Environmental History of a Garry Oak/Douglas-Fir Woodland on Waldron Island, Washington

Authors: Dunwiddie, Peter W., Bakker, Jonathan D., Almaguer-Bay, Mitchell, and Sprenger, Carson B.

Source: Northwest Science, 85(2) : 130-140

Published By: Northwest Scientific Association

URL: https://doi.org/10.3955/046.085.0205

Peter W. Dunwiddie[1], **Jonathan D. Bakker**, School of Forest Resources, University of Washington, Box 354115, Seattle, Washington 98195

Mitchell Almaguer-Bay, 2517 226th Pl NE, Sammamish, Washington 98074

and

Carson B. Sprenger, Rain Shadow Consulting, PO Box 107, Shaw Island, Washington 98286

Environmental History of a Garry Oak / Douglas-fir Woodland on Waldron Island, Washington

Abstract

Understanding a system's historical conditions is a key first step in mapping out restoration goals and strategies. We examined the age structure and stem density of a stand dominated by Garry oak (*Quercus garryana*) and Douglas-fir (*Pseudotsuga menziesii*), and related this structure to its environmental history. Our reconstruction was based on 139 increment cores and 197 stem cross-sections collected from trees in 21 plots. Individuals of both species were more than 200 years old, indicating that the stand had a mixed composition for centuries. The historical tree density was ca. one-tenth that present prior to restoration (oak release) activities. This open oak/Douglas-fir savanna was maintained for centuries by fires set by Native Americans. It began to infill with oak, and later Douglas-fir, in the 1800s, particularly following Euro-American settlement in the 1860s. Douglas-fir encroachment continued throughout the 1900s, with a very large cohort becoming established in the early 1970s. This recent wave of recruitment has occurred in many sites in the region, and may reflect interactions among climatic and environmental conditions, together with changes in land use, including the cessation of livestock grazing and logging. Oak release actions were undertaken to re-open the forest structure, and involved the removal of 55% of the trees, primarily small-diameter Douglas-fir. Comparisons with historical information suggest that the post-release stand is still much denser and biased towards Douglas-fir than the stand was historically.

Introduction

Garry oak (*Quercus garryana* Dougl. ex Hook.) occurs from California to southern Vancouver Island. It is the only native oak species in the northern part of its range. This deciduous tree frequently grows with conifers, particularly Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). Garry oak tends to be shade-intolerant, and is found in a variety of xeric and mesic communities, from open savannas and woodlands to closed canopy forests. Today, many of these communities have been cut, converted to agriculture, or destroyed by development. The few remnants have been highly altered by invading conifers and non-native shrubs.

Considerable conservation effort has been directed towards Garry oak ecosystems, particularly in the Willamette Valley of Oregon (Oregon Oak Communities Working Group 2010), the Puget Lowlands of Washington (Chappell 2006), Vancouver Island, and the San Juan and Gulf Islands of Puget Sound and the Georgia Basin (GOERT 2002). Over 100 rare plants and animals are associated with these habitats, including *Sciurus griseus* (western gray squirrel), *Melanerpes lewisii* (Lewis' woodpecker), *Erynnis propertius* (propertius duskywing), and *Castilleja levisecta* (golden paintbrush) (Dunn and Ewing 1997, Fuchs 2001, Thyssel and Carey 2001).

Research in Garry oak habitats has been particularly directed at conservation of extant oaks and associated understory vegetation (GOERT 2002, Devine and Harrington 2006, Devine et al. 2007). Other studies have examined the composition, structure, and distribution of Garry oak communities (Thilenius 1968, Tveten and Fonda 1999, Thysell and Carey 2001, Regan and Agee 2004, Lea 2006, Erickson and Meidinger 2007), and the historical ecology and dynamics of the oak stands themselves (Kertis 1986, Agee 1987, Salstrom 1989, Barnhart et al. 1996, GOERT 2002, Gedalof et al. 2006, Smith 2007). These studies are beginning to provide the in-depth understanding of historical conditions that is a key first step in mapping out restoration goals and strategies (Dunwiddie 2001, Hosten et al. 2006).

[1]Author to whom correspondence should be addressed. Email: pdunwidd@u.washington.edu

Most Garry oak stands have experienced considerable encroachment by Douglas-fir and other woody species over the last century (Thilenius 1968, Fuchs 2001, GOERT 2002). Understanding which ecological processes maintained these stands in the past, and how they have changed in recent years, is critical if they are to be protected and managed as viable communities.

We conducted our study on Waldron Island, San Juan Islands, Washington, in an area dominated by mature Garry oak and Douglas-fir. Our objectives were to understand how this stand developed, characterize its historical composition and structure, and utilize these data to evaluate how well recent oak-release activities have restored stand characteristics. To accomplish these objectives, we evaluated species, diameter, and age structure data collected from trees in the stand.

Study Site

Waldron Island (Figure 1) is a small (11.8 km^2), sparsely-inhabited island close to the Canadian border in northern Puget Sound. Our study focused on a portion of Point Disney, a northeast-southwest trending headland that forms the southeast tip of the island. The ridge rises to a height of 187 m, and is dominated at higher elevations (above ca. 100 m) by Douglas-fir forest, though several benches support stands with considerable Garry oak (Figure 2). Grasslands and savannas occur on the lower slopes. Annual precipitation averages 77 cm, with the majority falling in winter, and a pronounced summer drought (PRISM Climate Group 2010).

The study site is located at an elevation of 100-120 m in a 4.5 ha stand that supports a mixed Garry oak/ Douglas-fir forest, and includes many of the largest specimens of both species on Point Disney. There is no vehicular access to the site. Many of the largest Douglas-fir are mature trees with heavy, low-hanging limbs, but the oaks often exhibit reduced foliage, constricted crowns, partial and even complete die-back as a result of crowding and overtopping by adjacent Douglas-fir (Sprenger et al. 2005). Numerous smaller Douglas-fir trees and saplings are found throughout the stand. Shrubs such as hairy honeysuckle (*Lonicera hispidula* [Lindl.] Douglas ex Torr. & A. Gray) and snowberry (*Symphoricarpos albus* [L.] S.F. Blake) dominate the understory, and herbaceous diversity is low. Soils are generally thin and unproductive.

Animals such as squirrels and jays, which are ecologically important in mainland Garry oak communities, particularly in dispersal of acorns, are notably absent on Waldron. Deer were once abundant but were extirpated from Waldron in the 1920s (Ludwig 1972).

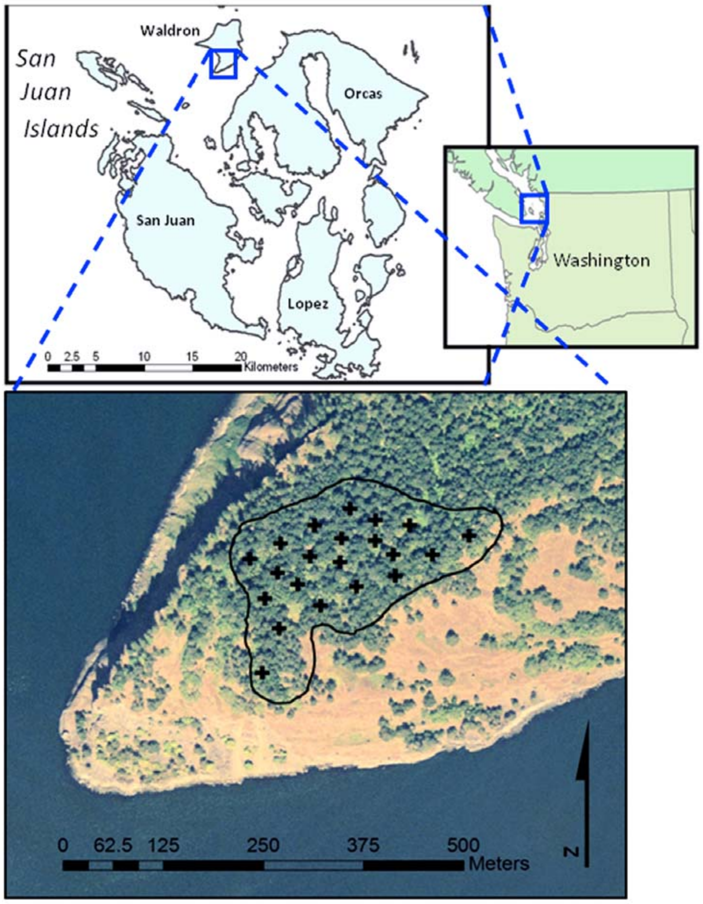


Figure 1. Location of study site on Point Disney, Waldron Island, Washington.

Euro-American settlement began on Waldron Island in the 1860s (Ludwig 1972). Farmers were living along the shore of Cowlitz Bay by the 1870s. Sheep grazing began on Point Disney in the late 1870s, and goats were present by 1907; both would have had significant influences on the grasslands and forest understory (Ludwig 1972, Salstrom 1989). Significant logging occurred on portions of Point Disney during the 1940s, 1950s, and 1968-1972 (Ludwig 1972, William Carlson, Waldron resident, personal communication); some logging may also have coincided with quarrying activities at the tip of Point Disney in 1907-08 (Ludwig 1972). Livestock numbers declined in the 1960s, with the last animals removed in ca. 1971.

In their conservation plan for the site, Sprenger et al. (2005) noted that mortality of Garry oaks due to competition with Douglas-fir was progressing rapidly, would greatly alter the future composition and structure of the community, and was therefore the most critical and easily-reversible threat to the long-term viability of the site. Actions to restore compositional and structural

Figure 2. Garry oak and Douglas-fir growing in a savanna on Point Disney (Photo: Peter Dunwiddie).

components began in autumn 2006. Large numbers of Douglas-fir were removed to release surviving Garry oaks. The freshly cut stumps of these trees provided a unique opportunity to study the timing, extent, and distribution of Douglas-fir encroachment into the stand.

Methods

We used *n*-tree distance sampling methods to collect data from trees in variable-radius plots (Lynch and Wittwer 2003, Brown and Cook 2006) during winter 2007. Twenty-one plots were located across the entire 4.5 ha oak/Douglas-fir stand at a regular 45 m spacing. Garry oak, small-diameter Douglas-fir, and large-diameter Douglas-fir were examined separately. Since most of the Douglas-fir were < 20 cm diameter at breast height (dbh), we used this as our cutoff between large- and small-diameter trees. At each plot, we sampled the nearest 3 Garry oak, 10 small-diameter Douglas-fir, and 3 large-diameter Douglas-fir, for a total of 336 individuals. For each individual, we recorded the distance and bearing to plot center. We measured the dbh of each tree and the inside-bark diameter (average of two perpendicular measurements) and height of each stump. Stumps (small-diameter Douglas-fir only) obviously no longer had a dbh; therefore we estimated their dbh using a published allometric relationship (Omule & Kozak 1989). We calculated the stand basal area and density before and after the treatment, weighting each species / diameter class by the inverse of its radius (distance to furthest tree in that class) in each plot.

Tree ages were obtained from cookies taken from stumps (small-diameter Douglas-fir only) and from cores taken from live trees (all species and diameter classes). Core height was usually 55 cm but varied occasionally due to branches or stem defects. We collected a total of 197 Douglas-fir cookies, 76 Douglas-fir cores, and 63 Garry oak cores. Samples were mounted on plywood, sanded, and read to determine the pith year. All of the Douglas-fir samples were cross-dated, but only a portion of the oaks could be cross-dated. The pith was present in 65% of the samples. For those that did not intersect the pith, we estimated the number of rings to pith using Applequist's (1958) method if the inner rings had sufficient curvature, and by measuring early radial growth if they did not. Applequist's method was applied to 74 samples, and the median number of missing rings to pith was 4 (range: 1 to 23). The early radial growth method involved dividing the missing stem radius by the mean radial growth rate of the innermost 10 years of the core (e.g., Gedalof et al. 2006). This method was applied to 42 samples; the median number of missing rings to pith was 34 (range: 0 to 328).

Establishment ages were obtained by correcting for core or cookie height using species-specific age-height relationships from Kertis (1986). Since Kertis' data were limited to heights above 10 cm, we assumed that pith age equaled establishment age for individuals sampled below this height. The age structure of the stand was calculated using all establishment ages, weighting data by plot radii. We also related tree age to dbh. We focused this analysis on those trees with the most accurate ages—those whose cores intersected the pith and those that did not but had enough ring curvature to use Applequist's method to estimate the number of rings to pith. A separate equation was fit for each species using SigmaPlot.

To get a sense of what the stand was like historically, we identified trees that established before 1881, prior to significant modification by Euro-American settlers. Stumps and snags were not included, but were few in number. We calculated the density of live trees of each species. Historical tree size is more difficult to reconstruct (Bakker et al. 2008) and was beyond the scope of this project.

Results and Discussion

Below, we discuss what the composition and structure of this stand was like historically, how it developed over the last two centuries, and how it was affected by the oak release treatment recently implemented by land managers.

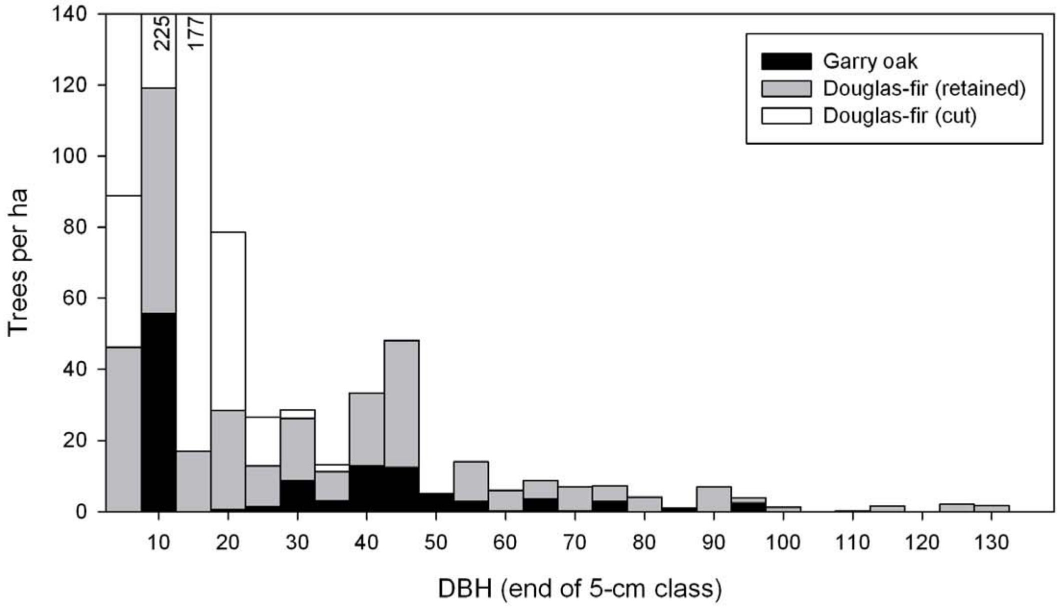
Historical Composition and Structure

Archeological evidence indicates that Native Americans were active in the San Juans for thousands of years (Stein 2000), and shell middens confirm their presence on Waldron Island. Native Americans used fire to improve hunting conditions and to promote the growth of plants used for food, fiber, and medicinal purposes (Suttles 1974, Turner 1975, 1999, Boyd 1999a). Until the mid-1800s, Native American burning resulted in fires on Point Disney occurring on average every seven years, although fire frequency varied considerably during this period (Sprenger 2006, Sprenger and Dunwiddie 2011). Fire frequency declined as Native American populations fell by 70-80% with the introduction of smallpox in the region beginning in the 1770s (Boyd 1999b), followed by outbreaks of a malaria-like illness in 1836, measles and tuberculosis in 1847, and smallpox again in 1853-54 (Agee 1987). Our study, together with the reconstructed fire history for Point Disney (Sprenger and Dunwiddie 2011), clarifies how the vegetation composition and structure have changed at this site over the last two centuries.

Garry oak ranged in age from 27–509 yr; 16% (ten trees) were more than two centuries old (Figure 3). Douglas-fir had a similar range, from 17–454 yr; 3% (seven trees) exceeded 200 yr in age. However, heart rot was prevalent on most trees of both species, and substantial estimation was required on several; the oldest ring counts were 308 years on oak, and 281 years on Douglas-fir. Since few of the extant trees established earlier than 1800, we can only speculate about the vegetation structure that existed when the influence of Native Americans on the landscape was more pronounced. However, the fact that individuals of both species are more than 400 years old suggests that the stand had a mixed composition for centuries (Figure 3). This is in contrast to many other studies, which have described Garry oak stands as largely monospecific (Thilenius 1968, Thysell and Carey 2001, Smith 2007), though Day (2005) concluded that a stand in the Willamette National Forest was co-dominated by Garry oak, Douglas-fir, and ponderosa pine (*Pinus ponderosa* C. Lawson).

Changes in Stand Composition and Structure: Pre Euro-American Settlement

We reconstructed historical stand parameters based on trees that established before 1881 and were still alive at the time of our sampling (Table 1). These generally were also the only trees in the stand that exhibited the spreading form and heavy lower limbs of trees that once grew in open woodland or savanna habitats. The historical density of these older trees was 99 trees/ha, with slightly more oaks than Douglas-firs (Table 1). An unknown number of individuals—presumably Douglas-fir, as the oaks had little merchantable value—may have been removed by historical logging. We believe that few trees were removed from the study area, at least in the most recent logging entries, as very few stumps were present. The historical density is almost one-tenth the density of the stand prior to the recent restoration thinning. Comparable data from other oak and oak/Douglas-fir stands in the Pacific Northwest vary widely. Gedalof et al. (2006) report densities of trees with an open-grown form as ranging from 210 oak trees/ha in historical savannas to 390 trees/ha in woodlands. At the



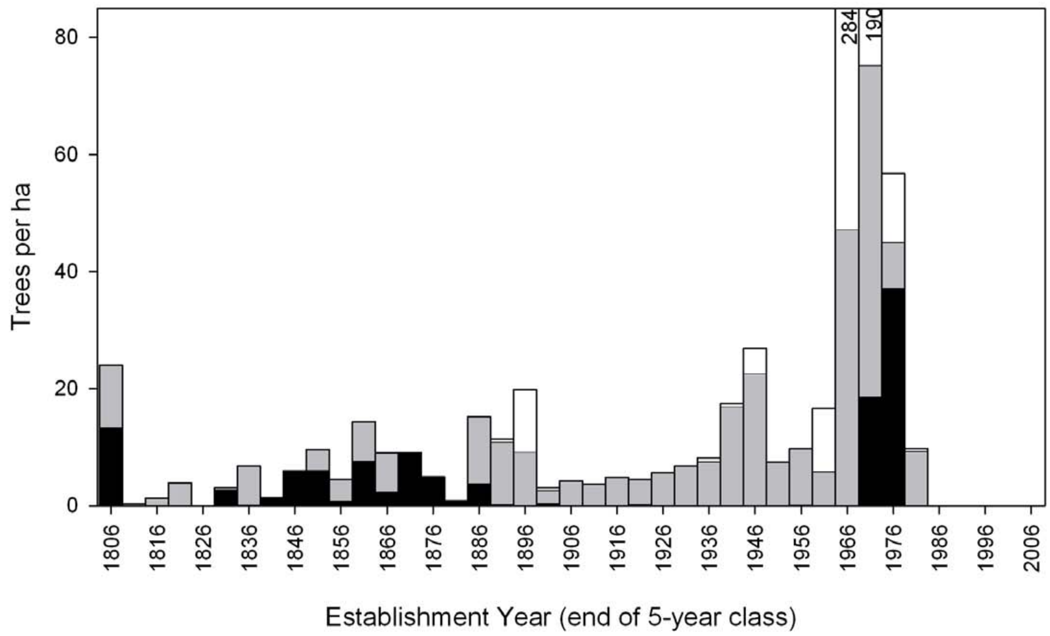


Figure 3. Tree age diameter (top) and age (bottom) distributions at Point Disney. Note several classes of Douglas-fir thinned in 2007 (clear bars) are truncated.

TABLE 1. Stand structure (trees taller than breast height) of a Garry oak / Douglas-fir stand at Point Disney, Waldron Island, Washington. Calculations of historical basal area were beyond the scope of this project. Df = Douglas-fir; Go = Garry oak.

	Density (t/ha)			Basal Area (m^2/ha)		
Date	Douglas-fir	Garry oak	Total	Douglas-fir	Garry oak	Total
Historical (1881)	44	55	99			
Pre-treatment (2007)	811	116	927	39.8	10.9	50.7
Post-treatment (2007)	298	116	414	34.6	10.9	45.5

other extreme, Gilligan and Muir (2011) found densities of large, relict oaks averaged about 21 trees/ha in southern Oregon oak stands. The data from the older Point Disney trees fall between these values. The low stand density, together with the open-grown form of most of the older trees, suggest that the stand historically was more akin to a savanna or woodland than a forest. These habitats currently occupy about one-third of Point Disney (Sprenger et al. 2005), but appear to have been considerably more extensive prior to Euro-American settlement. Their open structure was likely maintained by the low-intensity fires that regularly burned across the droughty, south-facing slope.

Tree establishment on Point Disney has not been continuous, but rather occurred in several clear pulses (Figure 3). This pattern has been observed at many other sites throughout the ecoregion (Agee and Dunwiddie 1984, Agee 1987, Gedalof et al. 2006, Smith 2007, Gilligan and Muir 2011). Most of the extant oaks on Point Disney became established in a 60-year long pulse beginning in the mid-1830s. Exactly which factors triggered this wave of oak establishment, and subsequent pulses of Douglas-fir establishment, are not entirely clear. Three principle mechanisms are frequently cited for stimulating tree establishment in grasslands and savannas: changes in climate (Rochefort and Peterson 1996, Woodward et al. 1995), alterations in grazing regimes (Dunwiddie 1977, Vale 1981), and changes in fire intensity or frequency (Arno and Gruell 1986). These mechanisms may interact with one another and with factors such as seed availability, herbivory, and vegetation competition, resulting in complex patterns of tree establishment (Riege & Del Moral 2004, Dovciak et al. 2008, MacDougall 2008, Haugo et al. 2010). Furthermore, in much of North America, these changes occurred simultaneously with declines in Native American populations, and with Euro-American settlement and the associated suppression of native-set fires, introduction of livestock, and hunting of native herbivores (MacDougall 2008). Therefore, it is difficult to disentangle the separate effects of these interacting mechanisms.

At Point Disney, the onset of the oak establishment period coincides with one of the most widespread fires that occurred on the site (1834) and continued through a period when fires burned with regularity (Sprenger and Dunwiddie 2011). It is unclear whether these oaks regenerated from seed or resprouted from root sprouts on older genets. However, many were single-trunked trees, suggesting a seed rather than resprout origin. Douglas-fir also established during this period, though the numbers of extant individuals are lower than for Garry oak, possibly because conditions were more favorable to the establishment of oaks or because of later selective logging of Douglas-fir.

Several other studies in the region describe similar waves of tree establishment in the early-mid 1800s. At Rocky Point on Vancouver Island, ca. 50 km southwest of Waldron Island (Gedalof et al. 2006), Garry oak and, to a lesser extent, Douglas-fir, invaded an open prairie in an 80-year pulse beginning in the 1850s, two decades after establishment began on Point Disney. At Young Hill on San Juan Island, 13 km southwest, Agee (1987) documented a period of oak regeneration from 1830-60 into an oak/Douglas-fir woodland. In an oak-dominated stand on Blakely Island, 22 km southeast, Batiuk (personal communication 2009) reported that 83% of the oaks regenerated between 1835 and 1900, with the main pulse occurring from 1850-1895. In southern Oregon, considerable Garry oak regeneration began at multiple sites starting in the 1830s, with peak establishment generally occurring between 1850-1890, and ceasing with increasing suppression of fires (Gilligan and Muir 2011). Both Gedalof et al. (2006) and Agee (1987) attributed the pulse of tree establishment during this time period to the cessation of Native American burning. Thilenius (1968) also implicated fire suppression as resulting in the infilling of Garry oak savannas in Oregon over the last century. Smith (2007) concluded that both fire and disturbance associated with Euro-American settlement, rather than climate, contributed to patterns of tree establishment that began in the latter 1800s.

Changes in Stand Composition and Structure: Post Euro-American Settlement

As in other regions, dramatic reductions in fire frequency followed settlement in the Pacific Northwest (Agee 1993, Boyd 1999a, Turner 1999). At Rocky Point, tree encroachment coincided with Euro-American settlement, the initiation of grazing, and the cessation of frequent fires (Gedalof et al. 2006). At eight sites in the Gulf Islands and Vancouver Island, Smith (2007) also concluded that a pulse of tree recruitment typically occurred at or shortly after Euro-American settlement. The scenarios at Point Disney and Young Hill are more complex as establishment began several decades before Euro-American settlement, although Native American populations had already been declining. The 1834 fire on Point Disney occurred after a relatively lengthy fire-free period, and may have stimulated establishment. The end of the pulse occurred several decades after Euro-

American settlement and roughly coincides with the commencement of livestock grazing on Point Disney, and may reflect oaks' low tolerance of trampling and livestock herbivory (Jackson et al. 1998). Gilligan and Muir (2011) also found little regeneration of Garry oak during the 1900s in southern Oregon.

The wave of Garry oak establishment on Point Disney ended as a century-long period of Douglas-fir regeneration began (Figure 3). Extensive infilling of Douglas-fir during the 20th century has been reported from many other sites in the region (Agee and Dunwiddie 1984, Agee 1987, Peterson and Hammer 2001, Spurbeck and Keenum 2003, Gedalof et al. 2006, Smith 2007). At Point Disney, this occurred in three increasingly larger waves: 1882-1896, 1937-1951, and 1962-1976. Only a few more fires were documented on the site once this period began, with the last fire occurring in 1906 (Sprenger and Dunwiddie 2011). Young Douglas-fir trees are readily killed by burning, and once fires were removed, significant infilling by this species converted much of the savannas and woodlands to forest. Increasing conifer density in the 20th century precluded further establishment of oaks, which can germinate but do not establish successfully under a Douglas-fir canopy (Thysell and Carey 2001). During this period, the primary disturbances on the site were livestock grazing and, to some extent, selective logging from the 1940s to the early 1970s. However, we have insufficient detail on the nature of these events to closely evaluate the causal relationships with the observed pulses in tree infilling, with the exception of the most recent wave. An enormous and rapid pulse of Douglas-fir regeneration began ca. 1962, with thousands of young trees forming dense stands in the forest understory and in many savanna and woodland openings (Figure 3). This last wave was particularly concentrated from 1972-1976, and was exceptionally large; it accounted for 73% of the trees in the pre-restoration stand.

This recent wave of Douglas-fir establishment was previously documented on Point Disney by Salstrom (1989), and closely resembles similar pulses that have been reported at several nearby locations. We have observed similarly-aged young cohorts of Douglas-fir that have colonized grassy balds, bluffs, and headlands at numerous other locations in the San Juans, including Sentinel Island, multiple sites along the south shore of Lopez Island, on the slopes of Mt. Constitution on Orcas Island, and American Camp on San Juan Island, to name but a few. Agee and Dunwiddie (1984) described a wave of Douglas-fir regeneration into open grasslands on Yellow Island, 9 km south of Point Disney. The oldest tree in this cohort germinated in 1963; the invasion peaked in the early 1970s but continued into the 1980s, when managers began to remove trees from the grasslands on the island. Increased summer moisture was suggested as a probable factor that may have helped initiate this event (Agee and Dunwiddie 1984). Agee (1987) documented a similar period of recent tree establishment on Young Hill on San Juan Island. Douglas-fir was also the dominant species in this recruitment pulse, which began about 1965. Regeneration virtually ceased in the late 1970s in plots with an oak/Douglas-fir overstory, but continued in grasslands into the 1980s, particularly in a plot that burned in 1973. Agee (1987) found that favorable climatic conditions and good seed years were only weakly correlated to years of peak conifer recruitment, and attributed its initiation largely to the cessation of grazing around 1966. On Rocky Point, Gedalof et al. (2006) described a large wave of Douglas-fir establishment in the 1960s and 70s. They concluded this recruitment was "probably ongoing," but were uncertain what circumstances initiated it. It is noteworthy that at all of these sites where sufficient data exist, this recent recruitment event was by far the largest of any in well over a century.

Fire is not mentioned as a likely triggering factor for these recent events at any of the sites, with the exception of a small portion of Young Hill (Agee 1987). Although it has been suggested that changes in the abundance of native ungulates may contribute to tree encroachment events in some areas (Peterson and Hammer 2001, MacDougall 2008), the absence of such grazers on Waldron today is noteworthy. As on Young Hill, the beginning of the most recent conifer pulse on Point Disney closely coincided with the cessation of livestock grazing. Selective logging prior to the 1960s may have played a role on the Waldron site as well. Similar pulses of tree establishment occurring in response to release from grazing pressure have been reported in other grassland systems (Dunwiddie 1977, Vale 1981, Bakker and Moore 2007, Beschta and Ripple 2009). But, livestock grazing was never a factor on Yellow Island, which also experienced a simultaneous episode of Douglas-fir recruitment. Similarly, Gedalof et al. (2006) reported no changes in grazing at Rocky Point in the 1960s.

The widespread occurrence of similar events that are relatively simultaneous and almost unprecedented in magnitude across the region is striking. That this has occurred even in sites with no history of livestock grazing, such as Yellow Island, points toward causal factors that have common, widespread impacts across the region. Agee and Dunwiddie (1984) suggested an anomalous series of moister years occurred in the 1960s that were particularly favorable for the establishment of trees in xeric grassland habitats. Invasion continued to occur, even after drier conditions resumed, because the recently established trees ameliorated the microenvironment and created conditions that favored additional establishment (Halpern et al. 2010). More detailed analyses by Agee (1987) detected only a weak relationship between moist summers and with years of tree establishment. More detailed comparisons of climatic records, land use history, and tree recruitment data are needed at sites across the region to resolve these uncertainties. On Point Disney, we suggest the recent large wave of Douglas-fir recruitment most likely resulted from a combination of interacting factors, which included the cessation of livestock grazing, climatic factors, and perhaps logging disturbance.

By the early 1980s, this period of conifer invasion had virtually ceased. The apparent pulse of oak establishment in 1962-1966 and 1972-1976 (Figure 3) is an artifact of a single plot center situated in an opening amongst a few small oaks. Even though oaks are regenerating on Point Disney, reproduction occurs almost entirely in more open areas rather than under the conifer canopy. We recorded no tree regeneration of oak or Douglas-fir since 1987. Although this is partially a result of our sampling trees taller than breast height, it also reflects a real lack of establishment; less than a half dozen saplings were encountered during our sampling. However, oaks are regenerating well in more open areas of Point Disney, presumably where competition with Douglas-fir is less. This is in noted contrast to many other sites we have observed in the San Juans, where extensive deer browse has prevented any oaks from reaching sapling size.

Oak Release Activities

By the early 2000s, the historically open vegetation on Point Disney had been replaced with dense forests: the stand contained 927 trees per ha, 87% of which were Douglas-fir, before the oak release treatment was applied (Table 1). This density is nearly double the number reported in conifer forests on Orcas Island (Peterson and Hammer 2001). Basal area was 50.6 m^2 per ha, of which 78% was Douglas-fir. Most trees were in the 5-10 cm and, to a lesser extent, 10-15 cm dbh classes (Figure 3).

Douglas-fir is able to establish under a light-moderate oak canopy, and once established, grow significantly more rapidly than Garry oak at Point Disney. As a result, Garry oaks were older than Douglas-firs of the same size (Figure 4). This rapid growth, together with the large wave of conifer recruitment over the last century, explains the overtopping and crowding that is contributing to the decline and mortality of many of the oaks.

The extensive degradation and loss of oak-dominated communities throughout the Puget Lowland and Willamette Valley adds urgency to efforts to restore these endangered systems (Hanna and Dunn 1996, Vesely and Tucker 2004, Vellend et al. 2008). At many sites, oaks are witnessing considerable canopy die-back, alteration in form, and high rates of mortality due to competition for resources by fast-growing firs. On Point Disney, oak establishment has been largely unsuccessful for more than 100 years. However, there are virtually no examples of dry, lowland Garry oak/Douglas-fir systems that continue to be maintained by frequent fire in the Pacific Northwest, and the remnant oak stands we have are not representative of the full range of its distribution historically (Vellend et al. 2008). We therefore do not have good examples of reference conditions to guide the restoration of stand structure in these communities.

Restoring communities that have been significantly altered for extended periods presents large challenges. However, mechanical removal of competing conifers is a feasible and effective approach for ensuring survival of canopy oaks (Vesely and Tucker 2004, Devine & Harrington 2006, Harrington & Devine 2006). Beginning in 2006, large numbers of Douglas-fir that were less than 20 cm dbh, and select trees less than 30 cm dbh within one tree height of targeted oaks, were cut from the stand. A handful of individuals that could not be easily removed without damaging oaks were girdled. Overall, 55% of the trees were killed; the remote location of this site meant that all cut trees were burned on site. Since attention focused primarily on small diameter Douglas-fir (Figure 3), most of the cut trees were from the cohort established after 1970 (Figure 3), and only 10% of the overall basal area was cut (Table 1). Upon completion, Douglas-fir still accounted for 72% of the trees and 76% of the basal area.

The restoration work carried out on the site so far appears to have succeeded in accomplishing its primary objective of maintaining the mature oaks. We have not observed any increased mortality or significant wind damage to the oaks since their release. In addition, epicormic sprouting is beginning to reinvigorate the oaks with increased foliar cover. However, the post-treatment composition, density, and basal area data all differ significantly from historical values. Douglas-fir density in all diameter classes remains high, and basal

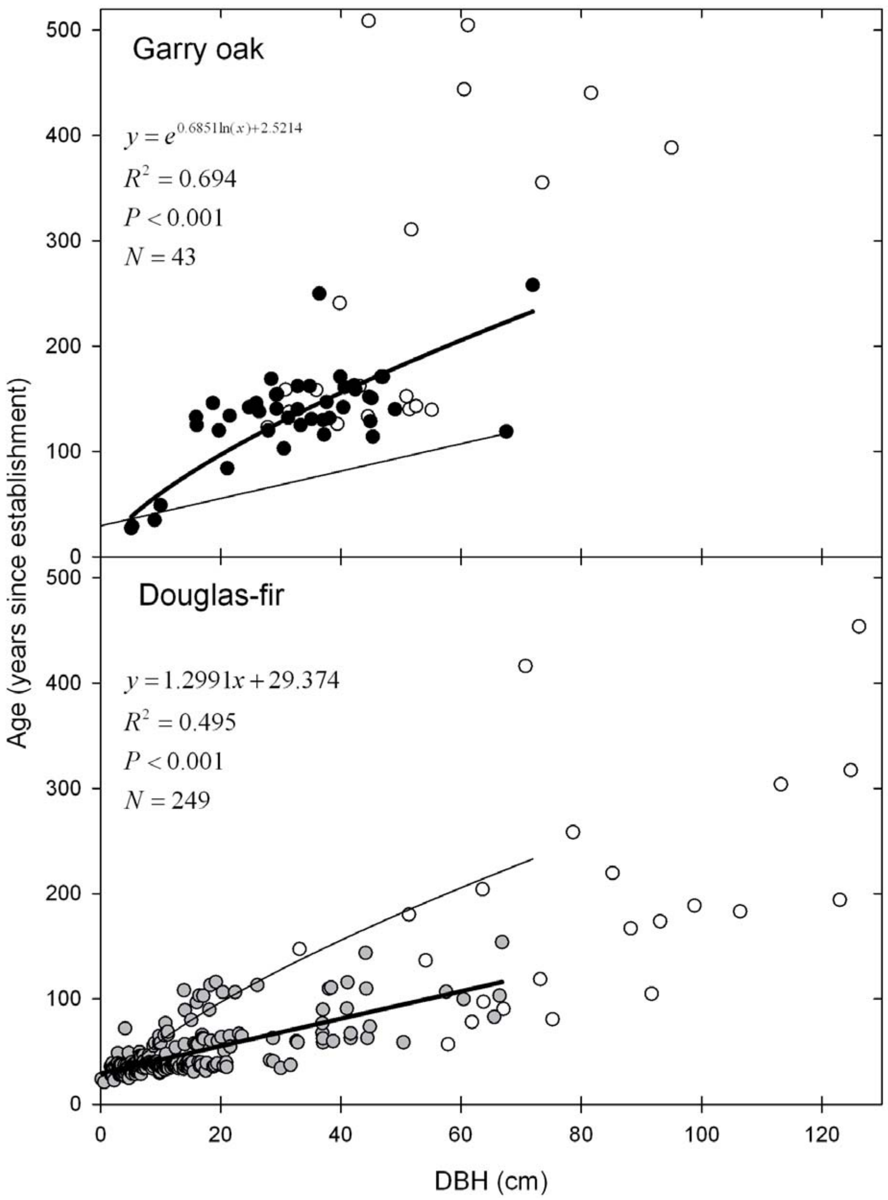


Figure 4. Relationships between DBH and age for Garry oak (top) and Douglas-fir (bottom). Equations are based only on those samples that hit the pith or where the number of missing rings was estimated using Applequist's method (shaded symbols). Samples whose ages were estimated with the early radial growth method are shown as open symbols (N = 20 for Garry oak, 22 for Douglas-fir). For reference, each graph also contains as a lighter line the best fitting line from the other species. Axes are on the same scale in both graphs.

area has been only slightly reduced. Although some smaller trees can still be felled and burned, removal of larger-diameter trees in numbers sufficient to return the stand to a woodland or savanna structure poses significant logistical challenges. Our best options may be to create patches and openings within the stand that will allow restoration of an understory more characteristic of an open canopy. However, the understory in the savannas and woodlands that still persist on Point Disney is currently dominated in many areas by invasive, non-native species. Experimental treatments are currently underway to identify the most effective strategies for controlling these invasives, as well as for re-establishing herbaceous grasses and forbs in areas where the forest canopy has been opened and where slash piles have been burned.

Numerous questions remain regarding the consequences of the restoration actions taken to date, and determining what future actions are most feasible. Have sufficient canopy gaps been created to ensure oak seedling survival at a rate sufficient to maintain the stand? Should competition from more of the larger Douglas-fir trees be removed, perhaps by girdling? How will invasive species respond to the increased light levels in the understory? How can significant accumulations of duff, needle litter, and woody debris be reduced to create conditions more suitable for supporting native herbaceous species? What is the desired stand density and composition? Has the removal of small-diameter Douglas-fir created conditions that will trigger a new wave of fir regeneration? What type of management should be initiated to maintain this stand as a mixed-species stand? Can fire be returned to the site as a significant ecological process? Future efforts will focus on answering these questions, and on developing strategies that will be most successful at enhancing the ecological attributes and long-term viability of this endangered system. Additional work is also needed to restore the substantial acreage of oak/Douglas-fir habitats that exists nearby (Ellison 2010).

Acknowledgments

The U.S. Fish and Wildlife Service and The Nature Conservancy supported restoration of the site. We thank Phil Green, Nick Hill, and Tony Scruton for assistance with field work. Doug Harshfield prepared the tree cores and cookies for analysis. Rob Fimbel and two anonymous reviewers provided helpful suggestions for improving the manuscript.

Literature Cited

Agee, J. K. 1987. The forests of San Juan Island National Historic Park. National Park Service Report CPSU/UW 84-2. National Park Service, Seattle, WA.

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

Agee, J. K., and P. W. Dunwiddie. 1984. Recent forest development on Yellow Island, San Juan County, WA. Canadian Journal of Botany 62:2074-2080.

Applequist, M. B. 1958. A simple pith locator for use with off-center increment cores. Journal of Forestry 56:141.

Arno, S. F., and G. E. Gruell. 1986. Douglas-fir encroachment into mountain grasslands in southwestern Montana. Journal of Range Management 39:272-276.

Bakker, J. D., and M. M. Moore. 2007. Controls on vegetation structure in southwestern ponderosa pine forests, 1941 and 2004. Ecology 88:2305-2319.

Bakker, J. D., A. J. Sánchez Meador, P. Z. Fulé, D. W. Huffman, and M. M. Moore. 2008. Growing trees backwards: description of a stand reconstruction model. *In* S. D. Olberding and M. M. Moore (technical coordinators.), Proceedings – Fort Valley Experimental Forest: A Century of Research 1908-2008. RMRS-P-55. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. Pp. 106-115.

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.

Beschta, R. L., and W. J. Ripple**.** 2009. Large predators and trophic cascades in terrestrial ecosystems of the western United States. Biological Conservation 142:2401-2414.

Boyd, R. 1999a. Indians, Fire and the Land in the Pacific Northwest. Oregon State University Press, Corvallis.

Boyd, R. 1999b. The Coming of the Spirit of Pestilence: Introduced Infectious Diseases and Population Decline Among Northwest Coast Indians, 1774-1874. University of Washington Press, Seattle.

Brown, P. M., and B. Cook. 2006. Early settlement forest structure in Black Hills ponderosa pine forests. Forest Ecology and Management 223:284-290.

Chappell, C. B. 2006. Upland plant associations of the Puget Trough ecoregion, Washington. Natural Heritage Rep. 2006-01. Washington Department of Natural Resources, Natural Heritage Program, Olympia, WA. Available online at http://www.dnr.wa.gov/nhp/refdesk/communities/pdf/intro.pdf (accessed 27 September 2010).

Day, J. W. 2005. Historical savanna structure and succession at Jim's Creek, Willamette National Forest, Oregon. M.S. Thesis. University of Oregon, Eugene.

Devine, W. D., and C. A. Harrington. 2006. Changes in Oregon white oak (*Quercus garryana* Dougl. Ex Hook.) following release from overtopping conifers. Trees 20:747-756.

Devine, W. D., C. A. Harrington, and D. H. Peter. 2007. Oak woodland restoration: understory response to removal of encroaching conifers. Ecological Restoration 25:247-255.

Dovciak, M., R. Hrivnak, K. Ujhazy, and D. Gomory. 2008. Seed rain and environmental controls on invasion of *Picea abies* into grassland. Plant Ecology 194:135-148.

Dunn, P., and K. Ewing (editors). 1997. Ecology and Conservation of the South Puget Sound Prairie Landscape. The Nature Conservancy of Washington, Seattle, WA.

Dunwiddie, P. W. 1977. Recent tree invasion of subalpine meadows in the Wind River Mountains, Wyoming. Arctic and Alpine Research 9:393-399.

Dunwiddie, P. W. 2001. Using historical data in ecological restoration: A case study from Nantucket. *In* D. Egan and E. A. Howell (editors), The Historical Ecology Handbook: A Restorationst's Guide to Reference Ecosystems, Island Press, Washington, D.C. Pp. 367-390.

Ellison, S. B. Z. 2010. A census of Garry oak (*Quercus garryana*) in the Point Disney preserve, Waldron Island, Washington. Senior project. University of Washington, Seattle, WA.

Erickson, W. R. and D. V. Meidinger. 2007. Garry oak (*Quercus garryana*) plant communities in British Columbia: a guide to identification. B.C. Ministry of Forest and Range, Research Branch, Victoria, B.C. Technical Report 040.

Fuchs, M. A. 2001. Towards a recovery strategy for Garry oak and associated ecosystems in Canada: ecological assessment and literature review. Technical Report GBEI/EC-00-030. Environment Canada, Canadian Wildlife Service, Pacific and Yukon Region.

Gedalof, Z., M. Pellatt, and D. J. Smith. 2006. From prairie to forest: three centuries of environmental change at Rocky Point, Vancouver Island, British Columbia. Northwest Science 80:34-46.

Gilligan, L. A., and P. S. Muir. 2011. Stand structures of Oregon white oak woodlands, regeneration, and their relationships to the environment in southwestern Oregon. Northwest Science 85:141-158.

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

Halpern, C. B., J. A. Antos, J. M. Rice, R. D. Haugo, and N. L. Lang. 2010. Tree invasion of a montane meadow complex: temporal trends, spatial patterns, and biotic interactions. Journal of Vegetation Science 21:717-734.

Hanna, I., and P. Dunn. 1997. Restoration goals for Oregon white oak habitats in the south Puget Sound region. *In* P. Dunn and K. Ewing (editors), Ecology and Conservation of the South Puget Sound Prairie Landscape. The Nature Conservancy of Washington, Seattle, WA. Pp. 231-246.

Harrington, C. A., and W. D. Devine. 2006. A practical guide to oak release. PNW-GTR-666. USDA Forest Service, Pacific Northwest Research Station, Olympia, WA.

Haugo, R. D., S. A. Hall, E. M. Gray, P. Gonzalez, and J. D. Bakker. 2010. Influences of climate, fire, grazing, and logging on woody species composition along an elevation gradient in the eastern Cascades, Washington. Forest Ecology and Management 260:2204-2213.

Hosten, P. E., O. E. Hickman, F. K. Lake, F. A. Lang, and D. Vesely. 2006. Oak woodlands and savannas. *In* D. Apostol and M. Sinclair (editors), Restoring the Pacific Northwest: The Art and Science of Ecological Restoration in Cascadia. Island Press, Washington, D.C. Pp. 63-96.

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.

Kertis, J. 1986. Vegetation dynamics and disturbance history of Oak Patch Natural Area Preserve, Mason County, Washington. M.S. Thesis, University of Washington, Seattle.

Lea, T. 2006. Historical Garry Oak ecosystems of Vancouver Island, British Columbia, pre-European contact to the present. Davidsonia 17:34-50.

Ludwig, C. H. 1972. A Brief History of Waldron Island, Second edition. By the author.

Lynch, T. B., and R. F. Wittwer. 2003. *n*-tree distance sampling for per-tree estimates with application to unequal-sized cluster sampling of increment core data. Canadian Journal of Forest Research 33:1189-1195.

MacDougall, A. S. 2008. Herbivory, hunting, and long-term vegetation change in degraded savanna. Biological Conservation 141:2174-2183.

Omule, S. A. Y., and A. Kozak. 1989. Stump and breast height diameter tables for British Columbia tree species. FRDA Report 062. British Columbia Ministry of Forests, Victoria, BC.

Oregon Oak Communities Working Group. 2010. http://www.oregonoaks.org/issues.shtml (accessed 15 September 2010).

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.

PRISM Climate Group, Oregon State University. 2010. http://www.prismclimate.org, created 4 Feb 2004 (accessed 20 September 2010).

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

Received 1 September 2010
Accepted for publication 13 January 2011

Riege, D. and R. del Moral. 2004. Arrested succession in old fields within a temperate rainforest. American Midland Naturalist 151:251-264.

Rochefort, R. M. and D. L. Peterson. 1996. Temporal and spatial distribution of trees in subalpine meadows of Mount Rainier National Park, Washington, USA. Arctic and Alpine Research 28:52-59.

Salstrom, D. 1989. Plant community dynamics associated with *Quercus garryana* on Pt. Disney, Waldron Island, Washington. M.S. Thesis. Western Washington University, Bellingham.

Smith, S. J. 2007. Garry oak savannah stand history and change in coastal southern British Columbia. M.S. Thesis. University of Guelph, Guelph, Ontario.

Sprenger, C. B., and P. W. Dunwiddie. 2011. Fire history of a Douglas-fir – Oregon white oak woodland, Waldron Island, Washington. Northwest Science 85:108-119.

Sprenger, C. B., A. Larson, M. Almaguer-Bay, and S. Martin. 2005. Conservation area plan for Cowlitz Bay and Bitte Baer Preserves, Waldron Island, Washington. Report prepared for The Nature Conservancy, Seattle, WA.

Sprenger, C. B. 2006. Fire history of a Douglas-fir – Oregon white oak woodland, Waldron Island, Washington. M.S. Thesis. University of Washington, Seattle.

Spurbeck, D. W., and D. S. Keenum. 2003. Fire history analysis from fire scars collected at Iceberg Point and Point Colville on Lopez Island, Washington State. Report to the U.S. Department of the Interior Bureau of Land Management, Spokane District, Spokane, WA.

Stein, J. E. 2000. Exploring Coast Salish Prehistory: The Archaeology of San Juan Island. University of Washington Press, Seattle.

Suttles, W. 1974. The Economic Life of the Coast Salish of Haro and Rosario Straits. *In*: American Indian Ethnohistory: Coast Salish Indians I. Garland, New York.

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. J. 1975. Food plants of British Columbia Indians, Vol. 1, Coastal Peoples. B.C. Provincial Museum, Victoria, B.C.

Turner, N. J. 1999. Time to burn: traditional use of fire to enhance resource production by aboriginal peoples in British Columbia. *In* R. Boyd (editor), Indians, Fire and the Land in the Pacific Northwest. Oregon State University Press, Corvallis. Pp.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 105:61-125.

Vellend, M., A. D. Bjorkman, and A. McConchie. 2008. Environmentally biased fragmentation of oak savanna habitat on southeastern Vancouver Island, Canada. Biological Conservation 141:2576-2584.

Vesely, D., and G. Tucker. 2004. A landowner's guide for restoring and managing Oregon White Oak habitats. BLM/OR/WA/AE-05/008-5820.

Woodward, A., E. G. Schreiner, and D. G. Silsbee. 1995. Climate, geography, and tree establishment in subalpine meadows of the Olympic Mountains, Washington, USA. Arctic and Alpine Research 27:217-225.