David L. Peterson,[1] U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Cascadia Field Station, Box 352100, Seattle, Washington 98195

R. David Hammer, School of Natural Resources-Soil Science, University of Missouri, 302 ABNR Building, Columbia, Missouri 65201

From Open to Closed Canopy: A Century of Change in a Douglas-fir Forest, Orcas Island, Washington

Abstract

During the past century, forest structure on south-facing slopes of Mount Constitution, Orcas Island, Washington, has changed from open-grown Douglas-fir (*Pseudotsuga menziesii*) mixed with prairie to primarily closed canopy forest. Density of open-grown Douglas-fir was approximately 7 stems/ha in the 19th century, while current density of trees in closed-canopy mature forest is 426 stems/ha. Trees occur at intermediate densities in areas of transition from savanna-like stands to closed canopy. Analysis of fire scars indicates that at least seven fires have occurred on Mount Constitution since 1736, but only one fire has occurred since 1893, which suggests that the recent increase in stem density has been caused primarily by fire exclusion. The high stem densities currently found in this landscape put the relict (120-350+ years old) Douglas-fir at risk from contemporary fires, which would likely be high-intensity crown fires. Given the transition of forests on Orcas Island during the 20th century to closed canopy structure, undisturbed open-grown coniferous forest is now extremely rare in the San Juan Islands.

Introduction

Open, savanna-like coniferous forest is a rare vegetative assemblage in western Washington state, although it is common in low-precipitation environments on the east side of the Cascade Range in the Pacific Northwest (Franklin and Dyrness 1988). The only areas of western Washington where this forest type is found is the San Juan Islands and the southern edge of the Puget lowlands. Open savanna-like stands are also found in portions of the rainforest of the western Olympic Peninsula.

Low-density Douglas-fir (*Pseudotsuga menziesii*) and some ponderosa pine (*Pinus ponderosa*) associated with prairies are found on well-drained outwash soils ranging from the Fort Lewis area to the eastern Chehalis River valley (Lang 1961, del Moral and Deardorff 1976, Tveten and Fonda 1999). In this region, the forest-prairie dynamics have been greatly modified by tree cutting and fire exclusion during the past century; most older trees have been removed, although Douglas-fir and Garry oak (*Quercus garryana*) are becoming established at some locations in the absence of fire (Tveten and Fonda 1999). Lower terraces of river valleys in the western Olympic Peninsula contain late-successional forest with low densities of very large Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) (Buckingham et al. 1995). The open structure of these forests is maintained through intense herbivory by Roosevelt elk (*Cervus elaphus*) (Woodward et al. 1994, Schreiner et al. 1996).

The Oregon Territory surveys of the San Juan Islands in 1855 noted that forests generally had open canopies, much like those on the east side of the Cascade Range (Agee 1984). Low-density coniferous forest and prairies on the San Juan Islands have been historically located on south-facing landforms and well-drained soils (Fonda and Bernardi 1976), where the relatively dry rain shadow environment of the islands is accentuated by low soil moisture during the summer (Agee and Dunwiddie 1984). Because the San Juan Islands have been occupied by Euro-Americans since the 1850s (White 1980, Agee 1984, Wessen 1986), many island ecosystems have been altered by logging, agriculture, livestock grazing, and likely by fire exclusion.

The few remaining areas of the San Juan Islands dominated by open forest and prairie at the beginning of the 20th century, and still relatively undisturbed by human activities, have changed greatly in terms of vegetative structure and species dominance. This is particularly true on Orcas Island, where a nature reserve provided the opportunity to observe temporal changes in forest

[1]E-mail: wild@u.washington.edu

structure in an area formerly dominated by open forest and prairie. In this study, we quantified the current structure of undisturbed closed canopy Douglas-fir forest on Orcas Island and compared it to reconstructed forest structure of the 19th century in order to document changes that have occurred to the increasingly rare savanna-like forest at this location.

Study Site

The San Juan Islands are an east-west trending chain that transects the Puget trough. They lie between the Olympic Mountains to the southwest, Vancouver Island to the northwest, and Cascade Mountains to the east. Mount Constitution, on Orcas Island (48°39'N, 122°50'W) (Figure 1), has an elevation of 731 m. This study was conducted between 210 and 580 m elevation within a 50-ha site on the southwest-facing aspect of the mountain.

Weather patterns affecting the area are directly influenced by neighboring mountain ranges and surrounding islands, with the San Juan Islands in the rain shadow of the Olympic Mountains to the southwest. On Orcas Island, mean temperatures near sea level are 9°C in January and 21°C in July, with annual precipitation of 73 cm (data for Friday Harbor at nearby San Juan Island, from the U.S. National Climatic Data Center, Asheville, North Carolina). Orcas Island receives 70% of its precipitation between October and March, primarily from storms moving across the island from the south and southwest.

Rock outcrops and underlying parent material on Mount Constitution consist primarily of Paleozoic and Mesozoic sandstones and siltstones (Easterbrook 1969). The San Juan Islands have been glaciated several times, most recently during the Vashon stade of the Fraser glaciation (15,000-13,000 BP) (Easterbrook and Rahm 1970). The regolith is mixed with glacial till and outwash sediments. Glacial erratics, carried down from their granitic source north of the Puget lowlands, are a common landscape feature.

Little descriptive information is available for the soils of Orcas Island. The glades on the south face of Mount Constitution were previously mapped as steep rock land, with 30-70% slope; forest soils are mapped as Pickett rock outcrop complex, with both 0-30% and 30-70% slopes (Schlots 1962). The Pickett soils are formed from weathered arkose sandstone and greywacke, modified greatly by colluvium and medium textured Vashon till. Soils are deeper and loamier than indicated in the existing soil survey (R.D. Hammer and D.L. Peterson, unpublished data).

Vegetation on the south-facing slope of Mount Constitution is characterized by intermingled areas of Douglas-fir forest and native grasses and forbs. The forested areas are characterized by relatively even-aged (<100 years old) patches of "regeneration forest," with much older "relict" trees (120-350+ years old) scattered throughout. These older trees are much larger than the younger stratum and have many large lower limbs, indicating that they were originally open grown (Figure 2). There is no historical or visual evidence of past logging, grazing, or other human-caused disturbance on this portion of the mountain since 1922, when the site was protected within the confines of Moran State Park. Native Americans are known to have set fires at other locations in the San Juan Islands (Agee and Dunwiddie 1984), and Native Americans lived on Orcas Island until around 1800, hunting and fishing on and near Orcas Island until Euro-American disruption in the mid 1800s (Wessen 1986).

Glades are defined here as areas dominated by grass and forb species with few trees (sometimes termed "grassbalds," Roché and Busacca 1987). Dominant vegetation in the glades includes Idaho fescue (*Festuca idahoensis*), blue wildrye (*Elymus glaucus*), colonial bentgrass (*Agrostis capillaris*), sedges (*Carex* spp.), bracken fern (*Pteridium aquilinum*), nootka rose (*Rosa nutkana*), yarrow (*Achillea millefolium*), meadow deathcamas (*Zygadenus venenosus*), few-flowered shootingstar (*Dodecatheon pulchellum*), field chickweed (*Cerastium arvense*), and various moss species. The glades also contain a few scattered regeneration Douglas-fir.

Douglas-fir is the dominant species in the forest stands, although there are scattered individuals of western hemlock, shore pine (*Pinus contorta* var. *contorta*), bigleaf maple (*Acer macrophyllum*), and bitter cherry (*Prunus emarginata*). Common understory species in the forest include dull Oregon grape (*Berberis nervosa*), stink currant (*Ribes bracteosum*), stinging nettle (*Urtica dioica*), pathfinder (*Adenocaulon bicolor*), broad-leaved starflower (*Trientalis latifolia*), and cleavers (*Galium aparine*). Some areas within the forest ("relict

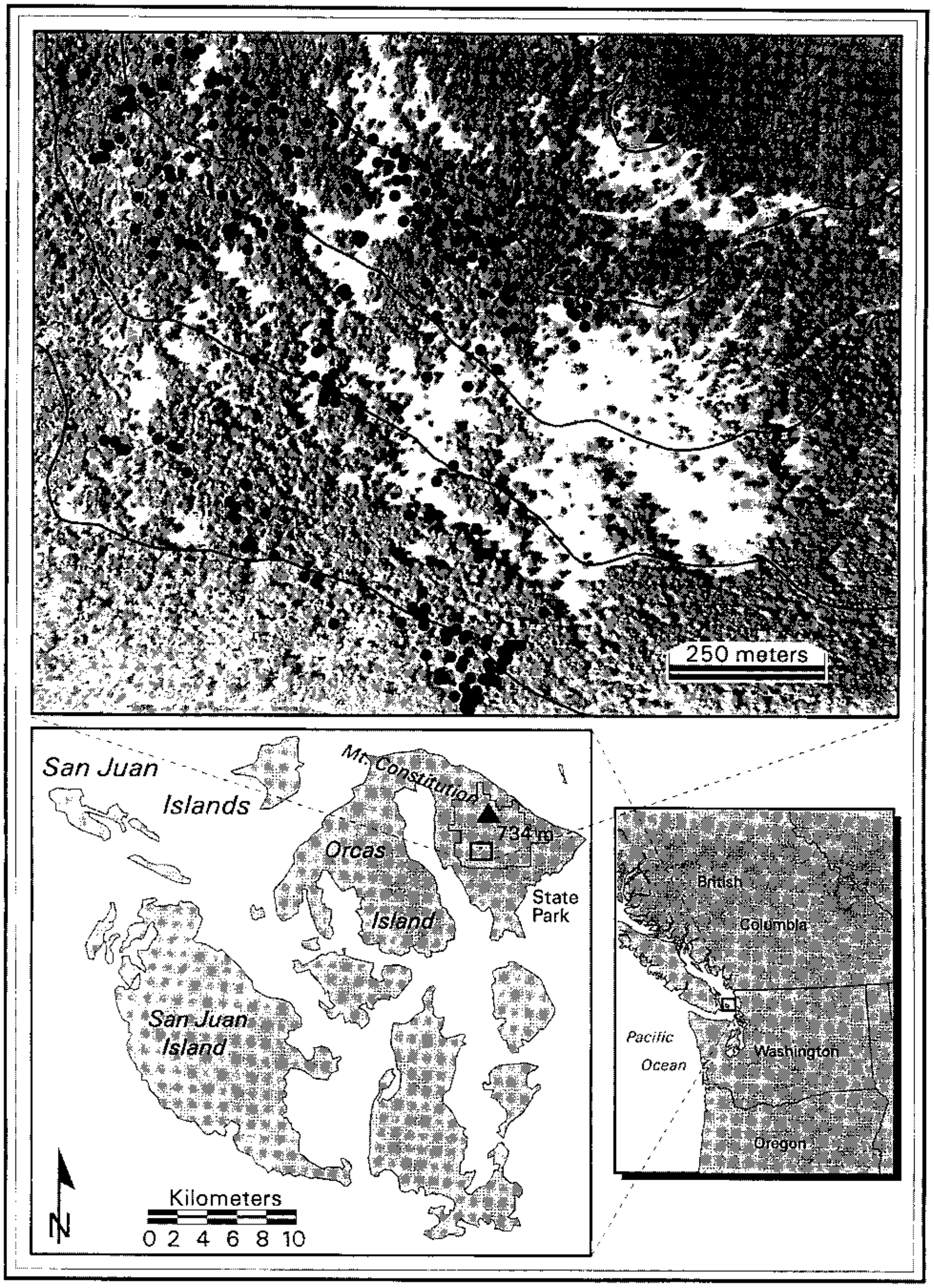

Figure 1. Location of the study site on Mount Constitution, Orcas Island, Washington. The photograph of the study site indicates current distribution of vegetation, with dots to indicate the location of all relict Douglas-fir. Elevation contour lines (100 m) are indicated on the photograph.

glades") contain grass, forb, and moss species typical of the glades, reflecting a transition from glade to closed canopy forest.

Methods

Field sampling was structured around three landscape units: (1) mature forest, dominated by

Figure 2. Two views of relict Douglas-fir on the south face of Mount Constitution, exhibiting characteristic open-grown form including large bole diameter and large lower branches. Note the high density of younger trees in the background.

Douglas-fir, (2) glades, and (3) relict glades, which contain a forest overstory and an understory with some vegetative characteristics of glades.

Regeneration forest vegetation was characterized within each landscape unit. Quadrats 0.02 ha in area were sampled at 50-m intervals along transects parallel to the slope. Number of quadrats varied, depending on the size of the forest stand being measured, with the following number of quadrats per landscape unit: mature forest (20), glades (18), relict glades (5). Species and diameter of all live trees greater than 1.5 m tall were recorded for each tree within the sample quadrat; only species was noted for trees less than 1.5 m tall. One codominant tree from each quadrat was cored (one core per tree) with an increment borer at 1-m height on the bole to estimate age.

Relict trees were sampled separately. These trees were characterized as having large diameters, very large crowns, and evidence of open-grown crown morphology with large branches near the ground. All relict trees were recorded throughout the study site, excluding only the large glades (there were no large trees in the glades). Location was recorded and diameter was measured for each tree. The geographic locations of all relict trees were mapped and compared to a scanned image of an aerial photograph of Mount Constitution (Figure 1).

A subsample (n=14) of relict trees was cored with an increment borer at 1-m height on the bole (usually two or more cores per tree) for analysis of tree age and fire scars (Barrett and Arno 1988). Only those trees with relatively open faces on fire scars were sampled, because the use of saws to obtain wedges was prohibited, and material was needed that would allow fire dates to be determined with cores. It is recognized that this sample may have underestimated the number of total fires over time.

Cores from regeneration and relict trees were mounted in wooden blocks and sanded until individual tracheids were visible under a microscope. All cores were crossdated visually and with the program COFECHA (Holmes 1983) in order to associate each tree ring with a specific calendar year (Stokes and Smiley 1968, Fritts 1976). Age was determined for regeneration trees, and age and (crossdated) fire dates were determined for relict trees. This estimated age is slightly lower than actual age, because 4-8 years generally are required for trees to reach the 1-m level on the bole. This slight inaccuracy of age determination does not measurably affect our inferences regarding large changes in stand structure over the past century.

Results and Discussion

Analysis of forest structure on Mt. Constitution shows that current structure is considerably different than it was at the beginning of the 20th century. The closed canopy forest has a high stem density dominated by Douglas-fir that are 50-95 years old (Table 1). Furthermore, there are few large woody debris on the forest floor and few standing dead trees, which suggests that the current stand dominated by the younger tree stratum is unique within (at a minimum) the past few hundred years. Stem density in relict glades is only 25% of that in closed canopy forest; regeneration trees are slightly younger than in the closed canopy forest, which suggests that tree establishment was more recent in relict glades. It is impossible to reconstruct precisely the past demography and stand structure in the absence of tree mortality data over the past century. However, we feel that minimal large woody debris in the understory—in the absence of recent fire—are strong evidence that tree mortality has generally been low (at least for larger trees) and that the current stand structure is a major change from that of the 19th century and earlier.

A 100% sample of relict trees on the study site indicates a density of only 7.7 stems/ha (Table 1); stem density is about twice as high on the lowest part of the study site, which is considerably less steep than adjacent slopes. Mean diameter of the relict trees is 133 cm, with the largest tree measured having a diameter of 265 cm. Most of the relict trees are dominants, with the top of their crowns above the main part of the canopy. Only 18 standing dead trees and only a few fallen, dead trees were observed. Although we do not have a complete record of the demography of Douglas-fir, the apparent lack of significant mortality of large trees indicates that much of the landscape has changed from open stands to a mixture of closed canopy forest and glades.

Forty-nine percent of the relict trees have visible fire scars on the lower bole, but no regeneration trees have fire scars. The most recent fire recorded in the fire-scar data from relict trees occurred in 1893. Prior to that time, there were fires (identifiable in multiple trees) in 1858, 1837, 1795, and 1773. We identified additional fire scars in 1765 and 1736, but consider these dates tentative because they were observed in only one tree. We have not been able to determine from historical records if these fires were caused by lightning

TABLE 1. Summary of tree diameters, densities, and ages in the different landscape units on Mount Constitution.

	Landscape unit	Mean stem diameter (cm) (± 1 SE)	Mean density (stems/ha) (± 1 SE)	Tree age at 1 m height on bole (range in years)[1]
Relict trees	Entire study site, excluding glades	133 (2)	7 (1)	120 – 350+[2]
Regeneration trees	Mature forest	37 (3)	426 (44)	50 – 95
	Glade	54 (3)	10 (5)	15 – 85
	Relict glade	51 (5)	100 (31)	60 – 65

[1]Age based on crossdated cores extracted at 1-m height.
[2]The radius of the oldest tree was longer than our increment borer; this tree was > 350 years old.

or humans, but regardless of cause, the fire scar data indicate that there have been at least seven fires on the island since 1736. Fire exclusion began on the Moran State Park property in 1923. The 1736-1923 fire return interval of 31 yr is lower than has been reported for several dry Douglas-fir forests of the Pacific Northwest (Means 1982, Agee and Dunwiddie 1984, Agee 1990, 1991b), but higher than in the Siskiyou Mountains of Oregon (Agee 1991a). It is possible that there were additional fires, because only a small number of trees were sampled and because some fires may not have caused visible scars in the tree-ring samples. Large woody debris are sparse in the forest understory on the south aspect of Mt. Constitution, which suggests that past fires (prior to 1900), in combination with decomposition, have been sufficient to remove most larger fuels, but not intense enough to kill most fire-tolerant relict Douglas-firs (Brown and Davis 1973; Peterson and Arbaugh 1986, 1989; Peterson et al. 1991, Agee 1993).

The absence of large fires during the 20th century was probably the critical factor that facilitated the establishment of new cohorts of Douglas-fir. However, the persistence of glades and relict glades indicates that fire is not the only environmental factor that determines forest/glade distribution. The southwest aspect of the mountain where this study was conducted clearly has high irradiance, and slopes are commonly >60%. The upper part of the soil profile normally is dry in late summer and could produce moisture stress in tree seedlings. Instrumental records show that average temperature in western Washington has increased by 0.9°C since 1900 (Mote 1999). The warmer climate of the 20th century contrasts with that of the Little Ice Age (ca. 1600-1850) during which most of the current relict Douglas-fir would have germinated. However, because the recent warming trend would be expected to increase moisture stress in tree seedlings, the effect of long-term climatic variation on regeneration at this site is probably small. We also observed extensive herbivory of small Douglas-fir in glades by blacktail deer (*Odocoileus hemionus*). In addition, many areas of the glades contain large populations of Townsend's vole (*Microtus townsendii*), which feeds on the vascular tissue of Douglas-fir and can reduce the survival of tree seedlings (West 1987). We have no way of ascertaining the importance of herbivory to regeneration at this site, but given that large mammalian predators have been absent during most of this century, it is likely the effects of herbivores on small trees have been relatively constant during this time.

On nearby San Juan Island, stem densities have increased greatly on some of the drier landscapes previously dominated by open-grown Douglas-fir and Garry oak (Agee 1984, 1987; Rolph and Agee 1993), but most of those forests were heavily cut during the late 19th and early 20th centuries. Agee and Dunwiddie (1984) have documented recent (last 40 years) establishment of Douglas-fir in grasslands on nearby Yellow Island, but attribute this regeneration to a period of above-average precipitation. Regeneration of young Douglas-fir has also increased at the forest-prairie ecotone of areas such as the Mima Mounds near Centralia, Washington (D.L. Peterson and R.D. Hammer, personal observation). It is most likely that a combination of fire regime, herbivory, climate, and perhaps movement of hillslope sediments has maintained the current distribution of forest and glades on Mount Constitution.

The closed canopy forest on the south face of Mount Constitution represents a forest structure that has not occurred at this location in the past 300 years and probably longer. As a result, it is likely that the last remaining savanna-like Douglas-fir forest in western Washington is being lost. The regeneration of younger trees at this location is analogous to the increased stem densities found in coniferous forests in low-precipitation environments on the east slope of the Cascade Range, where fire exclusion has contributed to altered stand structure over the past century (Agee 1993, 1998, Quigley et al. 1996). Current distribution of live fuels in the understory on Orcas Island will likely facilitate high fire intensities in the future, with a high probability of crown fires that will threaten the survival of the relict Douglas-fir.

If resource managers at Moran State Park wish to preserve the relict trees and restore open Douglas-fir forest on Mount Constitution, modification of the current forest structure is needed to reduce the likelihood of future crown fires. This could be achieved by manual thinning to reduce stem densities, especially in the vicinity of large trees. Alternatively, prescribed burning could be used to reduce stem densities, although the stem diameters of the newer cohort of Douglas-fir are large enough that controlled, low-intensity fire may not kill many trees. Repeated fires combined with manual thinning over several years, or perhaps cautious use of patchy crown fires, may be necessary to effectively restore stands with low stem density. Periodic prescribed burning could then be used more effectively and safely to reduce the density of understory trees.

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