Ze'ev Gedalof[1], Department of Geography, University of Guelph, Guelph, Ontario, N1G 2W1 Canada.

Marlow Pellatt, Parks Canada, Western Canada Service Centre, 300 - 300 West Georgia Street, Vancouver, British Columbia, V6B 6B4 Canada *and* School of Resource and Environmental Management, Simon Fraser University, Burnaby, British Columbia, V5A 1S6 Canada.

and

Dan J. Smith, University of Victoria Tree Ring Laboratory, Department of Geography, University of Victoria, PO BOX 3050 STN CSC, Victoria, British Columbia, V8W 3P5, Canada.

From Prairie to Forest: Three Centuries of Environmental Change at Rocky Point, Vancouver Island, British Columbia

Abstract

Garry oak (*Quercus garryana*) savannas are among the most endangered ecosystems in Canada. In coastal British Columbia the vast majority of Garry oak savannas have been developed for residential, agricultural, or industrial use. Much of the remaining habitat is threatened by conifer encroachment or invasion by exotics. In this study tree-ring analysis was used to reconstruct stand composition and structure of an oak savanna at Rocky Point, on southern Vancouver Island, British Columbia. At the time of European settlement, the site was largely open prairie, with a few scattered oak trees. Establishment of Garry oak at Rocky Point began shortly after settlement of the area by Europeans—probably due to the cessation of frequent burning by indigenous peoples. Since the 1950s, however, Douglas-fir and grand fir have been encroaching on the Garry oak savanna. The causes of this invasion are unclear, but the invasion signals a clear transition in the stand structure and composition. Oak seedlings are abundant, but few saplings exist—suggesting that oak is not regenerating at Rocky Point. Mechanical removal of conifers would help maintain the Garry oak community over the near future, but given the nearly complete lack of oak recruitment, some restoration of ecosystem processes—most likely fire—will be required to maintain a functioning Garry oak ecosystem. This management strategy will be severely constrained by changes in stand structure resulting from decades of fire exclusion, the potential for weedy exotics to invade the post-fire communities, and the presence of an ammunition depot nearby.

Introduction

Coastal British Columbia is better known for glaciers and temperate rainforests than for prairies or savannas. Nonetheless, along the relatively dry eastern margin of Vancouver Island and in the southern Gulf Islands mixed grass and shrub ecosystems with varying densities of Garry oak (*Quercus garryana*) reach their northernmost limits (Stein 1990). Garry oak associated ecosystems occupy a broad latitudinal range in western North America, extending from southern California to almost 50° N. In British Columbia, they are characterized by a mosaic of disjunct nearly treeless prairies and meadows, open savannas, and closed woodlands. In addition to Garry oak, the tree species most commonly associated with these environments include Pacific madrone (*Arbutus menziesii*), and Douglas-fir (*Pseudotsuga menziesii*). Less common associates include bigleaf maple (*Acer macrophyllum*), grand fir (*Abies grandis*), and shore pine (*Pinus contorta* var. *contorta*). The understory in Garry oak communities supports a diverse range of grasses, herbs and shrubs that often are not found elsewhere in Canada (Fuchs 2001). Garry oak associated ecosystems are home to more than 100 "at risk" species, including 23 that have been identified as threatened or endangered throughout their global range (GOERT 2002). In spite of their ecological significance, over 95 percent of the original Garry oak ecosystems have been severely degraded or converted to urban or agricultural use (Lea 2002). Most of the remnant patches are subject to increased pressure from browsing by ungulates, urban and agricultural expansion, invasive species, and increased fragmentation (Fuchs 2001).

Two broad categories of Garry oak communities are generally recognized in British Columbia. Scrub oak ecosystems typically occur on thin rocky soils that are often excessively drained (Roemer 1993). These communities are usually found on rocky bluffs and outcroppings, and along shorelines. Parkland Garry oak communities occur on

[1]Author to whom correspondence should be addressed.
E-mail: zgedalof@uoguelph.ca

deeper soils, are usually larger in size, and support a distinct array of understory vegetation (Roemer 1993). Parkland sites have been disproportionately subjected to agricultural and urban development over the last 150 years due to their high production and aesthetic values. For example, much of the city of Victoria was formerly occupied by Garry oak parkland (Fuchs 2001). Because the two community types support a distinct assemblage of understory species, they represent distinct conservation priorities. Garry oak parkland is generally seral to conifer forest, and in the absence of perturbations would be replaced by Douglas-fir (Franklin and Dyrness 1973).

The suite of ecological processes that maintain savanna communities in temperate environments are not well understood (Scholes and Archer 1997, Jeltsch et al. 2000, House 2003, Sankaran et al. 2004). The most commonly described processes include edaphic controls (Roemer 1972, Erickson 2002), and anthropogenic burning by indigenous peoples (Agee 1996, Turner 1999, White 1999, Williams 2000). However, the impact of browsing by wild, feral and agricultural ungulates is not well understood (e.g. Vale 1981, Archer 1989, Hibbs and Yoder 1993, Jackson *et al.* 1998). The harvest of camas (*Camassia* spp.) bulbs by indigenous peoples may also have influenced stand structure and composition in Garry oak ecosystems, and may be an overlooked ecosystem process (Beckwith 2004). Lastly, the interactions among these processes, as well as the role of climatic variability, are complex and probably exhibit emergent properties (Scholes and Archer 1997, Jeltsch *et al.* 2000, Laroque *et al.* 2000/2001, House *et al.* 2003, Sankaran *et al.* 2004).

Analysis of sedimentary pollen records indicates that Garry oak first arrived on southern Vancouver Island ca. 8300 years BP (Pellatt *et al.* 2001, Brown and Hebda 2002). Oak pollen abundance reached a maximum ca. 7500 years BP (Pellatt *et al.* 2001), coincident with a westward range expansion (Brown and Hebda 2002). After ca. 7000 years BP oak pollen abundance decreased considerably, suggesting a reduction in the extent of Garry oak ecosystems on southern Vancouver Island (Allen *et al.* 1999, Pellatt *et al.* 2001). Pollen records from southwestern Vancouver Island suggest that the maximum westward expansion of Garry oak occurred from 6500 to 3000 years BP (Brown and Hebda 2002). This range expansion is not matched in records from the nearby Olympic Pensinsula, suggesting that climatic variability is not the only factor influencing the range of Garry oak (Heusser 1960, Brown and Hebda 2002). Furthermore, oak pollen persists in the record even while pollen from temperate rainforest species increase throughout the region, indicating that edaphic or cultural factors may have influenced Garry oak ecosystems during the late-Holocene (Pellatt et al. 2001). Increased abundance of oak pollen generally corresponds to high levels of sedimentary charcoal, supporting the link between Garry oak ecosystems and wildfire (Pellatt *et al.* 2001, Brown and Hebda 2002; see also Leopold and Boyd 1999).

There is good evidence that many indigenous people used prescribed fire in Garry oak ecosystems to promote the growth of food and forage species (Agee 1993, 1996, Leopold and Boyd 1999, Turner 1999, White 1999, Williams 2000). The journals of early explorers throughout the Pacific Northwest are rich with descriptions of intentional burning. For example, during his travels through the Willammette Valley, David Douglas noted: "beautiful solitary oaks and pines… all burned and not a single blade of grass" (cited in Williams 2000). Later Douglas writes: "Some of the natives tell me it [burning] is done for the purpose of urging deer to frequent certain parts… Others say that it's done in order that they might better find wild honey and grasshoppers, which both serve as articles of winter food" (cited in Williams 2000). Thelma Adamson (cited in Leopold and Boyd 1999), while speaking to indigenous informants during the 1920s and 1930s, wrote: "Chiefs make Inds. Burn prairies in Aut., to make grass, strawberries, & black berries grow." An 1849 newspaper article in *The Times* of London reported "Miles of the ground were burnt and smoky, and miles were still burning. The Indians burn the country in order to [promote]…more especially, the roots which they eat" (cited in Turner 1999). As suggested by these quotes, fire was used to encourage the growth of a wide variety of resources. On southern Vancouver Island, the most important resource used by indigenous peoples was probably camas (*Camassia quamash* and *C. leichtlinii*), which was nearly the only source of starch in coastal indigenous peoples' diets (Turner and Bell 1971). Many other important resources were also derived from Garry oak associated ecosystems, including bracken fern (*Pteridium aquilinum*), hooker and wild onion (*Allium acuminatum, A. cernuum*), wild strawberry (*Fragaria* spp.), Saskatoon (*Amelanchier alnifolia*), blueberries (*Vaccinium* spp.), and many others (Turner and Bell 1971).

While it seems clear that anthropogenic fire has affected Garry oak ecosystem dynamics, the ecological role(s) of these fires is less well understood. In particular, the frequency, severity, seasonality, and variability of prescribed wildfire is not known. Also, the effects of those fires on community composition and structure are not well understood. Some Garry oak associates, notably the food and forage species used by indigenous peoples, would likely benefit from prescribed fire. However, few of these species are rare or threatened on the modern landscape. The effects of fire on rare species, and those not used by indigenous peoples, are more difficult to evaluate due to sparse oral records and limited experimental data. Because fire exclusion has been successful at most locations for most of the last 150 years, even at undisturbed sites the modern plant communities will differ from communities that experienced recurring fires. Thus, the reintroduction of prescribed fire— even if historical fire regimes could be accurately reconstructed—would likely not achieve the intended ecological effects due to changes in fuel structure and the presence of invasive exotic species (Agee 1996).

One reason that fuel structures have changed over the last 150 years is that like many temperate savannas (Cole 1977, Vale 1981, Archer 1989, Scholes and Archer 1997, Peterson and Hammer 2001, Lepofsky *et al.* 2003), Garry oak ecosystems are undergoing encroachment by adjacent forests (Barnhart *et al.* 1996, Tveten and Fonda 1999, Fuchs 2001, Thysell and Carey 2001). Climatic and edaphic factors, fire exclusion, herbivory (esp. livestock grazing), competitive interactions, and human intervention have all been identified as contributing factors (Scholes and Archer 1997, Streng and Harcombe 2005), although the relevant processes and synergisms are poorly understood (Archer 1989, Jeltsch *et al.* 2000). Encroachment has been observed at nearly all Garry oak savannas, and poses considerable challenges to the management of these areas (Fuchs 2001, GOERT 2002).

The purpose of this study is to reconstruct the environmental history of a Garry oak ecosystem along a prairie-savanna-woodland gradient at Rocky Point, southern Vancouver Island, British Columbia. Specifically, we used a range of analytical tools, including a review of historical documents, aerial photographs, dendrochronology, and spatial analysis, in order to reconstruct fire history, stand composition, structure, and trajectory. These analyses provide a context for assessing proposed management and restoration actions in Garry oak communities in coastal British Columbia.

Methods

Study Site

The Department of National Defence (DND) maintains and operates the Canadian Forces Ammunition Depot at Rocky Point, on southern Vancouver Island (Figure 1). This area is home to one of the largest remaining intact, and most intensively studied, Garry oak ecosystems on Vancouver Island. The area was first visited by James Douglas, who explored the region in 1842, but found it unsuitable as a location for a Hudson's Bay trading post (Weir 1983). Captain W. Colquhoun Grant, who explored the west coast of Vancouver Island beginning in ca. 1850, describes the point as "a fine open prairie extending nearly across to Becher Bay…interspersed with oak trees" (Grant 1857). At the time of European contact the area was occupied by the Ka-Ky-Aakan and T'Soke people. However in May, 1850, the Metchosin region including Rocky Point was sold by the Ka-Ky-Aakan Nation to the Hudson's Bay Company, resulting in the relocation of the residents to Sooke and Victoria (Weir 1983). Europeans began settling Rocky Point in the mid-1850s. The study site was settled by Tom Parker in 1859, who raised horses, cattle, and sheep, as did all neighbours for whom records exist (Sooke and North Sooke Women's Institute 1971). Rocky Point was appropriated by DND in 1951 and remains their property to this day, although grazing by sheep and cattle continued until the mid 1990s. Apart from aggressive fire suppression, very little active resource management has been undertaken at Rocky Point. Because the site has been used as an ammunition depot since 1951, fire has effectively been excluded, and is not an option for any ecological restoration programs.

At Rocky Point a representative Garry oak meadow was selected for analysis. A site was chosen that extended from open prairie, through savanna, and into an encroaching conifer forest. This site showed little evidence of human impact

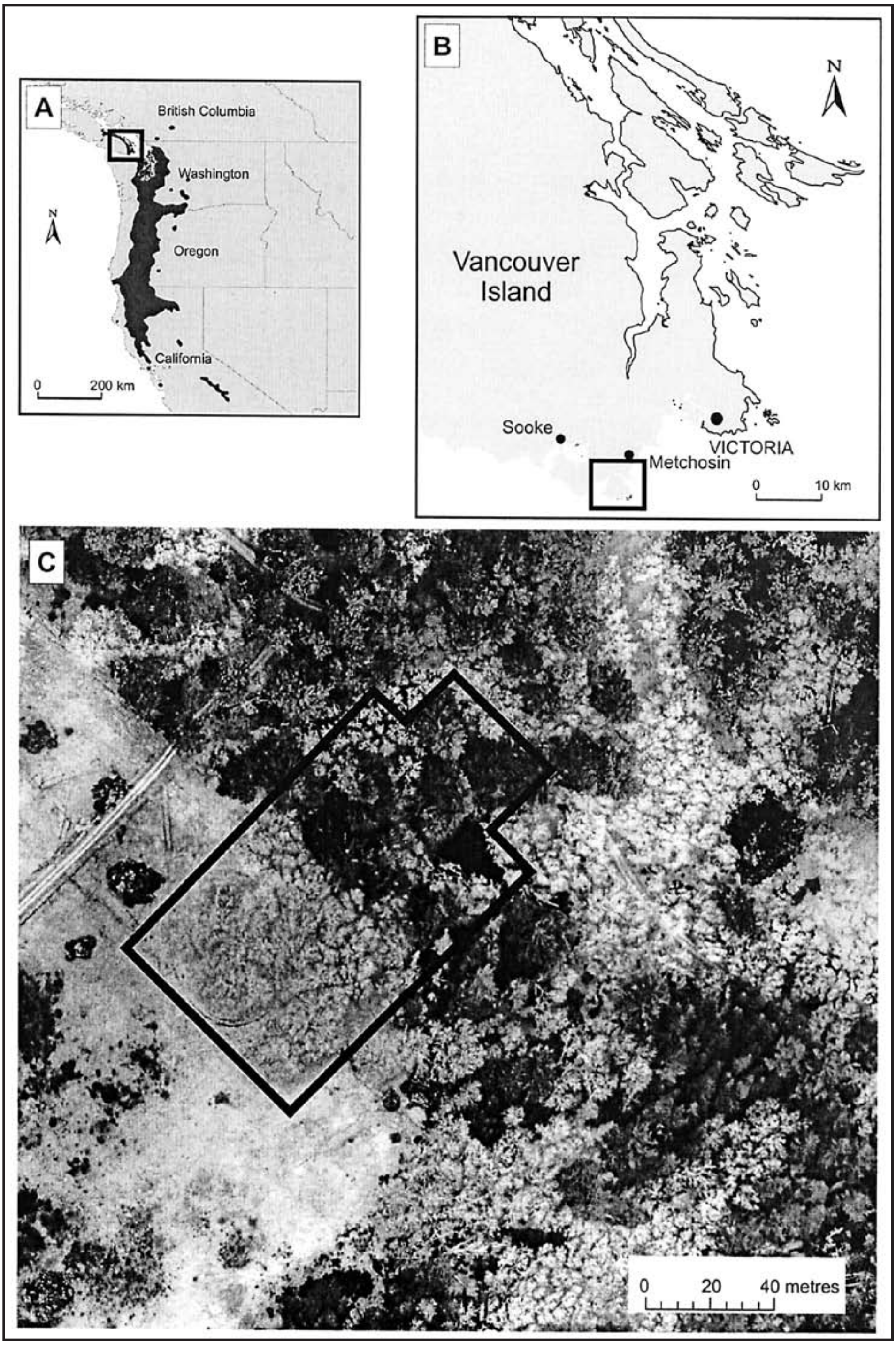

Figure 1. (A) The distribution of Garry oak in western North America. (B) Southern Vancouver Island. Rocky Point is located in the area indicated. (C) a March, 2004, orthophoto of Rocky Point, and the approximate location of the study site. The oak has not leafed-out, and appears much lighter in colour and less dense than the conifers toward the northeastern portion of the study area.

(e.g. fence lines, stumps, ditches), thereby simplifying interpretation of the ecosystem dynamics. The presence of a number of large old trees provided the potential to reconstruct a fire history for the site, and also suggested that the availability of propagules had not limited seedling establishment (c.f. Fastie 1995). The southeast corner of sample plot RPA is located at N 48° 19' 28.5" W 123° 32' 45.3" (horizontal accuracy ± 5m). The site is generally flat, with only a few small undulations (<1 m) in topography. The understory vegetation is very depauperate, and is composed primarily of introduced grasses, with coverage of approximately 30 percent orchardgrass (*Dactylis glomerata*), 30 percent colonial bentgrass (*Agrostis capillaris*), 20 percent sweet vernal grass (*Anthoxanthum odoratum*), and 20 percent bracken fern. With the exception of Scotch broom (*Cytisus scoparius*) and gorse (*Ulex europaeus*) there are no shrubs in the area. Herbs are also rare within the area sampled, but include self-heal (*Prunella vulgaris*), Gairdner's yampah (*Perideridia gairdneri*), and tansy ragwort (*Senecio jacobaea*).

Stand Structure and Composition

Within the study site a location was identified that extended from the treeless prairie, through a Garry oak stand, and into an adjacent coniferous forest (Figures 1, 2). This area was subdivided into a grid of 10 m × 10 m grid plots for sampling. The total area sampled was 80 m × 120 m, but six plots from two corners of the sampling area were excluded from analysis due to anthropogenic disturbance (Figure 2). Within each of the 90 plots, increment cores were collected from all trees greater than 10 cm diameter at breast height. Cores were taken as close as practical to ground level to accurately estimate establishment dates. Diameter measurements were taken for all individuals less than 10 cm in diameter, and all seedlings (individuals less than 1.5 m tall) and saplings (individuals more than 1.5 m tall, but less than 10 cm in diameter) were counted. Large snags and downed woody debris were identified by species and measured. When these samples were sufficiently solid, an increment core was extracted in order to determine the year of death.

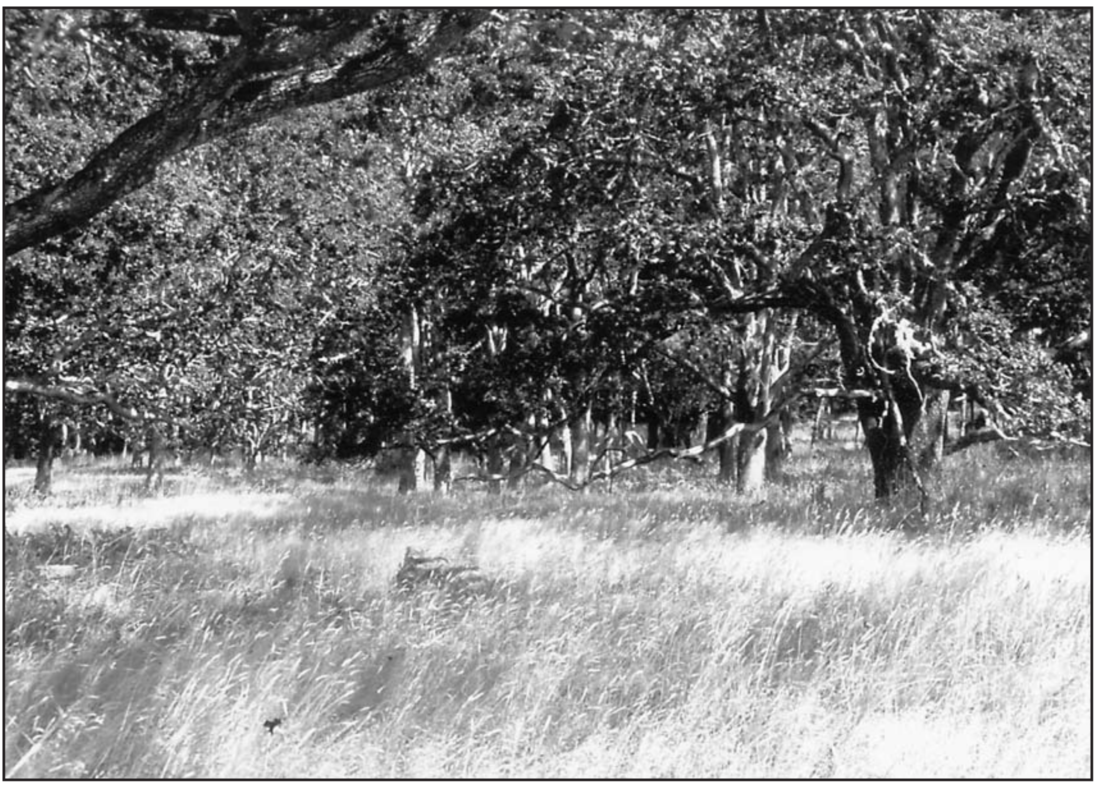

Figure 2. The Garry oak savanna / woodland studied in this analysis.

Each overstory tree was classified into one of three morphological categories: (1) savanna-grown individuals included those trees that exhibited large lower branches, a wide crown, and a deep canopy; (2) woodland-grown individuals exhibited few lower branches, a narrow, tall crown, and a generally erect posture; and, (3) transitional individuals included those that either exhibited intermediate features (e.g. an erect stem or stems, but with a deep canopy), or were in the process of transforming from one morphology to the other—usually through senescence of lower limbs.

Fire History

Fire history was reconstructed using three main methods: First, all trees exhibiting evidence of fire (i.e. visible scars, a characteristic "cat's nose" indentation in the bole, or charred or scorched bark) were intensively sampled using the back-boring method (Agee 1993). This was the preferred method for determining fire history, as it is based on direct evidence, and potentially provides sub-seasonal temporal resolution. Second, the reconstructed age structure of the stand was examined for evidence of cohorts. The discontinuous canopy that is characteristic of Garry oak meadows typically reduces the severity of wildfires, making it less likely that distinct cohorts would be detectable in these environments (Agee 1993). Third, cores collected within the plots were inspected visually for the presence of trauma rings. These rings are characterized by callous tissue that is much darker in colour than preceding rings, are typically quite resinous, and may be associated with an abrupt change in growth rates. This traumatic response typically persists for three to seven years following a damaging event (McBride 1983). Although trauma rings can be caused by a variety of factors, including insect attack, frost, lightning, and hail, fire is by far the most likely cause in coastal British Columbia. Historical documents were also used to assess cultural attitudes towards fire and patterns of European settlement in order to characterize the likelihood of intentional fire use by indigenous people. These methods vary in their sensitivity to very low severity fires, such as typically occur in grass dominated ecosystems. In particular, fire scars are unlikely to be formed if there is high fuel moisture, low fuel loads, or thick bark (Baker and Ehle 2001).

Sample Preparation

Increment cores were mounted in slotted boards, and sanded with progressively finer sand paper to reveal individual cells. For most of the conifer samples, a 400-grit paper was sufficient. However for nearly all of the Garry oak samples, a 600-grit paper followed by a polishing cloth was required to make the ring boundaries sufficiently clear to distinguish during analysis.

Ring-Width Measurement

Increment cores were visually cross-dated using standard techniques (Stokes and Smiley 1868, Fritts 1976). A WinDendro image analysis system (Régent Instruments, version 2002) that makes use of high-resolution optical scanning technology was used to measure the width of annual growth rings. All cores were scanned at a minimum resolution of 800 dpi, which provides a maximum measurement error of ±0.05 mm. Although arbutus trees were cored, the species does not appear to produce an annual growth ring (c.f. Cherubini et al. 2003), and no measurements were taken on these samples.

Many of the core samples collected did not contain the pith, or innermost growth ring. There are several reasons for this: many savanna-grown trees have asymmetrical morphologies, causing the pith to be located away from the center of the bole (Schweingruber 1996); the tree may have been too large to reach the pith with an increment borer; the tree may have heart-rot or butt-rot, causing the wood to disintegrate during sampling; or the operator may have simply aimed the borer in the wrong direction. In order to accurately determine the date of tree establishment it is important to estimate the number of rings missing from the sample. The number of missing rings was determined by measuring the curvature of the innermost ring using a transparent template and dividing the radius of the missing growth portion by the average growth rate for the tree during its period of early development (Villalba and Veblen 1997).

Statistical Analyses

Two main statistical tests were used to assess the significance of relevant hypotheses. A one-tailed two-sample t-test was used to test for differences between sample means (Zar 1999). Specifically, t-tests were used to test the hypotheses (stated as predictions) that (1) the mean date of establishment is earlier for Garry oak than for Douglas-fir, and (2) for savanna morphology trees than for woodland morphology trees. A difference of proportions test (Zar 1999) was used to test the hypotheses that (3) oak seedlings occur more frequently in plots with no overstory conifers than in plots with overstory conifers. All analyses were undertaken using Matlab (ver. 9.0). The level of significance was set at P=0.05.

Results and Discussion

Stand Structure and Composition

There appears to have been considerable infilling of conifers since the time of Grant's 1850 visit. Analysis of historical vertical aerial photographs (1954 [BC 1668], 1964 [BC 5091], and 1975 [BCC 107]) shows that by 1954 there was evidence of a closed-canopy conifer forest along the northeastern shore of Rocky Point, as well as infilling along ephemeral creek channels. Following acquisition of the site by DND several roads were constructed, streams were channelized, and a holding pond was excavated.

The oldest tree identified at Rocky Point established in ca. 1706 (Figure 3). Following a long period without recruitment two distinct pulses in recruitment occurred. Beginning in ca. 1850 Garry oak began establishing. Oak recruitment continued until ca. 1940, with a peak in establishment rates at ca. 1890. Douglas-fir began to establish in ca. 1860, although in much smaller numbers than Garry oak, and continued until ca. 1920. A few grand fir and shore pine also became established towards the end of this interval. The second pulse in recruitment began at ca. 1950, and except for a single oak tree is characterized entirely by conifer recruitment. Although this pulse in recruitment appears to have peaked in the 1970s or 1980s it is probably ongoing. Becausetrees smaller than 10 cm in diameter were not cored, most of the recently established trees are still considered saplings and are not represented (Figure 3).

Savanna morphology trees (both Garry oak and Douglas-fir) established earlier than those with woodland morphology (P=0.027 and P<0.001 respectively). For both species there is no significant difference between establishment dates for savanna and transitional trees, suggesting that transitional trees represent early establishers that initially exhibited savanna morphology, but are now being shaded-out due to infilling. Support for this inference is provided by an analysis of tree density within each sample plot. Plots containing savanna-grown Garry oak trees have an average density of 2.1 trees per plot; for transitional trees the average density is 3.0 trees per plot; and for woodland-grown trees the density is 3.9 trees per plot (390 trees/ha). Two sample t-tests indicate that these differences in density are significantly different (P=0.020 for savanna-grown versus transitional trees, and P=0.008 for transitional versus

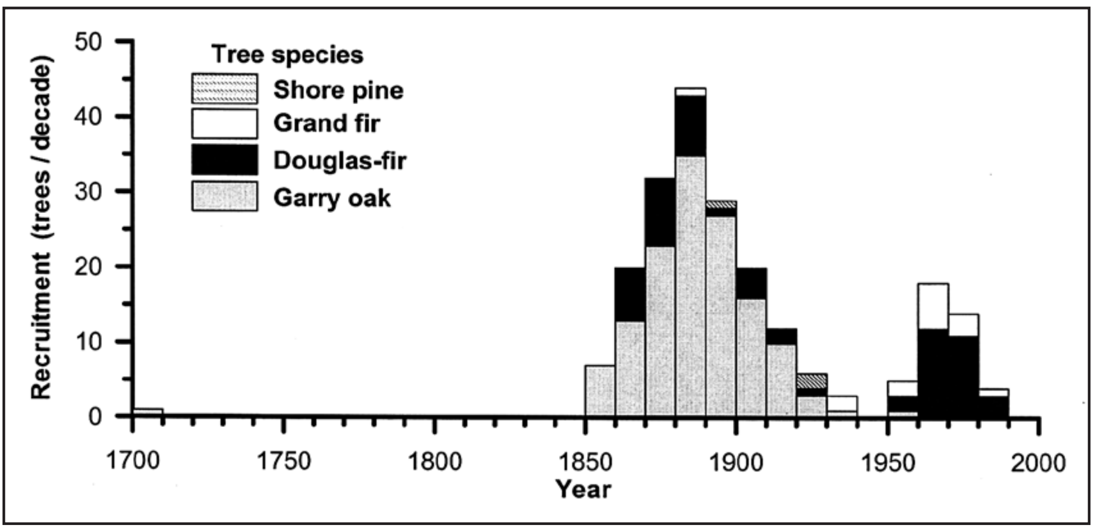

Figure 3. Tree recruitment within the study area by species and decade.

woodland-grown trees). Analysis of the Douglas-fir did not reveal any significant differences, perhaps indicating greater tolerance to crowding, or possibly reflecting the relatively small sample size. Eighteen Garry oak snags were found. The average density in plots containing these snags was 4.6 trees per plot (460 trees/ha), which is significantly higher than the average density for woodland-grown trees (P=0.026). Only three of the oak snags provided useable increment cores, and indicate death dates of 1992, 1999, and 2001 respectively.

A map of the locations of all seedlings, saplings, and trees sampled reveals three important insights into likely patterns of future stand development (Figure 4). First, conifer encroachment is proceeding largely from the north and west sides of the plot towards the center. The oldest conifers are located along the edges of the plot, with generally younger conifers towards the plot center. Second, Garry oak seedling presence is strongly associated with the absence of overstory conifers. Only 45 percent of plots with overstory conifers contained oak seedlings, compared to 74 percent in plots with no overstory conifers (difference of proportions test P<0.001). Similarly, a t-test indicates that oak seedling density was also lower in plots with overstory conifers (P=0.001); although 37 percent of the plots contained overstory conifers only 10 percent of the oak seedlings were located in those plots. This result suggests that Garry oak is unable to establish successfully underneath a conifer canopy, consistent with results from Washington (Thysell and Carey 2001, Harrington and Kern 2002) and California (Barnhart *et al.* 1996).

Last, and perhaps most importantly, Garry oak seedling establishment does not appear to be a good indicator of subsequent overstory recruitment. Garry oak seedlings are very abundant at Rocky Point. Of the total seedling population, 91 percent (678 individuals) were Garry oak. In contrast, oak accounts for only 6 percent of the 53 saplings identified. Even assuming a very short understory residence time, this rate of recruitment is not sufficient to replace the current overstory population.

There are several possible controls on sapling recruitment at this site. Browsing by ungulates may be suppressing stem growth, causing the

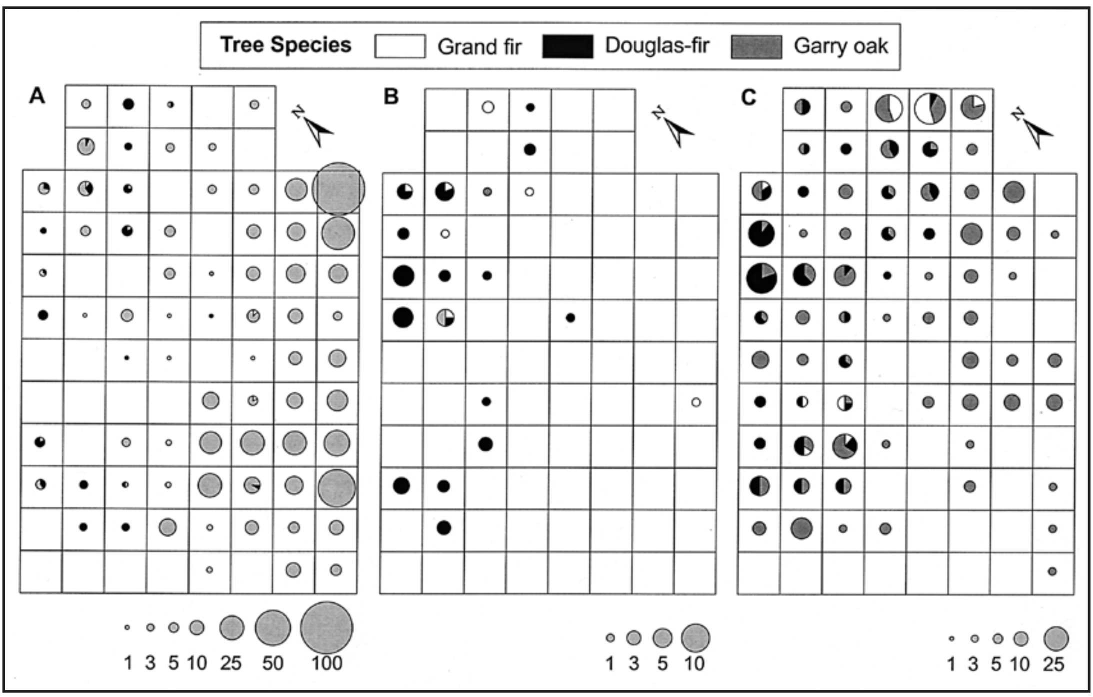

Figure 4. Number of trees per plot, and relative species proportions at Rocky Point for (A) seedlings, (B) saplings, and (C) trees sampled at site RPA. Garry oak is indicated in grey, Douglas-fir in black, and grand fir in white.

seedlings to allocate resources to below-ground production. Garry oak is rated as "good to fair" as browse for deer, but is "poor" for livestock (Stein 1990). Jackson *et al.* (1998) found that Garry oak seedlings were more abundant in heavily grazed environments, but that sapling abundance was significantly reduced. They speculated that grazing of grasses may reduce competition with seedlings for resources, but that associated trampling and herbivory inhibit transition to the sapling stage. Browsing intensity has likely been high at Rocky Point since 1850, due to high endemic deer populations, and use of the site by farmers to graze sheep and cattle until the mid 1990s.

Competition with introduced annual grasses may also be inhibiting oak seedling survival. Mediterranean grasses are common at Rocky Point, including orchardgrass, colonial bent grass, and sweet vernal grass. Gordon and Rice (2000) found that recruitment of blue oak (*Quercus douglasii*) seedlings in California grasslands and woodlands was reduced in plots that contained introduced grasses. Exotic grasses depleted soil moisture more rapidly than native perennial grasses, increasing stress and reducing survival rates of oak seedlings. Additionally at Rocky Point, the introduced grasses mature later than native grasses, bringing them into more direct competition with oak seedlings. Jackson *et al.* (1998) suggest that above ground growth of oak seedlings may be slow until the root structure extends below the active layer available to annual grasses and forbs. However there is little evidence to support this hypothesis at Rocky Point where virtually no saplings have been recruited in recent decades, and there has been no recent recruitment to the canopy.

Fire exclusion at Rocky Point may also be restricting oak sapling recruitment. Episodic fire eliminates important competitors such as Douglas-fir and grand fir, allowing oak to gain a competitive advantage (Abrams 1992). Oak is well adapted to fire throughout its development, being able to sprout rapidly (Regan and Agee 2004), and developing a thick, fire-resistant bark over time. Oak trees are also typically resistant to rot following scarring by fire (Abrams 1992, Smith and Sutherland 1999). Peterson and Reich (2001) found that in a Minnesota oak woodland, sapling recruitment was maximized in sites that were burned once or twice per decade.

Climatic variability may also be exerting important controls on seedling establishment and survival. Treeline advance in subalpine environments has been found to coincide with multiyear intervals of favorable climate (Luckman and Kavanagh 1998, Laroque *et al.* 2000/2001, Esper and Schweingruber 2004). In spite of the regional importance of the Little Ice Age glacier activity (Luckman 2000, Larocque and Smith 2003) there is little evidence that the climate of southwestern British Columbia during the late 19th century was dramatically different from the mid 20th century (Larocque and Smith 2005, Zhang and Hebda 2005).

Due to the longevity of Garry oak [the oldest individual sampled is probably 300 years old, and there are reports of individuals in excess of 400 years in age (Warren 1952)] the current lack of recruitment at Rocky Point does not necessarily indicate that oak will ultimately disappear from the site. Given the episodic nature of oak regeneration, stand-wide disturbance every two- to three-hundred years could be at least theoretically sufficient to maintain a viable Garry oak population.

In the context of current conifer recruitment rates, however, it seems clear that the stand at Rocky Point is undergoing dramatic changes. Douglas-fir seedlings represent a small fraction of the total seedling population (53 Douglas-fir seedlings were found, representing 7 percent of the overall seedling population), but appear to survive to sapling sizes much more often than Garry oak. Of the 53 saplings identified, 41 were Douglas-fir. Also, young Douglas-fir trees at Rocky Point are growing very quickly – counting branch whorls suggests that seedlings typically reach heights of 2 to 3 m in less than a decade. Similarly, seven grand fir seedlings and eight grand fir saplings were found at the site. Overstory grand fir as young as 20 years old were sampled, suggesting that the understory residence time for these individuals will be relatively short. In spite of the low seedling abundance, recruitment of grand fir likely exceeds that of Garry oak. This high rate of conifer recruitment is a continuation of a pattern that began in the 1960s, and suggests that the structure and composition of the stand are undergoing a considerable shift relative to recent centuries.

Fire History

No trees with exposed fire-scars were found at the site or in the immediate surrounding region. Two large Douglas-fir trees were found adjacent to the sample site that exhibited "cat face" patterns in their bark, a feature consistent with a scarring caused by a fire that occurred long enough ago that the wound has closed-over completely (McBride 1983, Agee 1993). Numerous cores were taken from these trees in an attempt to locate the scar boundary or to sample coincident trauma rings, but heart-rot precluded useful cores from being extracted. However the intact portion of the longest samples extended back to ca. 1860 in both trees, suggesting that hot fire has not influenced these trees over at least this interval. Additionally, analysis of recruitment history does not provide any clear evidence for wildfire since ca. 1850.

The recruitment history of the stand does provide some insight into the disturbance history of the site (Figure 3). Although neither of the two obvious pulses in recruitment is sufficiently abrupt to suggest a response to wildfire, the first pulse corresponds with occupation of the site by European settlers. The rapid infilling of Garry oak that coincided with this event suggests a dramatic shift in the disturbance regime (Thilenius 1968). One candidate explanation is that the European occupation of the site signaled an end to the common practice among indigenous peoples throughout the region of using fire to maintain open prairies and savanna for resource exploitation (Turner 1999, Arno 2000, Williams 2000).

Indigenous peoples' practice of burning was widespread, and many sites were probably burned annually. For example, Grant (1857) wrote "The natives all along the coast have a custom of setting fire to the woods in summer…". Elsewhere he describes the fires as "kindled promiscuously" (cited in Turner 1999). Similarly, Suttles (1951; cited inTurner 1999) writes "After [indigenous people] were done digging for the season, they burned off the island so that it would be more fertile the next year." The practice of burning was considered "abominable" by European standards (Grant 1857), and was prohibited when possible. Burning was almost certainly undertaken at Rocky Point, at least prior to European settlement in the area. Grant lived nearby in Sooke, and in a report to Governor James Douglas he complained about burning by indigenous peoples: "I have endeavoured in the neighbourhood of Mullacherd [Grant's home] to check these fires by giving neither potlache or employment to any Indians so long as a fire was blazing in sight of my house" (cited in Turner 1999).

Fires set by indigenous people were typically low in severity due to limited fuel accumulation. An anonymous 1849 newspaper article in The Times of London reports "The fire runs along at a great pace, and it is the custom here if you are caught to gallop right through it, the grass being short, the flame is very little, and you are through in a second" (cited in Turner 1999). Given that when Grant visited Rocky Point in the 1850s it was largely open prairie, and that there is at least one Garry oak that was established as early as 1706, it seems plausible that the site was maintained in an open state by frequent, low-severity fire.

A second pulse in recruitment consisting entirely of conifer species began ca. 1950. It remains unclear what circumstances initiated this regeneration pulse, though given the generally low abundance of charcoal, charred bark, or killed trees, it seems unlikely that it was caused by fire. Furthermore, analysis of ring-width patterns and wood properties failed to reveal any consistent abrupt shifts in ring width, the presence of trauma rings, or other physical indications of fire. Lastly, there is no obvious cohort of Douglas-fir such as typically occurs following fire (Tappeiner *et al.* 1997, Winter *et al.* 2002). Fire cannot be categorically ruled out, however, as a very low-intensity grass fire might leave little lasting physical evidence. By 1950, the stand density was approximately 230 trees/ha—possibly high enough to limit establishment by oaks—but presumably not sufficient to limit establishment by the relatively more shade tolerant Douglas-fir (Minore 1979, Stein 1990).

Conclusions

Rocky Point has undergone a striking transformation from open prairie to savanna / woodland since the arrival of Europeans ca. 150 years ago. Prior to 1850, the site was probably largely treeless, with only a few scattered oak and Douglas-fir trees. Initial recruitment to the stand consisted largely of Garry oak, and was probably a response to fire exclusion at the site. Following this rapid infilling of Garry oak in the late 19th and early 20th centuries the stand appears to have stabilized, with little recruitment occurring from the 1930s to 1950s. Beginning in the 1950s conifer species began to become established in high numbers.

This change in stand composition and density is ongoing. Garry oak does not appear to be establishing at the site in sufficient numbers to maintain dominance, and conifer species are establishing at rates and densities that are sufficient to eventually eliminate Garry oak and many important associates from Rocky Point.

Management and remediation options are limited. Due to the use of Rocky Point as an ammunition depot by the DND, managers are understandably reluctant to use fire as a restoration tool. The mechanical removal of conifers would probably be sufficient to maintain Garry oak trees, but ultimately the causes of very low recruitment levels will need to be identified and addressed. Even if fire could be restored to this site, it would probably not readily achieve the desired ecological objectives. The relatively high stem density, abundant fuel, and the presence of ladder fuels suggests that extensive site preparation would be needed to avoid a stand replacing fire (Agee 1993, 1996). Several invasive exotic species are present at Rocky Point, including gorse, Scotch broom, orchardgrass, and cheatgrass (*Bromus* spp.). When used improperly, prescribed fire can cause these weedy species to become more abundant, rather than enhance the native plant communities (Agee 1996).

A related restoration dilemma also emerges from this analysis. At the time of European contact, Rocky Point was nearly treeless. Apart from the recent establishment of conifer species, even the abundance of oak trees at Rocky Point seems to be an artifact of recent fire exclusion. Consequently, there may be no set of ecosystem processes or management practices that could maintain the ecosystem in anything resembling its current state. The recipe to make a Garry oak savanna may be to start with a nearly treeless prairie, and then exclude fire for a century. A corollary to this assessment is that because Garry oak savannas are ephemeral entities, a large land base needs to be preserved in order to accommodate Garry oak associated ecosystems at various stages of development. Active management techniques are likely needed to promote desired conservation goals.

Acknowledgements

We are grateful to the Department of National Defence for allowing access and permission to sample at Rocky Point. Sarah Laxton and Darren Bos assisted with fieldwork. Dave Lewis and Alexis Johnson assisted with laboratory analysis. David L. Peterson reviewed an early draft of the paper. Two anonymous reviewers provided helpful comments. Figures 1 and 4 were prepared by M. Puddister, Cartographic Services, Department of Geography, University of Guelph. This research was supported by an Interdepartmental Recovery Fund grant awarded to M. Pellatt, an NSERC Discovery Grant held by D. Smith, and a Climate Change Action Fund grant awarded to all three authors.

Literature Cited

Abrams, M. D. 1992. Fire and the development of oak forests. Bioscience. 42:346-353.

Agee, J. K. 1993. Fire Ecology of Pacific Northwest Forests. Washington, D. C., Island Press.

Agee, J. K. 1996. Achieving conservation biology objectives with fire in the Pacific Northwest. Weed Technology. 10:417-421.

Allen, G. B., K. J. Brown and R. J. Hebda. 1999. Surface pollen spectra from southern Vancouver Island, British Columbia, Canada. Canadian Journal of Botany. 77:786-799.

Archer, S. 1989. Have Southern Texas Savannas Been Converted to Woodlands in Recent History? American Naturalist. 134:545-561.

Arno, S. F. 2000. Fire in western forest ecosystems. *In* Wildland fire in ecosystems. Gen. Tech. Rep. RMRS-GTR-42. J. K. Smith and J. K. Brown (Editors), Ogden, UT, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 2:97-120.

Baker, W. L. and D. Ehle. 2001. Uncertainty in surface-fire history: the case of ponderosa pine forests in the western United States. Canadian Journal of Forest Research. 31:1205-1226.

Barnhart, S. J., J. R. McBride and P. Warner. 1996. Invasion of northern oak woodlands by *Pseudotsuga menziesii* (Mirb.) Franco in the Sonoma Mountains of California. Madroño. 43:28-45.

Brown, K. J. and R. J. Hebda. 2002. Origin, development, and dynamics of coastal temperate conifer rainforests of southern Vancouver Island, Canada. Canadian Journal of Forest Research. 32:353-372.

Cherubini, P., B. L. Gärtner, R. Tognetti, O. U. Bräker, W. Schoch and J. L. Innes. 2003. Identification, measurement and interpretation of tree rings in woody species from mediterranean climates. Biological Reviews. 78:119-148.

Cole, D. 1977. Ecosystem dynamics in the coniferous forest of the Willamette Valley, Oregon, U.S.A. Journal of Biogeography. 4:181-192.

Erickson, W. R. 2002. Environmental relationships of native Garry oak (*Quercus garryana*) communities at their northern margin. *In* Proceedings of the Fifth Symposium on Oak Woodlands: Oaks in California's changing landscape. Gen. Tech. Rep. PSW-GTR-184.

R. B. Standiford, D. D. McCreary and K. L. Purcell (Editors), Albany, CA, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 179-190.

Esper, J. and F. Schweingruber. 2004. Large-scale treeline changes recorded in Siberia. Geophysical Research Letters. 31: doi:10.1029/2003GL019178.

Fastie, C. L. 1995. Causes and ecosystem consequences of multiple pathways of primary succession at Glacier Bay, Alaska. Ecology. 76:1899-1916.

Franklin, J. F. and C. T. Dyrness. 1973. Natural Vegetation of Oregon and Washington. Portland, Oregon, Forest Service, U.S. Department of Agriculture.

Fritts, H. C. 1976. Tree Rings and Climate. London, Adademic.

Fuchs, M. A. 2001. Towards a Recovery Strategy for Garry Oak and Associated Ecosystems in Canada: Ecological Assessment and Literature Review. Environment Canada, Canadian Wildlife Service, Pacific and Yukon Region. Technical Report GBEI/EC-00-030.

GOERT. 2002. Recovery Strategy for Garry Oak and Associated Ecosystems and their Associated Species at Risk in Canada, 2001-2006. Garry Oak Ecosystem Recovery Team.

Gordon, D. R. and K. J. Rice. 2000. Competitive suppression of *Quercus douglasii* (Fagaceae) seedling emergence and growth. American Journal of Botany. 87:986-994.

Grant, W. C. 1857. Description of Vancouver Island. Journal of the Royal Geographical Society of London. 27:268-320.

Harrington, C. A. and C. C. Kern. 2002. Will Garry Oak respond to release from overtopping conifers? Garry oak ecosystem restoration: progress and prognosis: Proceedings of the 3rd annual meeting of the British Columbia chapter of the Society for Ecological Restoration, Society for Ecological Restoration: 39-46.

Heusser, C. J. 1960. Late-Pleistocene environments of North Pacific North America. American Geological Society, Special Publication. 35.

Hibbs, D. E. and B. J. Yoder. 1993. Development of Oregon white oak seedlings. Northwest Science. 67:30-36.

House, J. I., S. Archer, D. D. Breshears, R. J. Scholes and NCEAS Tree–Grass Interactions Participants. 2003. Conundrums in mixed woody-herbaceous plant systems. Journal of Biogeography. 30:1763-1778.

Jackson, R. D., K. O. Fulgham and B. Allen-Diaz. 1998. *Quercus garryana* Hook. (Fagaceae) stand structure in areas with different grazing histories. Madroño. 45:275-282.

Jeltsch, F., G. E. Weber and V. Grimm. 2000. Ecological buffering mechanisms in savannas: A unifying theory of long-term tree-grass coexistence. Plant Science. 150:161-171.

Larocque, S. J. and D. J. Smith. 2003. Little Ice Age glacial activity in the Mt. Waddington area, British Columbia Coast Mountains, Canada. Canadian Journal of Earth Sciences. 40:1413-1436.

Larocque, S. J. and D. J. Smith. 2005. A dendroclimatological reconstruction of climate since AD 1700 in the Mt. Waddington area, British Columbia Coast Mountains, Canada. Dendrochronologia. 22:93-106.

Laroque, C. P., D. H. Lewis and D. J. Smith. 2000/2001. Treeline dynamics on southern Vancouver Island, British Columbia. Western Geography. 10/11:43-63.

Lea, T. 2002. Historical Garry Oak Ecosystems of Greater Victoria & Saanich Peninsula. Victoria, British Columbia, Terrestrial Information Branch, B.C. Ministry of Sustainable Resource Management.

Leopold, E. B. and R. Boyd. 1999. An ecological history of old prairie areas in southwestern Washington. *In* Indians, fire and the land in the Pacific Northwest. R. Boyd (Editor), Corvallis, OR, Oregon State University Press: 139-163.

Lepofsky, D., E. K. Heyerdahl, K. Lertzman, D. Schaepe and B. Mierendorf. 2003. Historical meadow dynamics in southwest British Columbia: a multidisciplinary Analysis. Conservation Ecology. 7: 5 [online] URL: http://www.consecol.org/vol7/iss3/art5.

Luckman, B. H. 2000. The Little Ice Age in the Canadian Rockies. Geomorphology. 32:357-384.

Luckman, B. H. and T. A. Kavanagh. 1998. Documenting the effects of recent climate change at treeline in the Canadian Rockies. *In* The Impacts of Climate Variability on Forests, Berlin, Springer-Verlag: 121-144.

McBride, J. R. 1983. Analysis of tree rings and fire scars to establish fire history. Tree-Ring Bulletin. 43:51-67.

Minore, D. 1979. Comparative autecological characteristics of northwestern tree species: a literature review. Pacific Northwest Forest and Range Experiment Station. USDA Forest Service General Technical Report PNW-87.

Pellatt, M. G., R.J. Hebda and R. W. Mathewes. 2001. High-resolution Holocene vegetation history and climate from Hole 1034B, ODP leg 169S, Saanich Inlet, Canada. Marine Geology. 174:211-226.

Peterson, D. L. and R. D. Hammer. 2001. From open to closed canopy: a century of change in a Douglas-fir forest, Orcas Island, Washington. Northwest Science. 75:262-269.

Peterson, D. W. and P. B. Reich. 2001. Prescribed fire in oak savanna: fire frequency effects on stand structure and dynamics. Ecological Applications. 11:914-927.

Regan, A. C. and J. K. Agee. 2004. Oak community and seedling response to fire at Fort Lewis, Washington. Northwest Science. 78:1-11.

Roemer, H. 1993. Vegetation and ecology of Garry oak woodlands. *In* Garry Oak-meadow Colloquium proceedings. R. J. Hebda and F. Aitkens (Editors), Victoria, BC, Garry Oak Meadow Preservation Society: 19-24.

Roemer, H. L. 1972. Forest vegetation and environments on the Saanich Peninsula, Vancouver Island. Victoria, BC, University of Victoria: 405 p.

Sankaran, M., J. Ratnam and N. P. Hanan. 2004. Tree-grass coexistence in savannas revisited - insights from an examination of assumptions and mechanisms invoked in existing models. Ecology Letters. 7:480-490.

Scholes, R. J. and S. R. Archer. 1997. Tree-Grass Interactions in Savannas. Annual Review of Ecology and Systematics. 28:517-544.

Schweingruber, F. H. 1996. Tree Rings and Environment: Dendroecology. Berne, Stuttgart, Vienna, Haupt.

Smith, K. T. and E. K. Sutherland. 1999. Fire-scar formation and compartmentalization in oak. Canadian Journal of Forest Research. 29:166-171.

Sooke and North Sooke Women's Institute. 1971. Sooke Past and Present. Sooke, BC, Sooke and North Sooke Women's Institute.

Stein, W. I. 1990. *Quercus garryana* Dougl. ex Hook. Oregon White Oak. *In* Silvics of North America. R. M. Burns and B. H. Honkala (Editors), Washington, U.S. Dept. of Agriculture, Forest Service.

Stokes, M. A. and T. L. Smiley. 1868. An Introduction to Tree-Ring Dating. Chicago, University of Chicago Press.

Streng, D. R. and P. A. Harcombe. 2005. Why Don't East Texas Savannas Grow Up to Forest? American Midland Naturalist. 108:278-294.

Tappeiner, J. C., D. W. Huffman, D. Marshall, T. A. Spies and J. D. Bailey. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. Canadian Journal of Forest Research. 27:638-648.

Thilenius, J. F. 1968. The *Quercus Garryana* Forests of the Willamette Valley, Oregon. Ecology. 49:1124-1133.

Thysell, D. R. and A. B. Carey. 2001. *Quercus garryana* communities in the Puget Trough, Washington. Northwest Science. 75:219-235.

Turner, N. and M. Bell. 1971. The ethnobotany of the Coast Salish Indians of Vancouver Island. Economic Botany. 25:63-104.

Turner, N. J. 1999. "Time to burn:" Traditional use of fire to enhance resource production by aboriginal peoples in British Columbia. *In* Indians, fire and the land in the Pacific Northwest. R. Boyd (Editor), Corvallis, OR, Oregon State University Press: 185-218.

Tveten, R. K. and R. W. Fonda. 1999. Fire effects on prairies and oak woodlands on Fort Lewis, Washington. Northwest Science. 73:145-158.

Vale, T. R. 1981. Tree Invasion of Montane Meadows in Oregon. American Midland Naturalist. 105:61-69.

Villalba, R. and T. T. Veblen. 1997. Improving estimates of total tree ages based on increment core samples. Ecoscience. 4:534-542.

Warren, W. H. 1952. A natural history of Beacon Hill Park. Victoria Naturalist. 9:26-31.

Weir, R. J. 1983. Metchosin's early history and native people. *In* Footprints: Pioneer Families of the Metchosin District. M. I. Helgesen (Editor), Metchosin, BC, Metchosin School Museum Society: 15-21.

White, R. 1999. Indian land use and environmental change. Island County, Washington: a case study. *In* Indians, fire and the land in the Pacific Northwest. R. Boyd (Editor), Corvallis, OR, Oregon State University Press: 36-49.

Williams, G. W. 2000. Early fire use in Oregon. Fire Management Today. 60:13-20.

Winter, L. E., L. B. Brubaker, J. F. Franklin, E. A. Miller and D. Q. DeWitt. 2002. Initiation of an old-growth Douglas-fir stand in the Pacific Northwest: a reconstruction from tree-ring records. Canadian Journal of Forest Research. 32:1039-1056.

Zar, J. 1999. Biostatistical Analysis, 4th Edition. Upper Saddle River, N.J, Prentice Hall Press.

Zhang, Q.-B. and R. J. Hebda. 2005. Abrupt climate change and variability in the past four millennia of the southern Vancouver Island, Canada. Geophysical Research Letters. 32: doi:10.1029/2005GL022913.

Received 4 October 2005
Accepted for publication 23 February 2006