Island (Spurbeck and Keenum 2003) and Orcas Island (Peterson and Hammer 2001, Higuera et al. 2005), all within the San Juan Islands. Most similar in methodology and vegetation type are the three centuries of reconstructed fire histories from Iceberg Point and Point Colville, two sites on southern Lopez Island (Spurbeck and Keenum 2003). While *Q. garryana* does not occur at either Lopez site, both contain dry grassland and rocky outcrop plant communities similar to southern Waldron Island. As with most native grasslands throughout the Puget Trough, the Lopez sites are experiencing a loss of open habitats due to encroachment of shrubs and conifers (Dougherty 2004). Analogous to our study, Spurbeck and Keenum (2003) documented frequent recurring fire events from the middle of the 17th century up through the late 19th century. This period was also referred to as a historical period and for the two sites yielded a mean FRI of 11.4 yr at Iceberg Point and 14.8 yr at Point Colville, about 1.5 – 2 times that of Waldron. The larger size of the Waldron study site (155 ha vs. 25 ha each for the Lopez sites) introduces some scaling issues (Johnson and Gutsell 1994, Baker and Ehle 2001). In particular, it likely increased the number of intact sample trees to select from thus partly explaining the difference in mean FRI.

Both the Waldron and Lopez sites share a marked reduction in the frequency of fire events beginning in the late 19th century. For all three sites, only three fires occurred after 1880. Spurbeck and Keenum (2003) attribute the small number of 20th century fires on Lopez Island to the influence of Euro-American settlers, asserting that settlers would have suppressed fires. Settlement also resulted in the relocation of Native American peoples, effectively reducing or eliminating deliberate human ignitions. Based on the frequency of historical fire occurrences, and the timing of the shift toward very infrequent fires, Spurbeck and Keenum (2003) consider the source of ignition for most of the historical fires at Iceberg Point to be anthropogenic in origin.

Direct comparisons with the two studies on Orcas Island (Peterson and Hammer 2001, Higuera et al. 2005) is limited due to differences in methods chosen to detect past fire occurrences. Higuera et al. (2005) constructed a fire chronology to be used in conjunction with rates of charcoal accumulations taken from small-hollow sediments. The millennial-scale sediment history, combined with several centuries of near annual resolution from tree ring information, provided a unique and long-term perspective into the site's fire regime. For reconstructing fire events from tree rings, increment core sampling techniques were employed (see Barnett and Arno 1988) as well as analysis of age-structure. Fires from all three severity classes (high, mixed, and low) were detected from across the site, though mean fire return intervals from the fire chronology were not calculated. In general, the more mesic *P. menziesii* forests of this site, falling within the dry *Tsuga heterophylla* zone (Franklin and Dyrness 1988), were characterized as having a high- to mixed-severity fire regime and are thus considered quite different from the more xeric *P. menziesii–Q. garryana* woodlands of Waldron Island.

A better comparison to southeastern Waldron Island is the Peterson and Hammer (2001) site on Orcas Island. One of their objectives was to document structural changes in some relict *P. menziesii* woodlands on the south side of Mt. Constitution. A fire chronology derived from increment cores was also created that documented seven fire occurrences from the mid 18th century to the late 19th century. They considered an absence of any records of fires during the 20th century to be the leading cause for the encroachment of *P. menziesii* in grasslands and savannas across the site. Fire return intervals were not calculated. Like Higuera et al. (2005), Peterson and Hammer (2001) relied on the increment core method of determining fire scar dates (Barnett and Arno 1988), which likely resulted in considerable underestimation of fire occurrence.

Our study's 31-year fire-free interval from 1776-1807 is the longest gap in fire occurrence on Waldron during the historical period. One explanation for this long absence of recorded fire activity is its timing coincident with the first smallpox epidemic in Puget Sound during the 1770s (Boyd 1999b). The high mortality associated with this outbreak likely led to dramatic disruptions in the land management activities of affected peoples. During this long fire free interval, it is likely that both dead and live fuels accumulated significantly. Therefore, it is probably no coincidence that this 31 year fire-free interval was followed by the 3 largest fire-years recorded: 1807, 1817, and 1834.

No clear determination could be made regarding the source of ignition for each of Waldron's past recorded fire occurrences. Lightning storms are uncommon throughout the low elevation zones of Washington, and rarely ignite wildfires in the region (Agee 1993, Gavin et al. 2003). Although several lightning strike ignitions have occurred on other portions of Waldron Island in recent memory (Charles Ludwig, Waldron historian, pers. comm.), we found no records of suppression activity on Point Disney, and it is likely that, given its remote location, very little has taken place. Thus, we conclude the large majority of historical fires on Waldron were deliberate ignitions by Native Americans, and the dramatic lengthening in mean FRI coinciding with the arrival of the first Euro-American settlers and the absence of any recorded fire after 1908 reflect the disappearance of their role in shaping the composition and structure of this fire-adapted landscape.

The results of the seasonality of past fires indicate that all fires burned in the late summer or early fall and no fires burned during the spring or early summer. Spring burning can be done and fine fuels will ignite in the early season if conditions are right (Agee 1993). Thus seasonality of past fires recorded at Waldron Island is likely related to a preference in burning times on the part of the local human inhabitants and should provide guidance to managers in the future use of prescribed fire. Our conclusion that Native American burning on Point Disney occurred during the fall parallels those drawn by Storm and Shebitz (2006) in other Washington prairies.

Management Implications

The absence of frequent, low-severity fires during the 20th century within this *Pseudotsuga menziesii—Quercus garryana* woodland has led to changes in the composition, structure, and ecosystem processes comparable to changes in *Pinus ponderosa* (ponderosa pine) forests described by Covington et al. (1994) in the eastern Cascades. By eliminating a large number of regenerating trees and shrubs, frequent surface fires maintain an open, park-like stand structure and promote low tree densities. At our study site, fire intolerant species such as *Abies grandis* (grand fir), *Acer macrophyllum* (big leaf maple), and to a lesser degree *Thuja plicata*, were much less successful at establishing during periods of frequent fire. Typically, historical fires would have rapidly burned through the understory, fueled by grasses and other fine fuels rather than larger woody fuels. Accumulated quantities of coarse woody fuels, duff and leaf litter would have been low (Agee 2002).

The successful establishment of fire intolerant species can be seen across this study site, as well as throughout many of the modern, post-fire exclusion stands in the San Juan Islands. This change has been accompanied by increased fuel loads, higher tree densities, and the development of ladder fuels (Agee 1987, Peterson and Hammer 2001, Spurbeck and Keenum 2003, Gray and Daniels 2006). These ecological changes have created very different fuel characteristics that, when ignited, will burn with a greater intensity and could develop into much larger fires than those recorded by this fire history (Agee 1993). Rather than surface fires, these stands could burn as high-intensity crown fires, resulting in a mortality of not only younger trees and fire intolerant species, but much of the old-growth *P. menziesii*, *Q. garryana,* and many other important species as well.

This site's long fire-free period during the 20th century has also led to an overall reduction of rare and important open habitats. Waldron's native grasslands and oak communities are currently degraded and have been reduced in area by 50% or more (Sprenger et al. 2005). Some of the rarest species that depended on these communities (e.g., the butterfly *Euchloe ausonides insulanus*, the island marble) have likely gone unnoticed in their decline and may be locally extirpated. The structural and compositional trends attributable to fire exclusion, if left unabated, will undoubtedly lead to the continued loss of rare habitats and the species that depend on them.

The historical fires on Point Disney were frequent and widespread, burning through open, park-like stands. Many of the areas where fires once burned are now altered to such a degree that it would be nearly impossible to restore controlled fire to the landscape without the aid of mechanical fuel reduction treatments. Reducing hazardous fuels and restoring the open structure of these communities should necessarily be the first step toward the development of a prescribed burn plan, if one is pursued. Significant steps have recently been taken to begin this restoration by removing small- and mid-size *P. menziesii* from portions of Point Disney (Dunwiddie et al. 2011). A long-term burn plan will also need to consider recent compositional changes to the flora of Point Disney. As with similar oak dominated sites in the region, the numerous introduced non-native species now present on the site may respond quite differently to fire compared with the native flora (Tveten and Fonda 1999, MacDougall 2005, MacDougall and Turkington

2006). Real and perceived threats to these native plant communities resulting from any active management must be carefully evaluated in an adaptive management context.

If the application of prescribed fire is pursued, the patterns of Point Disney's historical fires should guide the development of a long-term burn plan. Specifically, the use of the Weibull confidence interval (WCI) is recommended as a starting point to inform the frequency of repeated prescribed fires (Grissino-Mayer 1995). Following the WCI, the target mean fire return interval would be 7.4 yr with a variation in return of 2 to 16 yr. However, this should be viewed as a general guide. If, as previously suggested, our record provides only a conservative estimate of historical fire frequency, a more appropriate interval might be considerably more frequent. A 7.4 yr mean FRI may prove to be effective at reducing the density of encroaching *Pseudotsuga menziesii* and woody shrub species within the woodlands; however, it may be insufficient in achieving the conservation objectives within the native grasslands (Tveten and Fonda 1999, Dunwiddie et al. 2001). Season of future burns should follow the historical data and, in general, be restricted to late summer and fall. Exceptions to the recommended frequency, variability, extent, and seasonality of prescribed fires will no doubt be considered given the potential for new and changing conservation goals as well as the feasibility of the actions designed to achieve them. Unquestionably, the reintroduction of fire—following historical patterns or not—will pose new and difficult challenges to the management of Point Disney.

Managers and conservationists interested in restoring and maintaining fire-adapted ecosystems must make difficult decisions regarding the feasibility and appropriateness of re-introducing prescribed burns. The data presented here provide a descriptive ecological context for making these decisions. However, questions about whether to restore these historical processes must be addressed within the political and social context defined by current and future Waldron inhabitants, as well as within the uncertain climatic conditions that may prevail in the future.

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