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Natural History of the Ahlstrom's and Roose's Prairies, Olympic National Park, Washington

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Final Report: Natural History of the Ahlstrom's and Roose's Prairies, Olympic National Park, Washington.

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Much of the work herein is summarized from:

Mark Gutchwesky, Master's Thesis in Geography completed May 2004
"A Paleoenvironmental Reconstruction of the Ozette Prairies from Analysis of Peatland Cores, Olympic National Park, Washington"

Kate Ramsden, Master's Thesis in Geography completed May 2004
"Spatial and Temporal Patterns of Recent Tree Encroachment on the Ozette Prairies, Olympic National Park, Washington"

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Project Summary

The objective of this research is to evaluate the wetland and forest dynamics in and around the Ozette Prairies to identify their origin and history since the Last Ice Age. The Ozette Prairies are treeless areas, dominated by unique associations of understory species in an otherwise heavily forested region. The prairies are historically (pre-European) persistent elements of the landscape in a region where the climate promotes forest growth. Presently, the prairies are undergoing encroachment by the surrounding forest. The patchy character of the vegetation attests to centuries, or more, of climate change, expansion and demise of forest populations and changing fire regimes. We used a suite of methods to address the environmental history of this landscape. The first phase of this project evaluated the soils of the vicinity (this research is on-going). The soils indicate that fire has been an important component in their formation. The second phase of the project begins to evaluate the incidence of fire on this landscape. Three approaches where taken: examining sediments accumulated in wetlands within the prairies, examining repeat aerial photographs of the prairies to document tree invasion, and vegetation sampling to identify tree demographics.

The wetlands in each prairie are very different in terms of their hydrology, chemistry and vegetation composition. The northern end of Roose's Prairie contains a large raised bog dominated by *Sphagnum* mosses. Ahlstrom's Prairie (where bisected by the Cape Alava Trail) contains a similar sized fen (a fen is a bog that has surface water flow) dominated by sedges and grasses. Sediment cores reveal a dynamic history since the late-Pleistocene. Our data suggest that the prairies began as lakes following glaciation by the Juan de Fuca lobe of the Cordilleran ice sheet. The lakes terrestrialized into wooded swamps approximately 8000 years ago. An increased fire regime removed the trees at about 2000 years BP, creating the forest openings we see today. A frequent fire return interval maintained the openings until homesteader abandonment. Since then native tree species have reestablished in the prairies. All ages are from materials radiocarbon dated in Ahlstrom's Prairie. Roose's Prairie shows a similar deposition sequence, but the sequence has not been dated. Charcoal (an indicator of fire) was found throughout the cores, with the largest concentrations occurring during the 2000-8000 year period when the sites were forested. A fire return interval of 166-266 years was calculated for the time period since 2400 years ago. This fire frequency suggests that these landscapes have burned much more frequently than other forests on the western Olympic Peninsula or Vancouver Island, where return intervals of 1150-2380 years have been calculated. The more frequent fires at the Ozette Prairies are likely due to human activities rather than natural ignition.

Repeat air photos clearly show the process of tree invasion at these sites. Roose's Prairie contained established tree patches in 1964, and prairie area decreased 32.7% during the 1964-2000 period. Ahlstrom's Prairie was a relatively treeless environment in 1964 that experienced rapid tree encroachment from the surrounding forest and from the few mature trees present within the prairie landscape. An overall decrease in prairie vegetation of 53.5% was detected over the same 36-year interval. Vegetation transects identified hundreds of small trees, which were identified to species, measured for height, diameter, and age. All trees species are native to the area. No strong statistical relationships were found between height or age of encroaching trees and distance from forest, suggesting that trees are establishing not only from the forest edge but also from patches within the prairie interior. Little infilling has occurred in the wetlands, but in areas surrounding the wetlands that have mineral soils containing abundant charcoal. The difference in infilling rates is believed to be related to the timing of cession of homesteader activities. Pete Roose abandoned his homestead in the 1930s, allowing the tree invasion seen in the 1964 photo. The rapid invasion of Ahlstrom's Prairie did not begin until the mid-1980s following Lars Ahlstrom's abandoned his homestead in the early 1960s. Markov modeling predictions based on air photo analysis suggests that tree encroachment will continue to advance at a rapid rate covering the entire prairie area within 100 years barring any future disturbances or intervening land management practices.

The forests were found to be mixed ages and species, suggesting that tree fall is the main disturbance factor rather than fire. Individual trees were dated in excess of 400 years old. Tree ring ages indicates that invasion on Roose's Prairie began as early as 100 years ago, while the tree invasion on Ahlstrom's Prairie began more recently (50 years ago). An attempt was made to determine the recent fire history of the prairies using tree rings. However, it was found (as expected) that ring widths in this environment are mostly related to sunlight availability. Thus, tree growth responds more to local disturbances (*e.g.* a tree falling and allowing sunlight to hit a neighboring tree) than climate, and no climate signature was detected, and the tree rings were not useful in reconstructing a fire history.

Project Background

Problem Statement

Meadows and prairies throughout the Pacific Northwest have received much attention by ecologists, anthropologists, and land managers because of recent changes that threaten their existence, specifically encroachment by surrounding forests. Ongoing interdisciplinary research provides useful background data for natural resource managers to make informed decisions regarding future management of such areas. Much of the research focus has been either on sub-alpine or montane meadows (*e.g.* Magee and Antos, 1992; Rochefort and Peterson, 1996; Woodward *et al.* 1995), or on Northwest prairies historically maintained by Native American burning (e.g. Agee and Dunwiddie, 1984; Turner, 1999; Storm, 2002; Wray and Anderson, 2003). Tree invasions in these open areas have been explained by a variety of reasons, including changes in disturbance regimes (including suppression of both natural fires and historic use of fire associated with Native American land management, and cessation of homesteader farming and grazing), and climate change, or a combination.

Reconstructing the history of disturbed landscapes poses a number of challenges to researchers and resource managers. A primary challenge is identifying the effects of interrelated variables and unrelated events over diverse temporal and spatial scales (Hadley, 1999). This undertaking requires a multifaceted research strategy that must overcome problems of sampling artifacts and recognize the effects of long-term versus short-term processes, and the complex interrelationships among their biological, geophysical, and socio-cultural components (Cole and Taylor, 1995; Knudson, 1999). Thus, the reconstruction of the Ozette landscape requires the integration of diverse data into a general, but accurate view of former vegetation conditions. Despite these difficulties, historical reconstructions of forest landscapes provide an essential basis for monitoring the effects of land use and management practices (Covington and Moore, 1994). Historical reconstructions are also important in identifying the role of past disturbances in governing modern forest patterns and processes (Agee, 1993; Lertzman *et al.* 2002) and in understanding how natural and anthropogenic disturbances interact over time (Hadley, 1999; Lepofsky *et al.* 2003). Resource managers must make informed decisions regarding future maintenance of these changing environments, and their priorities are often based on a combination of ecological processes, cultural implications, and public policies and law.

The origin and continued existence of the Ozette Prairies is controversial. There are at least four competing hypotheses for their formation: 1) The prairies are anthropogenic in origin with ties to pre-contact Makah land use, specifically burning. 2) The prairies are anthropogenic in origin, relating to early-European land use, specifically burning and livestock grazing. 3) The prairies are remnants of once larger coastal prairies or bogs with vegetation communities surviving from Pleistocene climatic conditions (refugia). 4) Some aspect of the soil (*i.e.* nutritional, physical barrier, moisture, *etc.*) under the prairies precludes the establishment of trees, allowing understory species to dominate. Evaluation of the soils, vegetation, and geological materials have led us to accept the first hypothesis.

The prairies are of interest by Olympic National Park for three primary reasons: cultural significance, endangered species habitat, and aesthetics/conservation. The prairies are culturally significant on two levels: There is an oral tradition of use, including burning to maintain the prairies for hunting and plant gathering by the Makah; and the prairies were homesteaded around the turn of the century. The species compostion of the prairies is very different from the surrounding coastal temperate rainforest. The pre-European vastness of the forests and ocean has created an island effect on the prairie ecosystems. The prairie habitat contains at least two rare species of butterfly and several rare plants (Pojar and MacKinnon, 1994; Pyle and Pyle, 2001; Pyle, 2002). These natural areas are in a designated wilderness area, along a major hiking trail, thus under the current mission of the Park Service are to be managed to preserve their natural aesthetics. An understanding of the formation and evolution of the prairies will aid in determining management options for the area.

Currently the prairies are undergoing an invasion by trees and shrubs. The invasion could be the result of many things, such as fire suppression, disturbance by hikers, or climate change. The question has arisen of how to manage the prairies in light of the vegetation invasion- burn? cut? or leave alone? If there is evidence for long term burning, then fires could be used to continue this process. This alternative might be preferred for cultural reasons: historical precedence, maintaining open space surrounding homestead sites, and fire management. However, the rare plants and butterflies might be sensitive to fire, thus burning would not be a viable management practice.

Objectives of Study

The objectives of this work are to determine the natural history the prairies beginning with their origin, how they fit into the natural ecosystem of the area, and how the prairies might have been used and/or modified by pre-contact people, subsequent European settlers, and the National Park Service and its users. Ultimately the findings of this work will aid in determining the best management plans to be implemented for the prairies.

This report summarizes studies examining the wetlands within the prairies, the history of sedimentation in the wetlands, the fire history recorded in these sediments and in tree-rings, and the rates and patterns of tree invasion over the last 40 years. A previous report documented the soils of the region (Bach and Conca, 2001).

Description of the Ozette Prairies

The Ozette Prairies are a group of treeless areas located to the northwest of the northern end of Lake Ozette, which is located along the Pacific Coast of the Olympic Peninsula. The three largest prairies are named after European homesteaders who settled the area around the turn of the century (structures on Figure 1). This study focuses on Roose's and Ahlstrom's Prairies, located in Olympic National Park, on the USGS Ozette, WA 7.5' quad (Figure 1). The prairies are 1-2 km inland from the coast along a hiking trail from Ozette to Cape Alava (Figure 1). Cape Alava is the site of a Makah village which has archeological evidence suggesting at least 2000 to 3500 years of occupation (Wray and Anderson, 2003). The prairies range in elevation from about 36 – 51 m, and contain gently rolling hills.

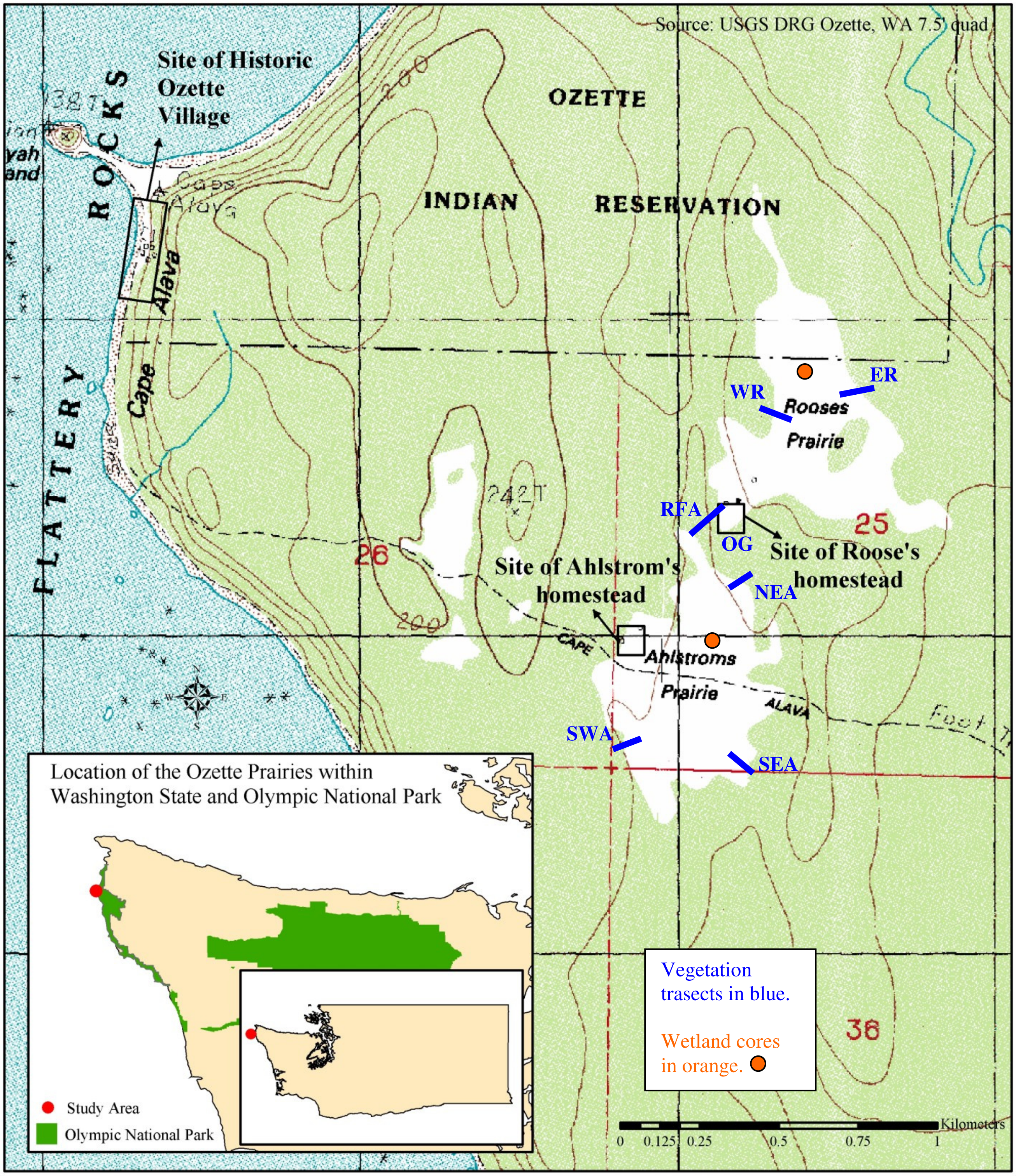
The term 'prairie' deserves attention. The term is used as part of place names for over 200 sites across Washington. These treeless areas range in elevation from sea level to subalpine, from wetlands to excessively drained soils, and from grasslands to tall shrublands. The climate, substrate, soils, vegetation communities, and natural and human histories are quite varied. For example, the geology and soils of the nearby Quillayute Prairie (Lotspeich *et al.* 1961) are nothing like what we observed. Many prairies in the Puget Sound contain(ed) camas and oaks, both absent at Ozette. The term 'prairie' is merely a place name, much like the terms 'meadow' or 'mountain;' and has no relationship with the origin, environmental process, or history of the feature. Many but not all prairies share the common traits of low vegetation cover with an absence of trees, prehistoric human use (*i.e.* hunting and gathering, management with fire), development by Euro-Americans (*i.e.* agriculture, grazing, and building), and recent vegetation changes (Storm, 2002). Even within the Ozette Prairies, as outlined in the vegetation and soils sections below, there is considerable variation.

Vegetation and Fire

The Ozette Prairies contain unique plant communities, dominated by mosses, sedges, grasses, herbs and shrubs, surrounded by a heavily forested landscape. Sometimes the prairies are referred to as bogs, since their core areas have wetland characteristics, including saturation for most the year, an accumulation of peat, and wetland vegetation species. The forest/prairie edge is a very obvious feature on the landscape, with the forest trees forming a distinct linear edge rising 30-40 m above the prairies. The prairies are historically persistent elements of the landscape in a region where the climate is extremely favorable for the growth of the surrounding forest (Reagan,1928). The General Land Office map (1897, based on an 1895 survey) shows the prairies; however, their outlines do not match those on recent air photos, suggesting that either the mapping is incorrect or that the prairies have expanded in some places and trees have invaded in others between 1895 and the oldest air photos (~1956).

The forest immediately surrounding the Ozette Prairies falls within the coastal forest zone, or the Sitka spruce (*Picea sitchensis*) Zone (Agee, 1993), and has been described as coastal temperate (or Olympic) rainforest (Franklin and Dyrness, 1988) or coastal western Hemlock forest in Canada (Pojar and MacKinnon, 1994). This forest zone normally extends only a few kilometers inland, except where it elongates up river valleys (Agee, 1993). The forest is predominantly comprised of sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), yellow cedar (*Chamaecyparis nootkatensis*) and western red cedar (*Thuja plicata*). Spruce and hemlock are noted for being susceptible to fire damage, lacking adaptations to survival in a frequent fire regime (Kauffman, 1990). The forest understory varies from dense to open, with deer fern (*Blechnum spicant)*, shrubs, and abundant coarse woody debris (often in multiple layers), all draped with mosses.

Figure 1. Location of the Ozette Prairies within Olympic National Park, Washington



Coastal temperate rain forests of the region are noted for near nonexistence of fire, and dominance of late-successional forest communities that experience small-scale tree-fall disturbances (Gavin *et al.* 2003A). The absence of Douglas-fir (*Pseudotsuga menziesii*), a species that requires frequent fire for establishment in the Pacific Northwest, distinguishes coastal temperate rain forests of the region (Agee, 1993; Gavin *et al.* 2003A). Estimated fire frequencies of coastal temperate rainforests based on soil charcoal studies and forest age-class data are ~1146-2380 years or more between events suggesting fire is a rare disturber for the ecosystem (Agee, 1993; Lertzerman *et al*. 2002; Gavin *et al*. 2003A).

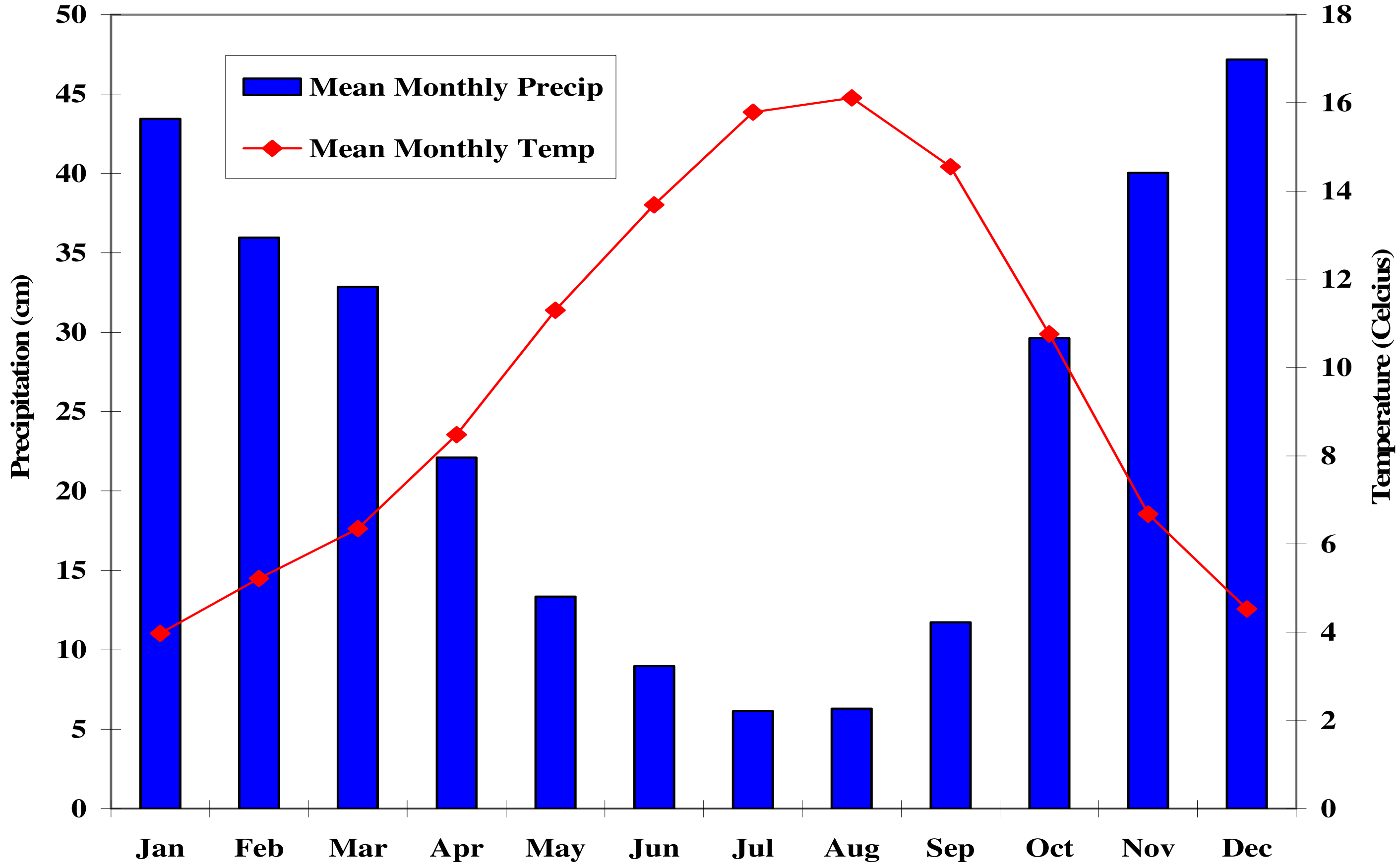
Natural fires tend to be less than 0.1 ha in size, but the 1978 Hoh fire burned 492 ha (Huff and Agee, 1980; Huff, 1995). Lightning fires occurred in less than one-third of the years 1916-1975 in Olympic National Park, most of which occurred in the mountains (Pickford *et al.*1980). Years with high incidence of thunderstorm activity did not have an increased number of fires (Huff and Agee, 1980). Fire occurrence may be more related to fuel moisture (drought) than ignition (Huff and Agee, 1980; Pickford *et al.* 1980). Investigations between the occurrence of fire and climate in the interior of the Northwest suggest that climatic variation has been a strong driver of the historical fire regime, but localized, non-climatic factors, such as topography and human activity, can supercede the climatic forcing (Mote *et al.* 1999; Skinner *et al.* 1999; 2002; Heyerdahl *et al.* 2001; 2002). Fires burning in adjacent forest types have in the past extinguished themselves upon reaching the coastal forest zone (Agee, 1993).

We did not closely investigate the vegetation composition of the prairies, but we did note several different communities which will be categorized into three broad groups here: sedge fens, *Sphagnum* bogs, and prairie uplands on the mineral soils. The mineral soils tend to be on slopes >2° surrounding the wetlands. There are several variations in species composition in the prairie uplands, but the defining composition is that of ~0.5-1 m high densely spaced woody shrubs with few sedges and grasses, many young trees 1-10 m high, and a thick understory of herbs, fern, lichen and mosses. Based on our soil analysis and the presence of many burnt stumps and snags in this zone, we believe that this vegetation community is a successional stage following the expansion of the prairies into the forest by burning. By far the two most common woody shrubs are bog laurel (*Kalmia polifolia*) and labrador tea (*Ledum groenlandicum*). Salal (*Gaultheria shallon)* is locally abundant especially near the forest edge, but is often short in stature. Deer fern, Nootka Reedgrass (*Calamagrostis nutkaensis)* and huckleberry (*Vaccium ovatum*) are less common. Sitka spruce, hemlock, and cedar saplings and young trees are locally common on the uplands. Annually, bracken fern (*Pteridium aquilinum*) grows up and over the shrubs, dying in early fall and producing a thatch.

The northern end of Roose's Prairie, the unnamed prairie along the Cape Alava trail west of Ahlstrom's, and scattered elsewhere are raised *Sphagnum* bogs. These wetlands are dominated by the growth of *Sphagnum* mosses, which have accumulated into peat. The mosses engulf woody vegetation and grow into mounds up to 0.5 m above the general ground surface. Most commonly the woody vegetation is crowberry (*Empetrum nigrum*), but bog laurel, labrador tea, salal and cedar are common as well. Trees growing in the bogs have yellowish needles (chlorotic), likely resulting from nutrient deficiencies or saturation (Tisch, 2002). The nutrient deficiencies are a product of the highly acidic nature of the bogs. Chlorotic foliage in spruce, hemlock and cedar has been shown to be related to competition with saal (Mallik and Prescott, 2001). Another explanation for the stunted, crooked appearance of the small trees may be the effects of elk browse (Harmon and Franklin, 1983; Schreiner *et al.* 1996). Western hemlock has been found to be among the major components of the diet of both elk and black-tailed deer during the winter months, the tips of which are consumed completely although twigs were not found to be completely stripped of their leaves (Leslie *et al.* 1984).

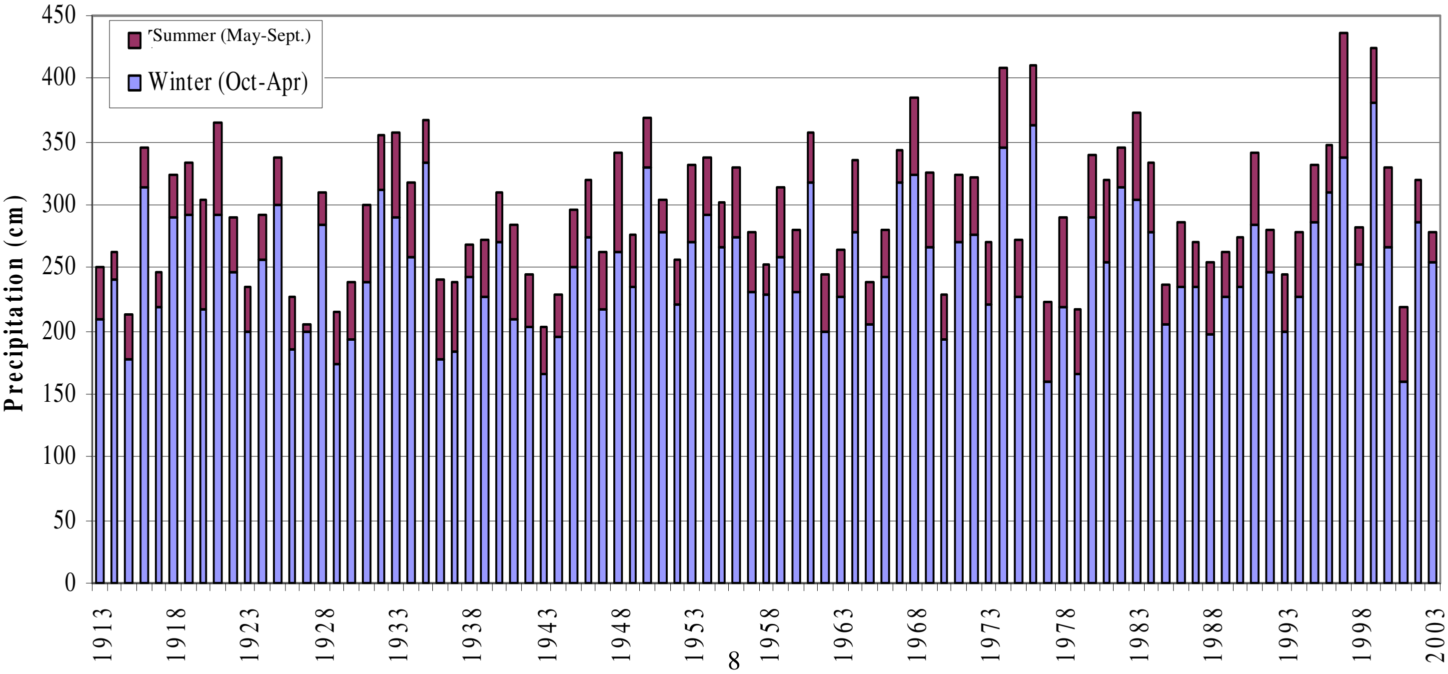
Central Ahlstrom's Prairie (where the Cape Alava trail crosses) and other small wetlands scattered around the prairies (including behind the Roose barn) are sedge-dominated fens. These fens appear as fields of tall grass. Fens occur where there is a slight slope and some drainage occurs, creating a less acidic environment. Small, deep streams trickle across the larger fens. While the surface has moss, it does not grow into mounds. Rather, a variety of graminiods (sedges, reeds and grasses) are the dominant vegetation type, with some herbs. Trees and woody shrubs are rare on the fens, although they differ from the bogs in that there is a distinct zone of woody shrubs growing along their edges where the wetland transitions to mineral soil.

Figure 2A Average Monthly Climate Data for Forks, WA (1928-2003)



source: NCDC

Figure 2B Annual Precipitation (Oct-Sept) of Forks, WA, from 1913-2003



Climate

The west coast marine climate of the region has mild seasons and high precipitation totals. Similar to other coastal regions in the Pacific Northwest, temperatures are moderated by the neighboring Pacific Ocean and are marked by cool, mild, winters, and warmer, though still mild, summers. The region experiences a maximum mean of approximately 16°C during the July to August period, and a minimum mean of approximately 4°C during the December to January period (Figure 2a). Although the region experiences moderate temperatures, its precipitation levels are extreme. The region receives an immense amount of rain due to its position as the first land surface to introduce uplift to the air masses arriving from the Pacific. The moisture laden air masses are components of mid-latitude cyclones capable of producing sustained winds in excess of 50 km/hour several times each winter. Annual precipitation in the Ozette region averages 290 cm, 85% of which falls between the months of October and April (Figure 2). Annual precipitation data (1913-2003) for Forks indicate that even the driest years receive over 200 cm of precipitation (Figure 2b). Summer fogs, low clouds, and dew on cool evenings help reduce stresses of evapotranspiration in times of summer drought (Franklin and Dyrness, 1988). The stable marine air tends not to generate thunderstorms, thus lightning strikes in the region are very rare, less than 0.025 strikes/km^2/year (Dettinger *et al.* 1999; http://www.life.uiuc.edu/hu/gavin/images/lmlightfire2.jpg).

The fire season is relatively short with the majority of the activity occurring July-September when temperatures are higher, precipitation is lower, and thunderstorms more common (Pickford *et al.* 1980). Precipitation frequency during the summer season is critically important to the fire regime of this area (Huff and Agee, 1980; Pickford *et al.* 1980; Agee, 1993). A moisture deficit for a sustained period of several weeks, coupled with a strong wind event (*i.e.* Chinook) can result in fire activity that can dominate fire season statistics. Variation in large-scale atmospheric flow has been shown to influence the frequency of air masses and frontal systems, hence precipitation, during any season (Skinner *et al.* 1999; 2002). The probability that a fire will occur is increased significantly by weather conditions associated with stable anticycliones that promote drying of forest fuels through low rainfall and higher than normal temperatures, but can generate convective activity that produces lightning to ignite fires and winds of sufficient strength to spread them (Skinner *et al.* 1999). These conditions recur at decadal intervals (Agee and Flewelling, 1983; Heyerdahl *et al.* 2002), related to climatic oscillations that influence the region (*e.g.* Pacific Decadal Oscillation or El Nino). Relationships between fire regime and these climatic systems have been demonstrated for other regions of the Pacific Northwest, but have not been investigated in the coastal zone (Heyerdahl *et al.* 2001; 2002).

The prairie/forest edge represents an important microclimatological boundary in this landscape. The exposure to sunlight and wind experienced on the prairies is very different than that under the forest canopy. Air and soil temperature, short- and long-wave radiation, relative humidity and wind speed have all been found to be significantly different on either side of a forest edge (Chen *et al.* 1995). The influence of the edge on weather conditions is variable, but climate conditions of one cover type (forest or prairie) typically extend 30-240 m into the adjacent cover type (Chen *et al.* 1995). Generally from the edge of the forest, air temperatures decrease during the day and increase at night. Edge orientation (aspect) plays a critical role for all variables, especially influencing the timing and magnitude of minimum and maximum values. The microclimatic edge effects play a critical role in influencing many ecosystem interactions and functions, including species composition and biomass, seed emergence and sapling survival, flying insect behavior, woody debris production and decomposition, and wildlife habitat (Chen *et al.* 1995).

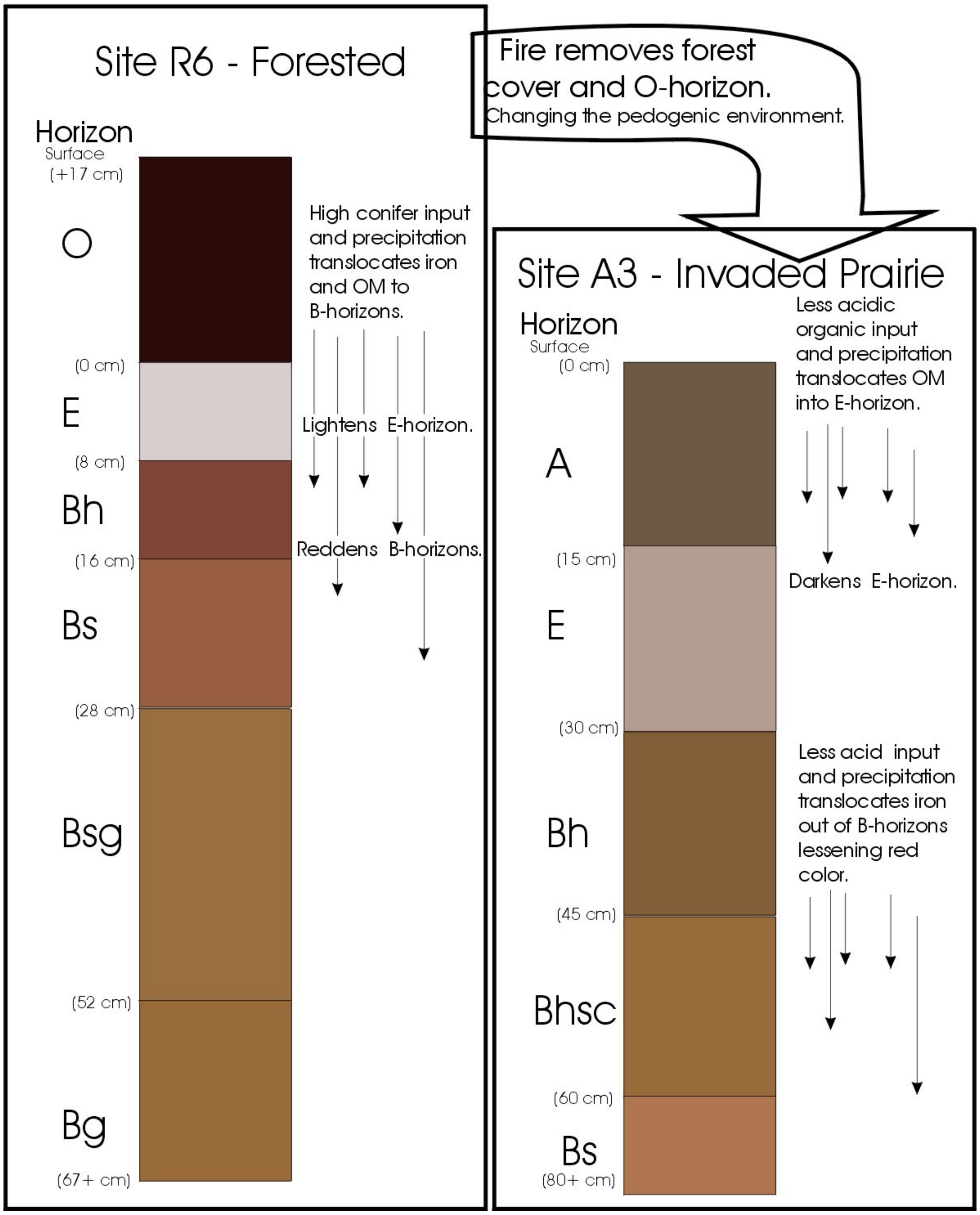
Geology and Soils

The area is underlain by late-Pleistocene age glacial drift primarily composed of unconsolidated sand, silt, clay, gravel, and boulders (Snavely *et al.* 1993). Glacial till underlying the nearby (~10 km east) Wessler Bog is dated at 14,460 year BP (Heusser, 1973). Geomorphic activity (*e.g.* colluvial and fluvial activity) might have resurfaced the area since that time. A variety of Tertiary-age sedimentary bedrocks occur under the glacial material at an unknown depth (Snavely *et al.* 1993). Nowhere in the study area has bedrock been observed at the surface. The topography of the area is composed of generally rolling hills with few steep slopes. The topography was created by continental glacial deposition, with moraines, kames, eskers *etc.* forming a deranged drainage system. Both prairies appear to occupy outwash channels.

About 30 soil pits have been excavated in the prairie area, and three soils types have been identified, two spodols (forest soils) and a histosol (organic soil) (Bach and Conca, 2001). Each soil type has distinctive soil properties, particularly the horizonation. Each soil strongly suggests a long history of different vegetative cover which produced the different soil types. The distribution of the soil types does not fully correspond with the current distribution of vegetation, suggesting that fire or other disturbances removed the forest cover from the perimeter of the prairie complex. This change in forest cover has altered the forest soils, resulting in depodzolization- the process of changing a spodosol into a different soil type (Barrett and Schaetzl, 1998). Sites on the wetland communities have histosols, where soil moisture conditions are saturated for long periods of the year. The saturated condition has slowed the decomposition process, allowing the accumulation of 0.5-3 m+ organic matter. This material is classified as peat (O-horizon in soil classification) with material originating from mosses, gramminoids and woody species.

The exact boundaries of each soil type have yet to be mapped, but all non-wetland (upland) sites were found to have distinctive spodosol horizonation. There are small areas of histic soils on uplands in depressions and drainages. Spodosols take thousands of years under forested cover to develop the distinctive O-E-Bhs-Bs-horizonation (Figure 3) observed in the field (Barrett and Schaetzl, 1992; Schaetzl and Mokma, 1988). The bleached white E-horizon is formed by intense leeching from inputs of acidic conifer needles and high precipitation totals (Soil Survey Staff, 1999). Organic matter and iron are translocated from the surface and accumulate in the underlying Bhs-Bs-horizons that appear as bright red-to-orange colors (Figure 3). The spodosols found on the prairie uplands are different than those in the forest, suggesting that the uplands are undergoing depodzolization (Barrett and Schaetzl, 1998). The O-horizons of the uplands are thinner than the forested sites, indicative of removal of organic matter by fire (Figure 3). The E-horizons of the uplands appear to be melanizing (darkening due to organic matter accumulation) compared with forest E-horizons. This melanizaiton suggests that organic matter that was previously eluviated through the E-horizon when there had been a forest cover is now illuviated and deposited in the E-horizon, causing it to darken in color. The lack of acidic conifer needles slows the decomposition rate of organic matter, thus allowing its accumulation, and a conversion from an E-horizon to an A-horizon (Figure 3). The subsurface Bhs and Bs horizons of the prairie soils are slightly less red in hue than the forested soils, indicating

Figure 3. Two representative soil profiles and a model of change in spodosol pedogenesis following removal of forest cover.



the removal of iron oxides from these horizons by leaching (Figure 3).

The development of spodosols has a significant influence on forest dynamics by restricting root growth to near the surface. Shallow water tables and dense to cemented, iron-rich Bh-horizons discourage deep root penetration. Roots tend to spread laterally just below the surface to access nutrients from the O-horizons. The shallow rooting habit, combined with occasional strong wind events, leads to wind blow-down as a major cause of tree mortality (Agee, 1993). The resulting uprooting, tree-throw, and post-fall tree decomposition creates a complex pit-mound micro-topography on the forest floor. Tree seedlings are often restricted to mounds and pits where seedlings experience less competition from moss and herbs (Harmon and Franklin, 1989).

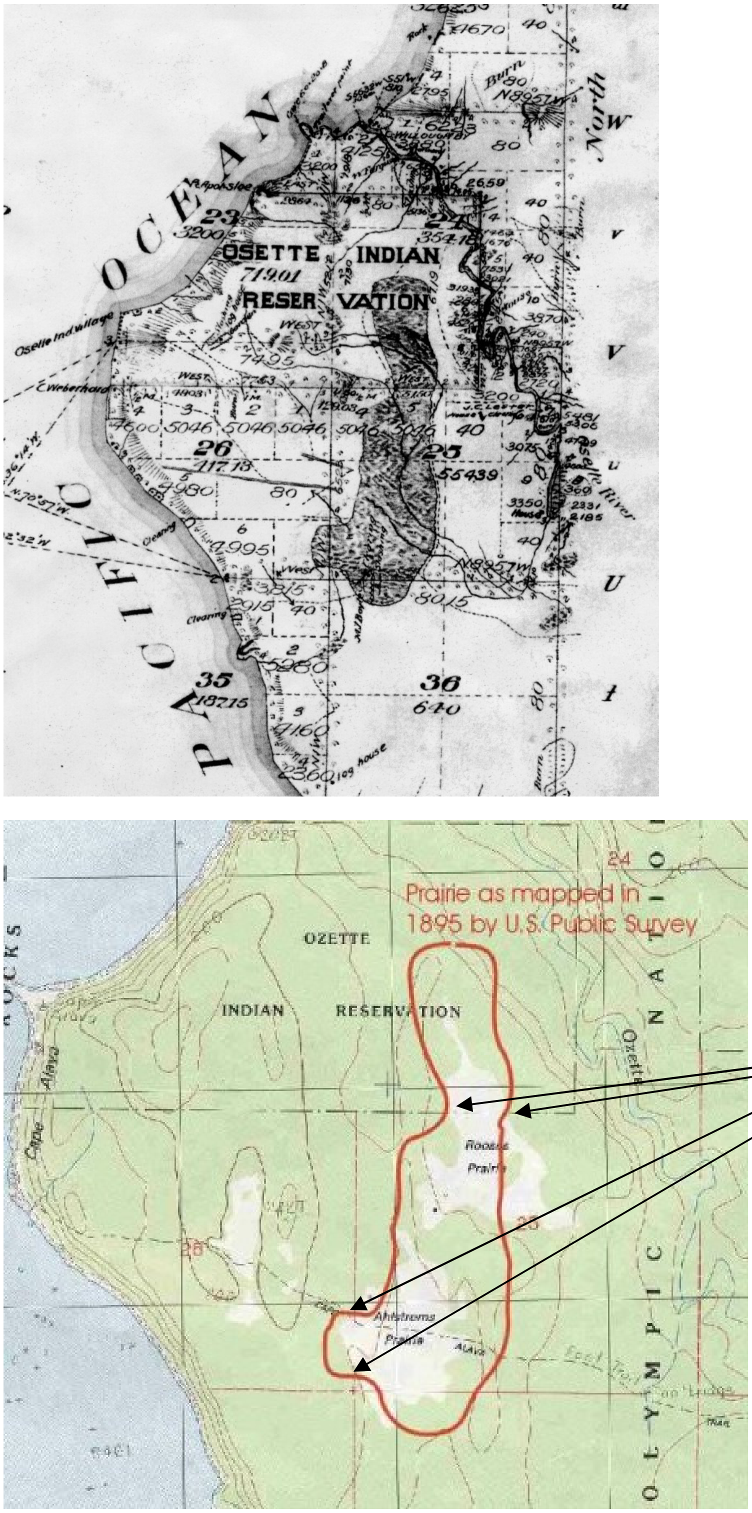
Human History

The Ozette Prairies and Cape Alava region have a long history of human occupation and use. Native Americans have been present on the northwest corner of the Olympic Peninsula for at least 3280 years (Gill, 1983; Wray and Anderson, 2003). The Makah tribe historically occupied a village site along the Pacific Coast approximately 1.5 km west of the Ozette Prairies (Figure 1). Traditionally fisherman who harvested whales, salmon, and seal (Bergland, 1984), the Makah also utilized the prairies as a hunting and gathering resource (Gill, 1983; Wray and Anderson, 2003). Other Native American tribes throughout the Pacific Northwest are known to have practiced burning in prairies for hunting and gathering purposes (Turner, 1999; Storm, 2002), however the extent which the Makah may have modified the structure and vegetative composition of the prairies is largely unknown. Roosevelt elk and black tailed deer, species that are attracted to edge habitats for forage, were hunted on the prairies by the Makah and used for food, clothing, and tools (Wray and Anderson, 2003). Plant resources were used as basketry, medicine and food by the Makah (Gill, 1983). Ethnographic research suggests the Makah harvested slough sedge (*Carex obnupta*), berries, bracken fern, *Sphagnum* peat, salal, and labrador tea as plant resources, all of which are common throughout the Ozette Prairies (Gill, 1983; Wray and Anderson, 2003). The prairies were easily accessible to the Makah by a footpath traversing from the village site to a fishing camp at Lake Ozette (Figure 1). Makah who lived near Neah Bay were known to have burned Tsoo Yess Prairie to facilitate cranberry production (Gill, 1983). Interviews with descendents of European pioneers provide ethnographic evidence that the Makah annually burned the Ozette Prairies (Tisch, 2002; Wray and Anderson, 2003). The Ozette village site along the coast remained inhabited until about 1922, when the remaining tribal people were relocated to Neah Bay and the Makah Indian Reservation (Gill, 1983). No physical evidence of pre-European use of the Ozette Prairies has been found to date (Anderson, 2001).

European activity began in the Ozette Lake region began just prior to 1900 (Evans, 1983). The General Land Office surveyed the Ozette Prairies and the Pacific Ocean coastline in 1895. This map portrays a larger, single opening comparable in shape to the general outline of the present-day shape of the two prairies (Figure 4). In addition, small burned areas are noted in the forest surrounding the prairies and at the southern end of present- day Ahlstrom's Prairie. Just after the turn of the century, two Scandinavian settlers, Lars Ahlstrom and Peter Roose, whom the prairies were subsequently named for, homesteaded the prairies (Figure 1). Each constructed cabins, barns, and fences, and cultivated small gardens and raised chickens for personal consumption. Roose reportedly grazed up to 100 head of sheep for the purpose of selling the wool (Evans, 1983). We have identified several features that appear to be drainage ditches (straight, deep channels, some crossing side slopes) in both wetlands. Roose's homestead was abandoned sometime in the 1920-30's, while Ahlstrom remained at his homestead until the 1960's. It is believed that Ahlstrom burned his property regularly to improve grazing (Wray and Anderson, 2003). Roose's homestead is currently maintained by the National Park Service as a National Historic Site. Aside from the homesteaders clearing land for their cabins and yards, commercial logging has not occurred west of the slopes immediately surrounding Lake Ozette.

The National Park Service acquired the 60-mile long coastal portion of the Olympic Peninsula, including the Ozette Prairies, and placed it under the management of Olympic National Park in 1953. Recreation users, including hikers and campers, continue to be the present-day anthropogenic impact at this site. The Cape Alava trail follows the historic footpath used by the Makah to reach Lake Ozette. Thousands of hikers use this boardwalk trail crossing E-W through the center of Ahlstrom's Prairie (Figure 1) during summer weekends. Based on user statistics acquired from the National Park Service Public Use Statistics Office website (URL: http://www2.nature.nps.gov/stats, accessed 13 April 2004), over the last ten years the average number of annual recreation visitors passing through the Ozette Ranger Station is

Figure 4. 1895 GLO map of Ozette Prairies (top), and the outline of the Ozette Prairies, as mapped in 1895, overlaid on the 1979 7.5’ topo map (bottom). The two prairies were initially mapped as one large prairie.



Note correspondence of 1895 mapping and topo map (based on 1956 air photo) occurs only where the 1895 prairie crosses surveyed lines.

estimated at just over 100,000, most of these visiting during the summer months. The estimates are based on counts of cars passing through the entrance near the ranger station, multiplied by 2.6 to include multiple persons per vehicle. Recreation users at this site include dayhikers and backpackers who travel to the ocean. Other recreation users include fisherman and boaters on Lake Ozette. It would be reasonable to estimate that thousands of recreation users pass through Ahlstrom's Prairie on their way to the coast every year.

Air Photo Analysis of Prairie Invasion

Repeat photography has been a tool proven useful in documenting historic changes in vegetation in various types of landscapes over time (Hadley, 1999; Miller, 1999; Soule *et al.* 2003). In the present study repeat aerial photography document the last half-century of change in vegetation at the Ozette Prairies. A series of five aerial photographs were analyzed in a GIS to assess the advancement of the forest perimeter into the meadows and areas of tree establishment within the meadows. Future changes were predicted using the results of the GIS analysis in a Markov model. The air photos help to identify spatial patterns of change and show where major change is occurring. The perimeters of both prairies have been advancing inward, and tree patches have established and expanded in size throughout the decades. The air photo interpretation also identifies where changes have not occurred. Areas where little to no change has taken place correspond with the wetlands.

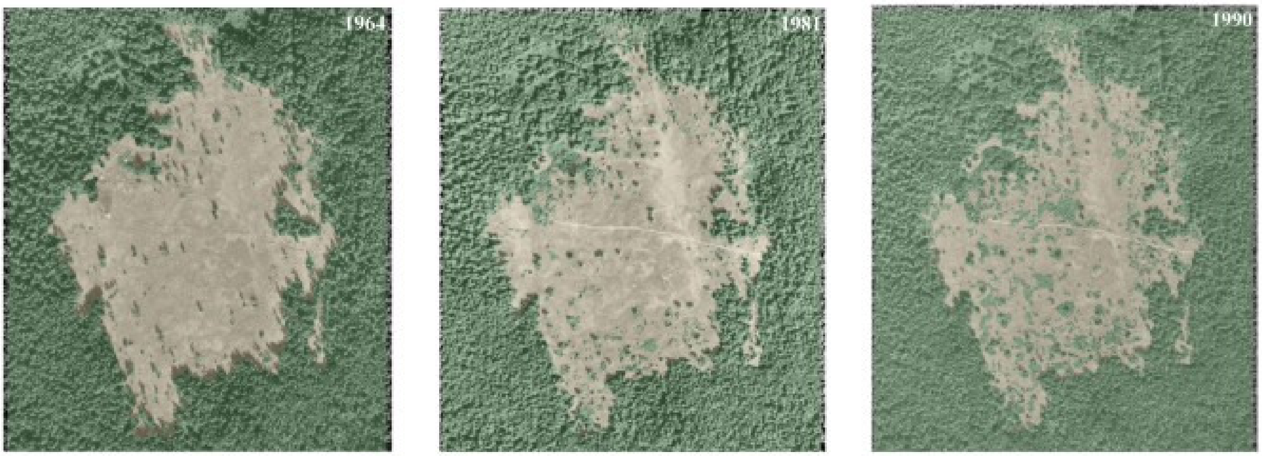
Air Photo Analysis Methods

Black and white aerial photographs for the years 1964, 1981, 1990, and 1997 (the only years available that included the Ozette Prairies) were obtained and scanned as high resolution JPEGS and imported into ArcGIS 8.3, along with a black and white digital orthophoto for the year 2000 (Figure 5). The JPEGS were converted into SID files to reduce file size and subsequently georeferenced to a 7.5 minute USGS Digital Ortho Quad (July, 1994) and projected in Universal Transverse Mercator coordinates (zone 10, NAD 27) (Soule *et al.* 2003). Approximately 30 control points were used to georeference each photograph, and the total RMS error was maintained below 2m. Each photograph was rectified using a first order polynomial transformation (Soule *et al.* 2003).

The aerial photographs were then digitized into vegetation maps with land cover type polygons classified as either forest, tree patches, or treeless. The tree patch cover (minimum mapping unit 3.0 m^2) included both single large trees and larger tree patches that fell within the perimeter of the prairie but did not touch the prairie edge. The treeless cover type included prairie vegetation and wetland vegetation. It also likely contained trees too small to distinguish on the air photos, either because they were lower than the surrounding shrub vegetation as was noticed during field visits or they were not structurally complex enough to be visible. After the land cover type polygons were established, they were merged for each year into one final vegetation map (Figure 6). Then, each vegetation map was converted into a raster with 0.5 m grids in the GIS. The raster calculator in ArcGIS was used to determine the number of 0.5 m cells, and therefore the area of land that transitioned from one cover type to another, allowing the rate of change from one photograph to the next to be quantified (Figure 6; Miller, 1999).

The air photo analysis was verified for accuracy by randomly selecting distances along vegetation transects established in the field (selection of transect locations described in the following section). Sixty random points were selected in total. An accuracy assessment was made between the vegetation type provided in field notes and the vegetation type as mapped in the air photo analysis (Campbell, 2002). An error matrix and calculation of the kappa value (percentage correct = 85%, kappa = 0.65), a standard statistic for testing the accuracy of classified images, indicates that the air photo analysis is accurate (Campbell, 2002; Ramsden, 2004).

This series of air photos was used to model future tree encroachment using a simple Markov chain analysis. A Markov process is one that deduces the probability of being in a land cover class type at a particular point in time given knowledge of the previous state of being, based on vegetation changes that take place between two known years (Usher, 1992; Miller, 1999; Urban and Wallin, 2002). Three cover class types were digitized in the vegetation maps – forest, tree patches, and treeless vegetation. Nine resulting change scenarios were therefore calculated, and they include the change from forest to forest, forest to tree patch, forest to treeless, tree patch to forest, tree patch to tree patch, tree patch to treeless,



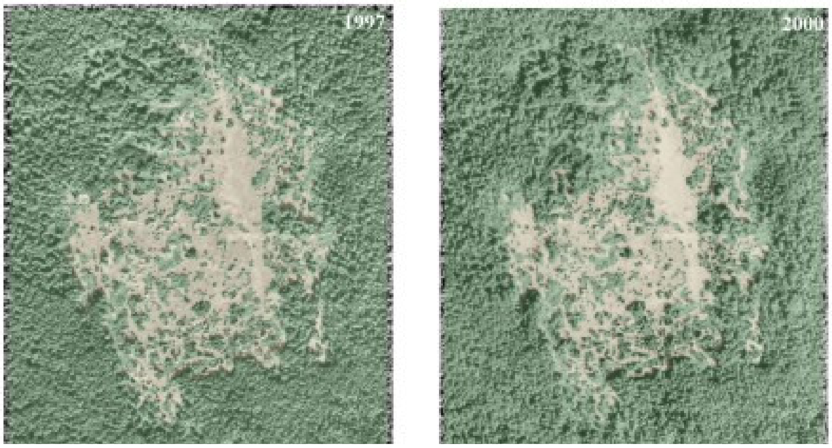
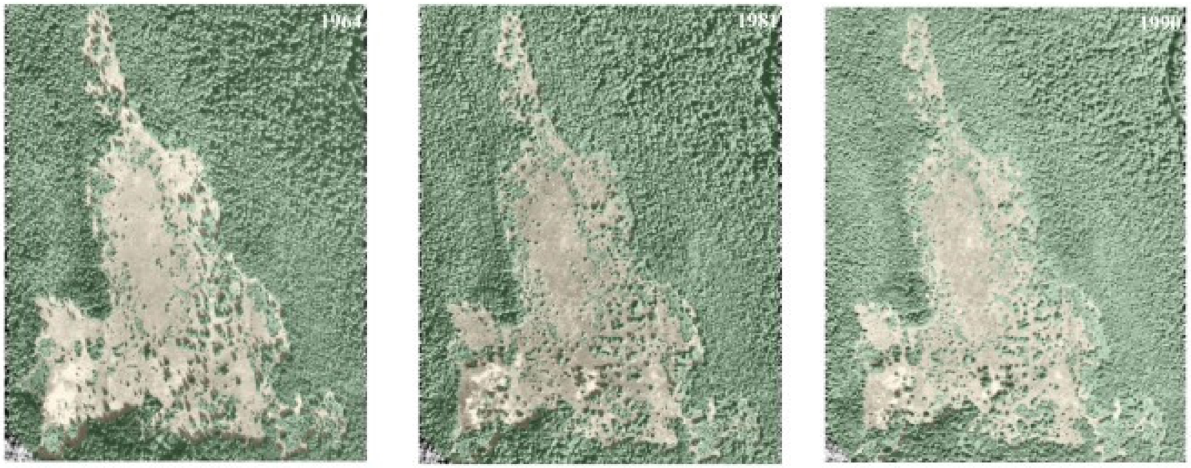


Figure5 a. Ahlstrom's Prairie Vegetation Maps. GIS polygon layer representing tree and non-tree land cover overlaid on black and white aerial photographs (1964-2000).

Air Photo source: Washington Department of Natural Resources



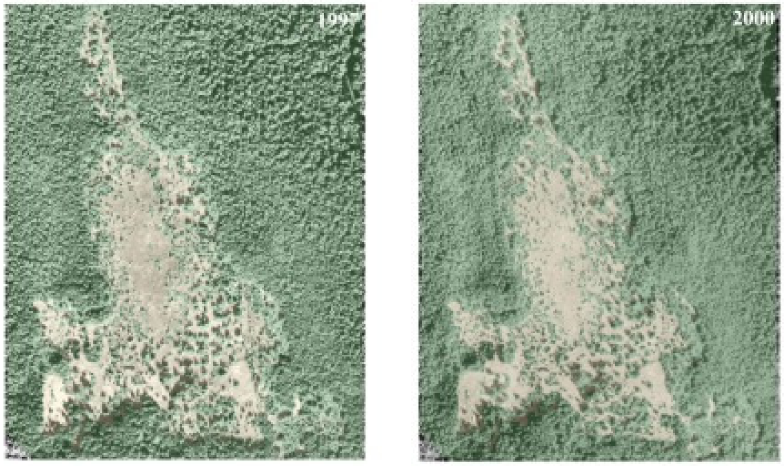


Figure 5b. Roose's Prairie Vegetation Maps. GIS polygon layer representing tree and non-tree land cover overlaid on black and white aerial photographs (1964-2000).

Air Photo source: Washington Department of Natural Resources

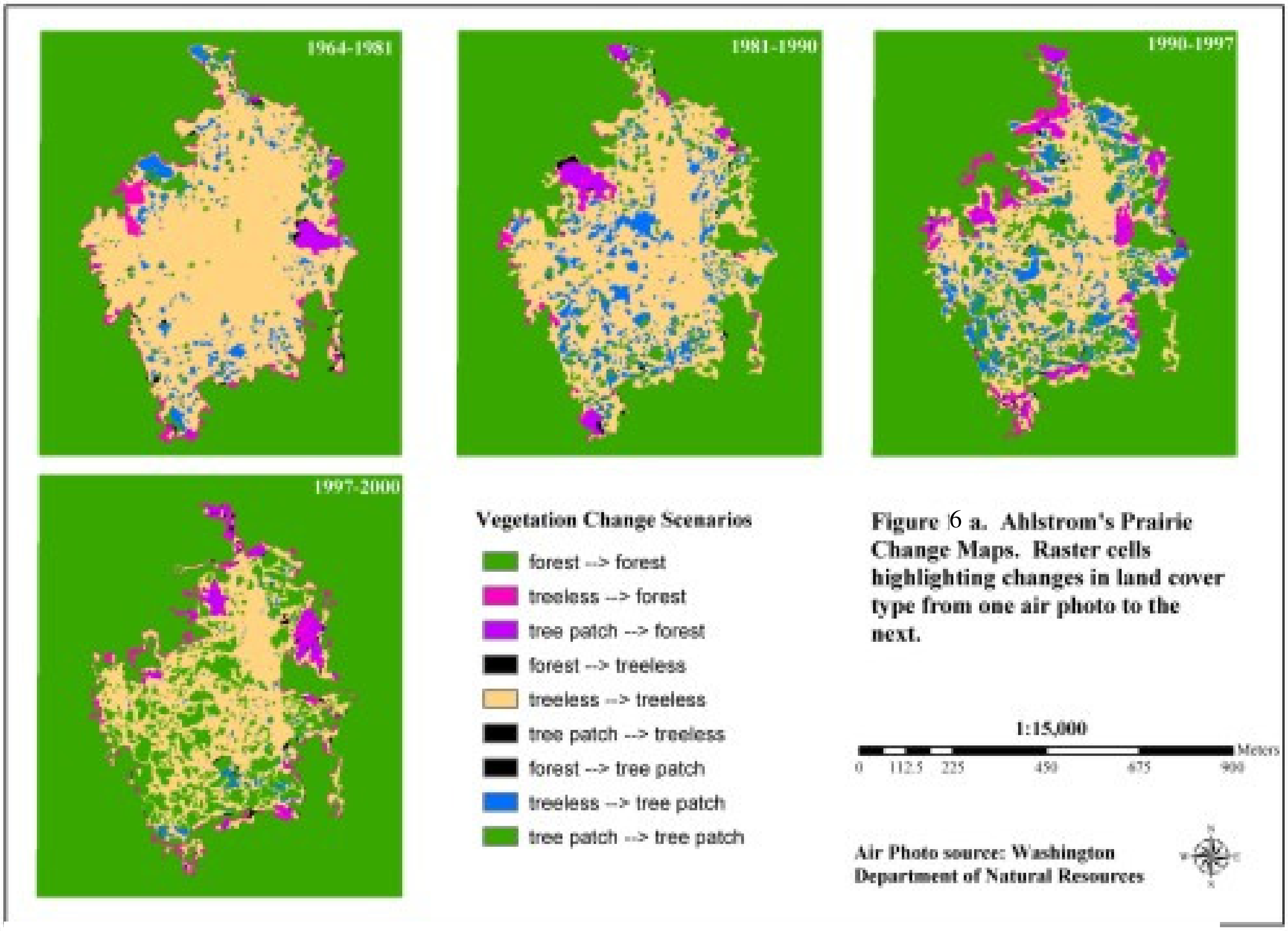


Figure 16 a. Ahlstrom's Prairie Change Maps. Raster cells highlighting changes in land cover type from one air photo to the next.

Air Photo source: Washington Department of Natural Resources

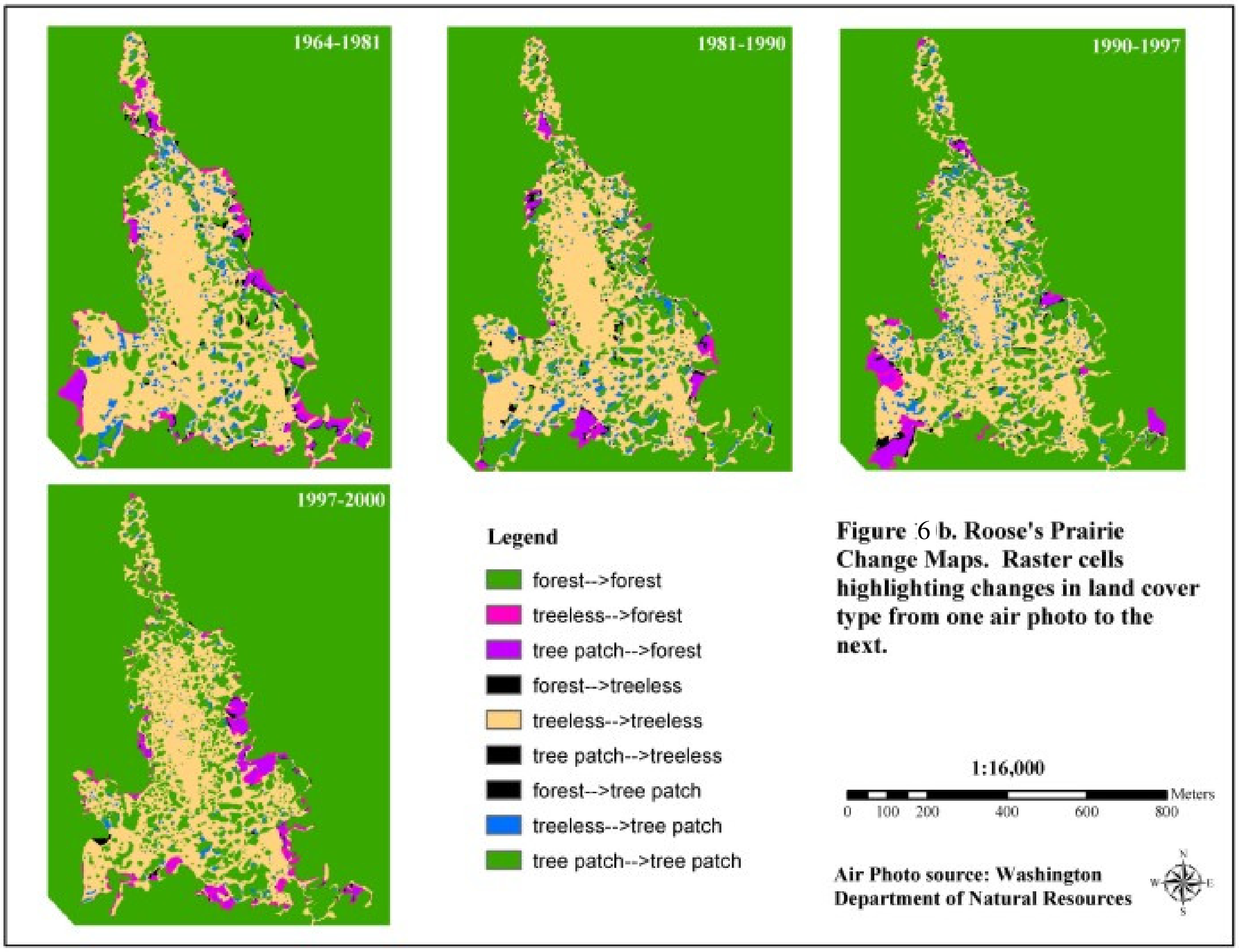
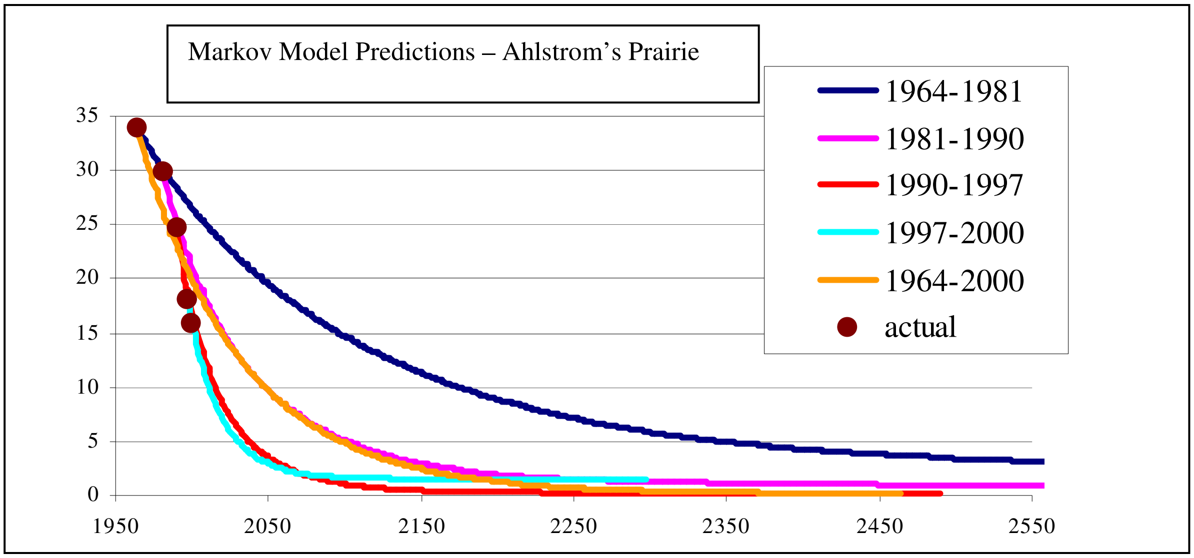
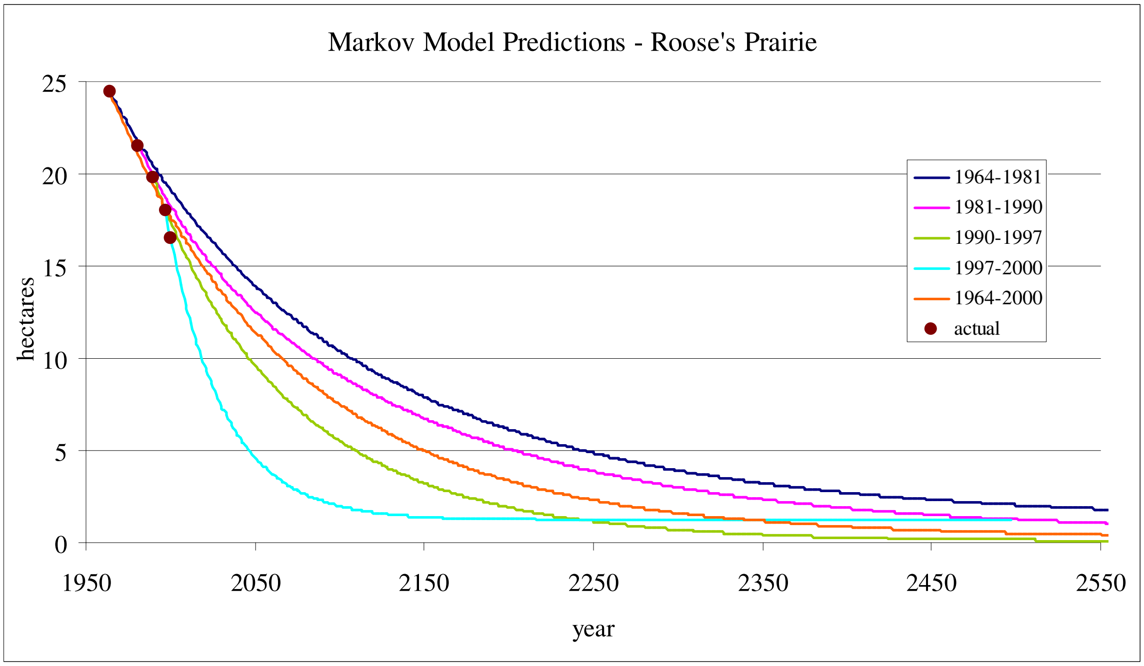


Figure 16 b. Roose's Prairie Change Maps. Raster cells highlighting changes in land cover type from one air photo to the next.

Air Photo source: Washington Department of Natural Resources treeless to forest, treeless to tree patch, and treeless to treeless. Of primary interest in this study were results from treeless to a forested-cover type. In this analysis, five different transition probabilities were used (1964 to 1981, 1981 to 1990, 1990 to 1997, 1997 to 2000, and the overall change probability 1964 to 2000). Each annual transition probability and its initial landscape conditions were entered into the Markov model (for example, the transition probability 1964-1981 was entered along with its initial condition of 1964). The annual probability matrices were used to project the five different scenarios into the future (Figure 7). The Markov model used in this analysis was acquired from Urban (2000) – the model markov.exe was downloaded from his website – accessed [online] URL: http://www.env.duke.edu/lel/env214/le_lab4.html in February 2002. The model was projected into the future until a steady-state condition was reached (*i.e.* no further land cover changes were detected). The model was verified by checking that the proportions of land cover for the last year in the time step used matched with the calculated value. For example, in the 1964-1981 transition, it was verified that the proportion of land cover for 1981 matched the actual proportion of land cover that was calculated in the vegetation maps.

Figure 7. Markov model predictions of decreasing prairie vegetation coverage for Ahlstrom's and Roose's Prairie. Large red dots represent actual numbers of hectares calculated for the years 1964, 1981, 1990, 1997, and 2000 from the vegetation maps. Colored lines represent predictions based on the annual rate of change for each transition scenario.





Air Photo Analysis Results

Aerial photograph interpretation shows that the amount of tree cover on both prairies has increased since 1964 (Figure 6), but at different rates for the two prairies. Tables 1a and b show the change in the area of land (in hectares) covered by trees for Ahlstrom's and Roose's Prairies.

Table 1a. Land cover type (hectares) for Ahlstrom's Prairie study area based on the vegetation maps (Figure 6a)

		tree cover		
year	treeless	Encroaching forest	tree patches	total tree cover
1964	31.3	0.0	2.5	2.5
1981	27.5	2.3	4.1	6.4
1990	22.8	4.0	7.1	11.1
1997	16.8	7.7	9.4	17.1
2000	14.6	10.7	8.7	19.3

Table 1b - Land cover type (hectares) for Roose's Prairie study area based on the vegetation maps (Figure 6b)

		tree cover		
year	treeless	Encroaching forest	tree patches	total tree cover
1964	24.7	0.0	9.0	9.0
1981	21.7	2.7	9.2	11.9
1990	20.0	4.1	9.6	13.7
1997	18.2	6.0	9.5	15.5
2000	16.6	8.3	8.7	17.0

In the earliest available photo (1964), Ahlstrom's Prairie was a relatively treeless environment with few scattered tree patches (8.1% of the study area), most of which were single large trees or small patches of trees (Figure 5a). By the year 2000, the amount of treeless vegetation decreased by 53.5% from 31.3 hectares to 14.6 hectares. Many scattered patches became apparent by the year 1990, and these patches continued to either expand in size or become part of the surrounding forest, shrinking the perimeter of the prairie (Figure 6a). This was particularly apparent on the northwest portion of the prairie, in the location of Lars Ahlstrom's cabin, yard, and barns (Figure 8b). The elongated north-south wetland in the center of Ahlstrom's Prairie remained treeless throughout the analysis (Figure 6a).

In 1964, Roose's Prairie was already partially covered with several scattered patches of trees (Figure 5b). The treeless area was calculated at 24.7 hectares, and tree patch area was 9 hectares. By the year 2000, the treeless area was reduced to 16.6 hectares, a decrease of 32.7%. Total tree patch area remained relatively stable; as new tree patches developed, existing tree patches near the perimeter became classified as part of the surrounding forest. The eastern portion of Roose's Prairie changed the most in terms of forest development. From 1964 to 2000, Roose's Prairie gained 8.29 acres of forest. Again, the central portion of the prairie remained relatively treeless corresponding with the wet *Sphagnum* bog which was verified during field visits (Figure 6b).

The land surrounding the homestead sites has experienced considerable forest growth. The area around Roose's homestead has experienced noteworthy tree growth, so much so in fact that about 6 years ago, and again in the summer 2004 the National Park Service cut down many small trees around his cabin, which is maintained as a National Historic Site. Large tree patches and forest growth has occurred both south and north of the homestead (Figure 8a). Similarly, the forest has completely enclosed the area around Ahlstrom's homestead, where his cabin, barn, and fenced-in yard were located (Figure 8b). These areas are probably quite nutrient-rich because of the sheep manure that was probably concentrated in the pastures, creating a fertilized soil. Further testing would be required to determine nutrient levels in these areas of tree growth.

To predict future changes in the vegetation structure in the prairies, the Markov model was applied for the five different change scenarios and projected forward until each became stationary (*i.e.* no more changes took place). Limitations of the model tend to under estimate the actual rate of change, it provides a useful approximation of future change and can be considered a conservative estimate (Urban and Wallin, 2002). Figure 7 shows the five different annual rates of decreasing amount of prairie vegetation for each prairie, as well as the five points calculated in the air photo analysis. The amount of underestimation was greatest in the earlier air photos transitions and decreased towards the later air photos transitions, becoming closer to the actual estimates. This indicated that the rate of change in vegetation cover as determined by the air photo analysis is occurring at an increasing rate each year. The overall change, 1964-2000, acted as an average and fell somewhere in between (Figure 7). The five Roose models were closer to each other than were the Ahlstrom models, most likely because the Roose models started off with considerably more

Figure 8A. Roose's homestead in 1964 (left) and 2000 (right). The yard just south of Roose's cabin and the tree patch north of the yard (circled in white) have increased in forest growth. Location of Roose's homestead noted on Figure 1.

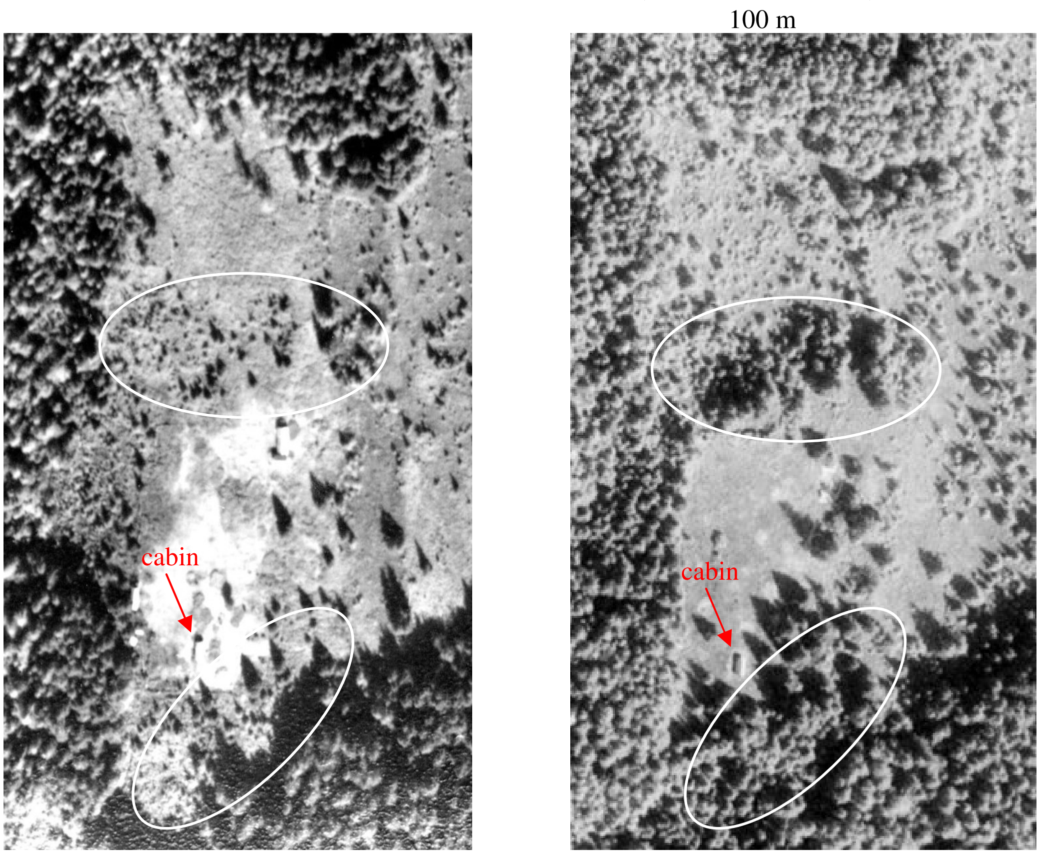
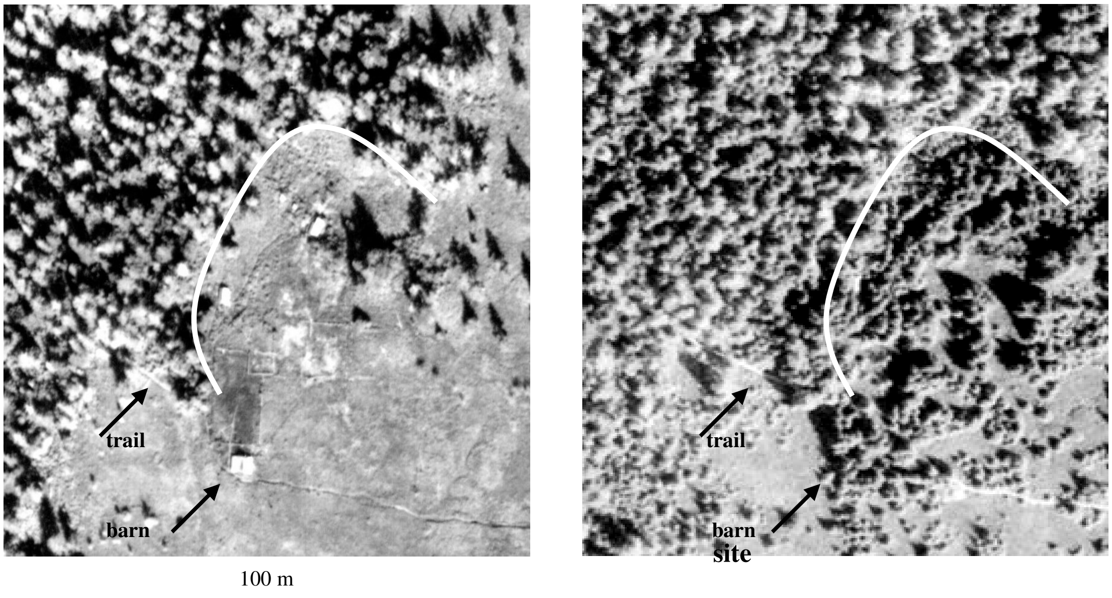


Figure 8B. Air photos of Ahlstrom's homestead in 1964 (left) and 2000 (right). The cabin and barns are no longer visible in the 2000 air photo, instead covered by dense forest growth. Location of Ahlstrom's homestead noted on Figure 1.



tree-coverage than did the Ahlstrom model, suggesting that the invasion process had been underway by the time of the 1964 photo. Markov models for both prairies suggest that prairie vegetation will decrease to less than 10% within the next 100 years (Figure 7). This analysis assumes no additional changes to the vegetation dynamics, such as fire, climate, disease, or human management.

Implications for tree encroachment as predicted by the Markov model are far-reaching in terms of loss of biodiversity and habitat. Compared to the surrounding forest, the prairies host a unique and diverse assemblage of plants, including shrubs, sedges, and herbs that are not found in the region. Encroachment of trees onto the Ozette Prairies would change the microclimate of the open area, and understory species composition will (and has) change(d) as a result (Chen *et al.* 1995). A change in species composition also creates a change in habitat for insect life. Currently, plants of the Ozette Prairies such as the state-sensitive listed swamp gentian (*Gentiana douglasiana*) and the bog cranberry (*Vaccinium oxycoccus*) are host to a butterfly species, the Makah Copper (*Lycaena mariposa*) that is a State Candidate of Washington and a Federal Species of Concern (Pyle, 2002; Pyle and Pyle, 2001). Presuming that trees will not establish on areas of saturated substrate, even the wetland areas in the Ozette Prairies will experience changes in microclimate and become more like woodland swamps.

Vegetation Studies Methods

Rates of tree invasion were also investigated by placing five belt transects throughout the two prairies (Figure 1). Placement of the transects was chosen for a number of reasons. The general locations were selected away from the Cape Alava trail crossing through Ahlstrom's Prairie to reduce the visual impact on park users. The placement of transects was chosen as representative of the prairie vegetation and the transition from forest to prairie. The vegetation transects within Ahlstrom's Prairie were paired along with a series of soil transects that were placed to examine the differences in soil characteristics between the forest soils, transition soils, and prairie soils. The beginning (zero point) of each transect within the forest was randomly selected and marked with a stake and a GPS point was acquired (whenever possible within the dense forest) so that the transects could be relocated at a later date.

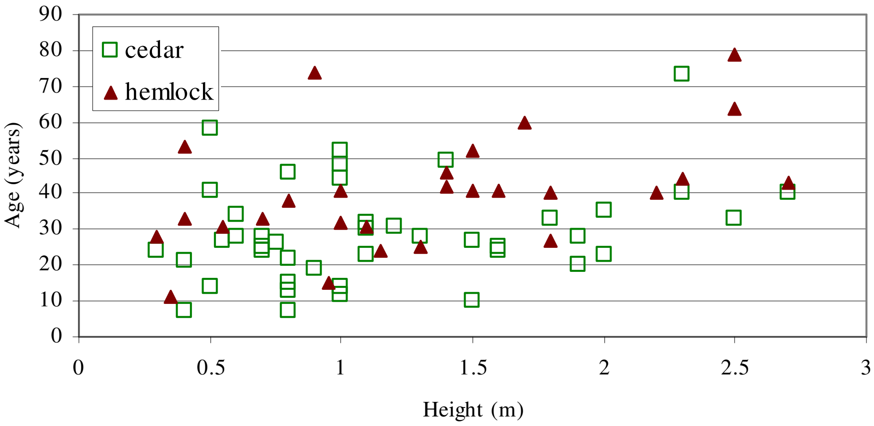
The transects began approximately 20-30 m in the forest, and ran perpendicular through the forest/prairie edge, or "transition zone," and extended into the open prairie (Figure 1). Transects were 5 m wide and 100-160 m long. All trees were counted in each transect, identified to species, and measured for height, diameter (basal or at breast height), and age (Miller and Halpern, 1998). Age was determined for most living trees of large enough size (>6 cm) by coring with an increment borer (Phipps, 1985). Small, encroaching trees were cored as close to the ground as possible, mature trees were typically cored at breast height, and height at coring was recorded for all cored trees. Small trees (<2 m) of various sizes were harvested to determine age at coring height and to estimate the ages of trees too small to core.

Tree cores and harvested tree disk samples were allowed to dry, mounted on wooden holders, and sanded with increasingly fine sandpaper (220, 320, 500, 600 grit) until the cell structure was visible through a dissecting microscope. Age was estimated by counting the annual rings. An estimate of additional rings was added to tree cores that slightly missed the center pith based on estimated distance to center and width of the last 5 rings available (Miller and Halpern, 1998). An attempt at crossdating the tree rings using the skeleton-plot method (Phipps, 1985) was made, but it was determined that crossdating for this site would not be possible due to a lack of consistent signature rings. Ring width variability in the coastal zones of the Pacific Northwest is often due to between-tree competition for environmental factors such as light and nutrients, while the most successful crossdating attempts are made in sites in which the limiting factor is some sort of climatic factor (Fritts, 1976).

Vegetation Studies: Tree Age, Size, and Distribution Characteristics

The transect data provided a more detailed description of forest structure on the Ozette Prairies than the air photo interpretation. Thousands of trees were encountered within each transect, ranging in size from just a few centimeters to over 40 m in height. The transect data and the corresponding statistics demonstrated the patchiness of these prairies. Nearly all trees within the transects were living; few large dead snags were encountered and almost no dead seedlings were found. Hundreds of snags, stumps and living trees throughout the prairies and forest edges had burn scars, but few were captured by our transects. Fifteen to thirty-five trees within each transect were sampled for age by tree coring. In addition, six to twenty-two small trees were harvested from within each transect and cut as close to the base of the tree as possible. Small trees were harvested from both prairies for the purpose of providing an age at core height adjustment for mature trees, and to estimate the ages of the small trees scattered throughout the prairies. Ages of harvested trees range from 7-79 years old, with an average age of 33.4 years. By prairie, the average age of harvested trees in Ahlstrom's Prairie is 29.3 years, and Roose's Prairie is 47.7 years. Heights range from 0.3-2.7 m tall with an average height of 1.23 m tall. Diameters range from 0.5-7 cm with an average diameter of 2.2 cm. Strong positive correlations are found between height and diameter at most harvest sites, but correlations are weak for both height-age and diameter-age relationships. Pearson correlations for age and height of harvested trees were positive but weak ($r^2 = 0.20$, $p = 0.001$ for all species combined; $r^2 = 0.08$ for cedar, $p = 0.07$; $r^2 = 0.19$ for hemlock, $p=0.01$), indicating that small trees are experiencing a stunted growth rate and in some cases are actually quite old (Figure 9). Therefore, no age correction for age at core height was applied to mature trees, which should be recognized when examining the data.

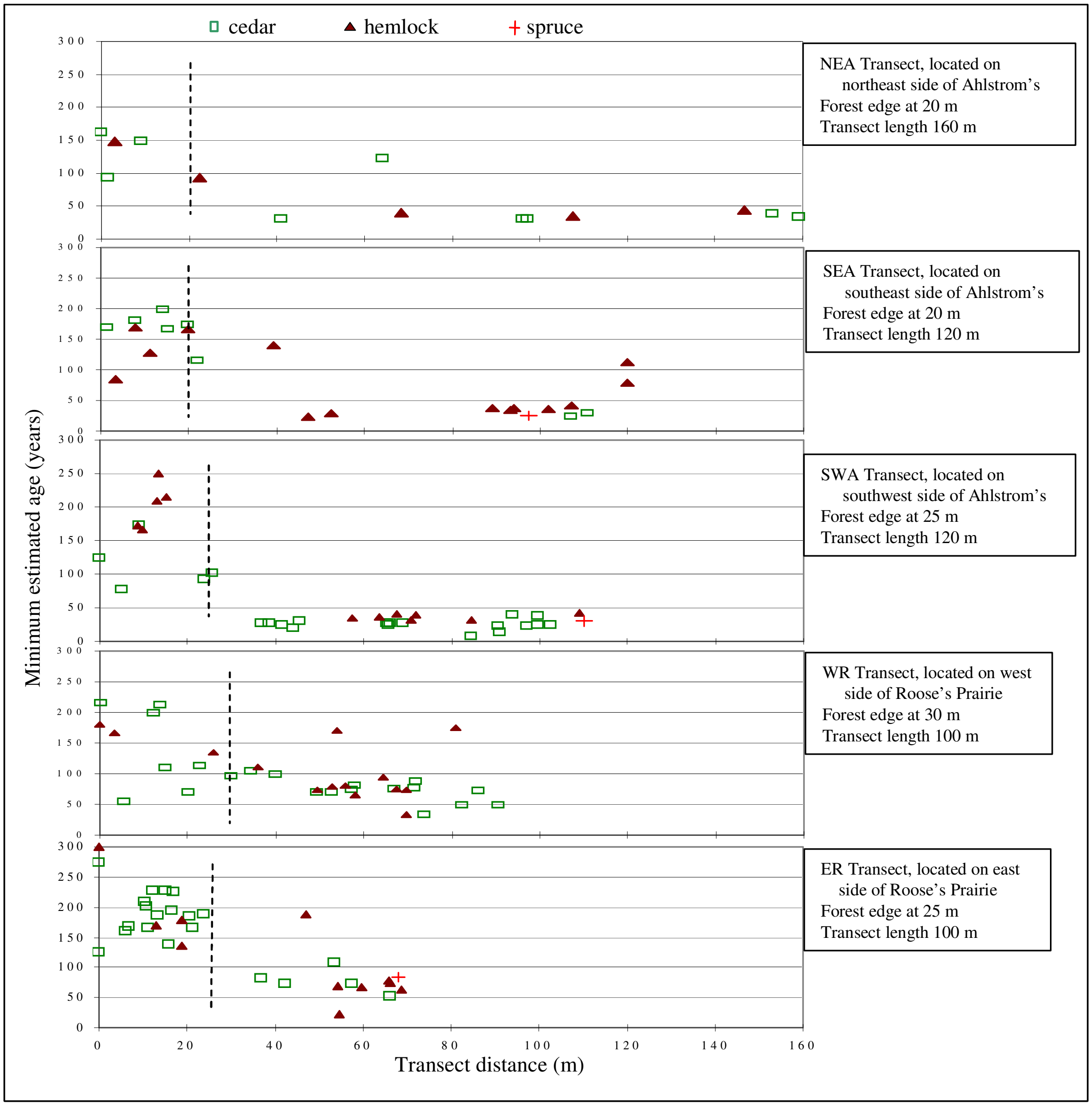
Figure 9. Age-height distribution of harvested trees within or near all transects.



The transect data revealed four vegetation units: forest, forest transition zone or edge, open prairie, and tree patches within the prairie. The forest unit contains a mature, mixed-age (75-300 years) forest dominated by red cedar and western hemlock trees. Many small hemlocks (<1m tall) were found growing on nurse logs. A well-defined forest edge captures a transition zone of trees smaller in height than the forest. The edge trees have branches extending horizontally toward the open prairie. These trees are young wolf trees. Wolf trees are conifers with thick, leafed branches all along the stem growing toward sun lit areas of a forest edge. Only two older wolf trees were observed in a survey of ~20% of the perimeter, suggesting that the forest edge has been dynamic. Within the prairie were small trees (<50-100 years old) and some patches containing larger trees (100-150 years old). Transects did not intersect the wetlands, which are described in the next section; however, few trees were observed in the wetlands. Detailed descriptions and transect data are available in Ramsden (2004).

Figure 10 shows the age distribution of trees cored along each transect. While tree ring counts provided only minimum ages, especially for the often-rotted mature forest trees, they proved to be a verification of what was interpreted from the air photos. Figure 11 shows the height and species distributions of all trees that were encountered within each transect. Spearman correlations show moderate negative relationships (-0.565 to -0.678) between distance along transect (including forest) and age for all transects, although when forest trees were excluded, Spearman correlations showed negligible to weak negative relationships between distance from forest edge and age (0.004 to -0.391). Spearman correlations

Figure 10. Distribution of tree species and ages along each transect. See Figure 1 for transect locations. The dashed lines represent the location of the abrupt forest edge.



indicate the patchiness level of tree size within the perimeter of the prairies is high. Positive correlations signify that tall (mature) trees are located within the central portions of the prairie. These mature trees within the prairie as well as at the forest edge act as seed sources for trees establishing throughout the prairies. Thus, the prairies are experiencing invasions not only from the surrounding forests, but the tree patches are enlarging as well; an observation confirmed by air photo analysis (Figure 6).

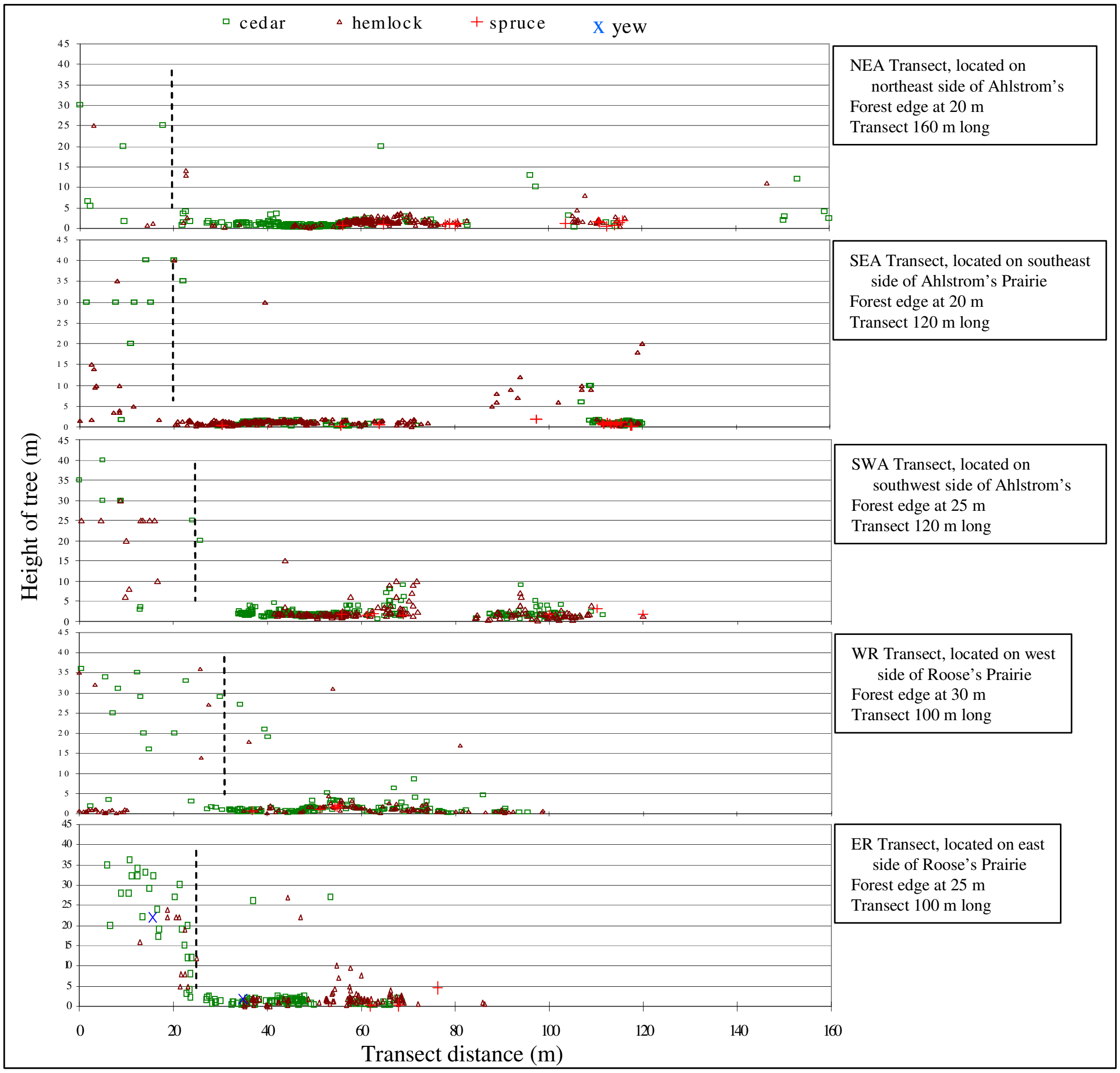
The establishment of young trees at the forest/prairie edge indicates that the forest perimeter is encroaching inward. However, the significant increase in ages of the majority of trees within the forest is strongly suggestive, but not conclusive, that this process may be historic in nature. If tree encroachment had been occurring for hundreds of years, then a more gradual progression of tree ages should have been observed from the prairie edge into the forest interior (Figure 10). Likewise, the scarcity of old wolf trees along the prairie edge suggests that the edge has been dynamic, signifying that the prairie edge has advanced into the forest.

Table 2 shows the percentages of encroaching trees by species for each transect (graphically portrayed in Figure 11). Most of the encroaching trees are western red cedar or western hemlock, with the remainder (less than 3%) being composed of Sitka spruce and Pacific yew. Transects on the west-side of both prairies contain a higher percentage of cedar encroachment than transects on the east-side of the prairies. The east-side transects experience more exposure to solar radiation and higher temperatures, than transects on the shadier west-side transects causing increased stress on tree seedlings mortality (Chen *et al.* 1995). Transects of the east-side of the prairies contain either equal proportions of cedar and hemlock, or in one case (SEA transect), a higher percentage of hemlock than cedar. To test for this difference, fifty random data samples of were extracted from each transect. Chi-square tests of heterogeneity demonstrate that the species composition is significantly different on east-side versus west-side (p = 0.005-0.28). Chi-square tests comparing east-side to east-side and west-side to west-side do not show significant differences. Mann-Whitney U Tests reveal that the distributions of cedar and hemlock are significantly different (p<0.001) for all transects. Four of five transects have cedar clustered closer to the forest edge than hemlock. In the fifth transect (SEA), hemlock is located closer to the forest edge than cedar.

Table 2. Species composition of all transects (locations on Figure 1).

Transect *(side of prairie)*	Species	Percentage
NEA	Cedar	48.3
(east side)	Hemlock	48.8
	Other	2.9
SEA	Cedar	34.9
(east side)	Hemlock	62.2
	Other	2.9
ER	Cedar	49.5
(east side)	Hemlock	48.5
	Other	2.0
WR	Cedar	59.4
(west side)	Hemlock	38.8
	Other	1.8
SWA	Cedar	63.0
(west side)	Hemlock	36.3
	Other	0.7
RFA - Roose's	Cedar	83.9
(west side)	Hemlock	12.9
	Other	3.2
RFA - Ahlstrom's	Cedar	48.8
(east side)	Hemlock	46.4
	Other	4.8

Figure 11. Distribution of tree species and heights along each transect. See Figure 1 for transect locations. The dashed lines represent the location of the abrupt forest edge.



The tree core data for encroaching trees indicate that there was a cohort of trees that established on Roose's Prairie between 50-100 years ago, synchronous with the departure of Peter Roose from his homestead. Both homesteaders grazed sheep (Evans, 1983; Wray and Anderson, 2003). Ahlstrom probably did not use Roose's Prairie for the purposes of grazing of his sheep after Roose left, because Ahlstrom's Prairie would have been more accessible from the location of his homestead and probably provided better browse than the hummocky peat bog of Roose's Prairie. Most of the small trees encroaching upon Ahlstrom's Prairie were aged to be 50 years or less, which is also synchronous with the departure of Lars Ahlstrom from his homestead. This <50 year cohort of trees is consistent with the air photo analysis, which showed a treeless landscape that developed into a patchy landscape over the decades. This suggests that the last major disturbance suppressing tree growth and tree establishment on the prairies was in the form of either sheep grazing or homesteader burning, or a combination of these disturbances. These findings concur with a study in montane meadows in the Oregon Coast Range, where increasing rates of tree encroachment followed the cessation of intense sheep grazing which had previously caused tree suppression by trampling or browsing (Miller and Halpern, 1998).

Many studies of recent tree encroachment in forest meadow landscapes in the Pacific Northwest have addressed the influence of climate, climate change, and tree establishment and have concluded that climate is a contributing, but not the sole factor in recent tree encroachment on meadows (*i.e.* Agee and Smith, 1984; Lepofsky *et al*. 2003; Miller and Halpern, 1998). Some tree species may not be able to establish during the first decade following a fire in the Olympic Mountains due to the moisture regime (Agee and Smith, 1984; Huff, 1995). A dry period occurred during the 1920's; including one extremely dry summer in 1927 (Figure 2b), at about the time that trees on Roose's Prairie became established. The establishment of trees on Ahlstrom's Prairie occurred in the 1950's during mostly above-average precipitation years. Periods of both above and below average precipitation have occurred in the last two decades (Figure 2b), and the tree core data indicates that trees are continually establishing on the prairies. The inconsistency of tree establishment and periods of below-average precipitation leads to the conclusion that while climate is probably a contributing factor in the establishment of trees on the Ozette Prairies, what drives this system more is the change in the disturbance regime such as cessation of fire or grazing. A similar conclusion was reached in an investigation of subalpine forests of the Olympic Mountains (Agee and Smith, 1984).

Vegetation Studies: Accuracy of the 1895 GLO Map

A transect (RFA - Figure 1) connecting Roose's and Ahlstrom's Prairies was placed to test the hypothesis that at the time of the General Land Office Survey, the two prairies were actually one larger prairie (Figure 4). A mature forest would indicate that the prairies were indeed separate at the time of the mapping excursion, and that the single, large prairie was actually a cartographic error. All trees were counted, identified to species, measured for height and diameter, and cored. Additional trees were cored within close proximity to this transect – including within Roose's yard, and to the southeast of Roose's yard, where a stand of large, evenly sized trees existed (OG - Figure 1).

The transect began at the southwest corner of Roose's cabin and ran through a fenced portion of his yard. The NPS had removed the small trees invading this yard but left some of the larger trees surrounding his cabin. These larger (10-20 m height) trees range from 27-44 years old. Tree saplings from Roose's yard range from 7-24 years of age. These trees were small (< 1 m in height), often hidden under a dense growth of salal (subsequently removed by NPS during the summer 2004). The forest between the two prairies contained both cedars and hemlocks with estimated minimum ages ranging from 72-279 years, with a mean age of 187 years. The age distribution is not unlike the forests of the other transects. The northern Ahlstrom's Prairie portion of the transect has experienced significant enclosure of trees onto the prairie and was densely covered with small trees and large tree patches. Ages of cored trees within Ahlstrom's Prairie range from 53-66 years of age.

Seven trees from a homogenous-looking stand (labeled OG on Figure 1) of relatively even-sized trees (both cedars and hemlocks) south east of Roose's yard were cored to determine the age and whether or not this was also open prairie at the time of the GLO's mapping expedition. Diameters ranged from 50-99 cm dbh and heights ranged from 38-45m in height. Ages ranged from 151-190 years old, mean age 165.6 years, with no age correction for coring at breast height.

The tree core data indicates that the forest between the two prairies did exist in 1895 and was mature (trees at least 50 years old), thus the GLO map is in error and there were two prairies. A comparison of the 1895 prairie perimeter georectified to the 1978 7.5' USGS topographic map shows that the prairie shapes are roughly the same, and coincide with one another only where the prairies intersect with survey lines. We speculate this cartographic error is based upon the sampling bias created by the systematic survey method of the Public Land Survey. Survey teams crossed the northern end of Roose's Prairie surveying the southern Ozette Indian Reservation boundary, and the south end of Ahlstrom's Prairie surveying the section lines (Figure 4). It is likely from these two crossing points that they looked across the long axis of each prairie and assumed them to be one and the same, not recognizing the small swath of forest we investigated (Bach *et al.* 2004).

Wetland Analysis

The vegetation communities within the wetlands at Ahlstrom's and Roose's prairies are noticeably distinct from one another in structure, composition, and function. The wetland of Ahlstrom's prairie has a narrow north to south oriented poor-fen vegetation community. It is dominated by graminoid species including, slough sedge (*Carex obnupta*), pale sedge (*Carex livida*), common rush (*Juncus effuses*), baltic rush (*Juncus balticus*), and Chamisso's cotton-grass (*Eriophorum chamissonis*). Others plants include, but by no means are limited to Bog Cranberry, Sticky False Asphodel, Swamp Gentian, King Gentian, and Great Burnet. These species grow from a thin (<2 cm) layer of *Sphagnum* moss that blankets a semi-acidic peat substrate characteristic of poor fen communities (Vitt *et al.* 2001). Woody species are generally absent, except along the wetland perimeter.

The wetland vegetation of Roose's prairie is typical of a *Sphagnum* dominated ombotrophic bog. The bog is blanketed by 0.1-0.7 m high hummocks of *Sphagnum* moss. The hummocks occur because of differential rates of peat accumulation from hummock to hollow (Tallis and Livett, 1994). Due to their water holding capacity and lack of hydrologic inflows and outflows, the *Sphagnum* mosses of Roose's peatland have paludified the entire basin of Roose's prairie and some surrounding slopes. The secondary species co-dominating this peatland include crowberry, bog blueberry (*Vaccinium uliginosum*), bog cranberry (*Vaccinium oxycoccos*), round-leaved sundew (*Drosera rotundifolia*), as well as the intermittent occurrence of transition species like salal, bog laurel, labrador tea, some graminoids, and stunted trees. The stunted trees are typically cedar, but spruce and hemlock are present as well. They are generally short trees (< 2 meters) and their needles are yellowish in color. The stunted trees are likely the result of a nutrient poor and highly acidic substrate typical of *Sphagnum* dominated bogs (Halsey *et al.* 2000). Trees 1-2.5 m in height in these bogs have been found to be 60-80 years old (Ramsden, 2004).

Wetland Analysis Methods

Classifying the Ozette prairies as wetlands helped determine the ecosystem forces behind their development and persistence as openings among a forested landscape. Classifications assisted in comparing and contrasting wetland functions and helped to develop their histories. Two standard classifications were performed in the field. The Cowardin classification, adapted from Cowardin and Golet (1995) and the hydrogeomorphic (HGM) classification adapted from Carter (1986) are classification schemes that summarize variables to accurately characterize typical wetlands in the United States.

Wetland Analysis Classification

Table 3 summarizes peatland characteristics of both prairies and categorizes them accordingly. The Cowardin classification described Roose's peatland as a palustrine/extensive peatland system with less than eight hectares of standing water at the surface. Because there is so little surface water in the peatland, there was no standard Cowardin subsystem that accurately described its hummocky *Sphagnum* topography. Extensive *Sphagnum* mosses absorb most of the water available at the surface. The *Sphagnum* dominance observed in Roose's peatland supports predominantly persistent emergent shrub wetland vegetation in which woody and herbaceous species grow between and atop *Sphagnum* hummocks (Gutchewsky, 2004).

(Table 3) Peatland classification summaries for Ahlstrom's and Roose's prairies.

Peatland:	**a) Ecosystem / Landscape Development:**	**b) Chemistry / pH Class:**	**c) Hydrology Class:**	**d) Vegetation Class:**	**e) Specific Peatland Type:**
Roose's	*Terrestrialization* and *Paludification* / Bog Succession	*Ombotrophic* Bog: Average pH: 3.6	*Ombrogenous:* Rainfall is dominant water source / no surface inflows or outflows.	Hummocky *Sphagnum* blanket with stunted hydrophytic trees and woody shrubs.	*Raised / Blanket Bog*
Ahlstrom's	*Flowthrough* / Fen Succession	*Rheotrophic* Fen: Average pH: 4.0	*Soligenous:* Recharge wetland with interflow and surface runoff.	*Carex* dominated over-story / thin *Sphagnum* surface under-story.	*Transitional / Poor Fen*

The Cowardin classification of Ahlstrom's prairie describes a palustrine peatland system. Though, again there was no subsystem to characterize the persistence of water present at the surface of the peatland. It is important to note; however, that shallow braided (2-5cm) rills transport water at the surface and potentially groundwater from north to south through this peatland. The Cowardin class of Ahlstrom's peatland also described persistent emergent vegetation but instead of *Sphagnum*, species composition was dominated by graminoids especially of the genus *Carex.* Persistent sedges and grasses remain standing in Ahlstrom's prairie throughout the year (Gutchewsky, 2004).

The HGM classification of Roose's prairie describes a peatland formed in a low lying, slightly north to south trending opening in the landscape. Through time the surface of the peatland appears to have paludified the basin including some of its transitional shrub dominated up-slopes. This paludification developed a center elevated above its boundaries creating a raised or domelike structure for the peatland. This appearance is indicative of *Sphagnum* dominated peatlands that terrestrialize or fill former lake environments with peatland succession (Mitsch and Gosselink, 2000). The only obvious water source for Roose's peatland is rainfall. Significant upslope drainage is minimized because the peatland occupies a topographic high. The hydrodynamics of Roose's peatland were therefore, dominated by vertical fluctuations of the water table controlled by the presence of *Sphagnum* moss hummocks, which absorb, store, and acidify water. Though the peatland is consistently saturated, very little standing water was observed on the peatland.

The HGM classification of Ahlstrom's prairie was more dynamic than that for Roose's. Paludification and *Sphagnum* development, which dominated the vegetation and hydrodynamics of Roose's peatland, were suppressed in Ahlstrom's. Hummocky *Sphagnum* topography seen in Roose's peatland did not occur in Ahlstrom's. Precipitation, overland and likely groundwater flows are all contributing water sources. Though there were no obvious streams flowing into this peatland, north to south basin elongation does create a complex pattern of surface drainage through the peatland. Terrestrialization by *Sphagnum* mosses in comparison to Roose's prairie is hindered by this low-gradient surface drainage. Shallow 0-4 cm braided rills flow north to south through central portions of the peatland draining water into an outflow stream south of the prairie, qualifying Ahlstrom's peatland as a recharge wetland. The outflow stream continues southwest into the forest toward the coast. Overall, the hydrodynamics of Ahlstrom's peatland were much more variable than those of Roose's. Both unidirectional flow from north to south and vertical fluctuation of water through the peat column were observed occurring in Ahlstrom's prairie.

Wetland classification shows that the two peatlands within 1 km of one another in adjacent north-south trending basins are significantly different. These differences can not be attributed to climate, which typically defines peatland processes (Gignac and Vitt, 1990). The peatlands have differing geomorphologies, hydrologies, pH, and vegetation dynamics (Table 3). Because the characteristics of the peatlands are so different, they will likely respond to forest encroachment differently through time, especially under the modern regime of fire suppression.

Subsurface Stratigraphy

Peatlands are natural archives that preserve continuous records of their development histories in the forms of stratigraphic air-fall materials including leaf litter, pollen, and charcoal (Whitlock, 1992;

Barber, 1993; Gavin *et al.* 2001). These materials are produced by nearby vegetation, which responds directly and indirectly to climate and other disturbance regimes. Interpretation of these materials, combined with age control, allows an environmental history to extend back thousands of years. The variation of materials through time can be related to other paleoenvironmental data to better understand the regional history. During the past 12,000 years these materials indicate that vegetation, fire and geomorphology have changed several times. Some changes reflect regional climate variations, while others are suggestive of localized changes, such as human activities.

Subsurface Stratigraphy Methods

A 5 cm diameter Livingston increment corer was used to recover subsurface sediments (Wright *et al.* 1984). Before coring, the peatlands were probed with steel rods to determine the deepest deposits to maximize details of earliest accumulation (Heusser, 1964). Sample site locations were selected in this way (Figure 1). In September 2002 three cores were taken from two sites at both Ahlstrom's and Roose's peatlands. Each core was generally described, wrapped in plastic, cased in PVC, and stored at 4°C (Gavin *et al.* 2001). Replicate cores at each site were offset to compensate for distortion, compaction, and sample loss, which can occur when core increments are used.

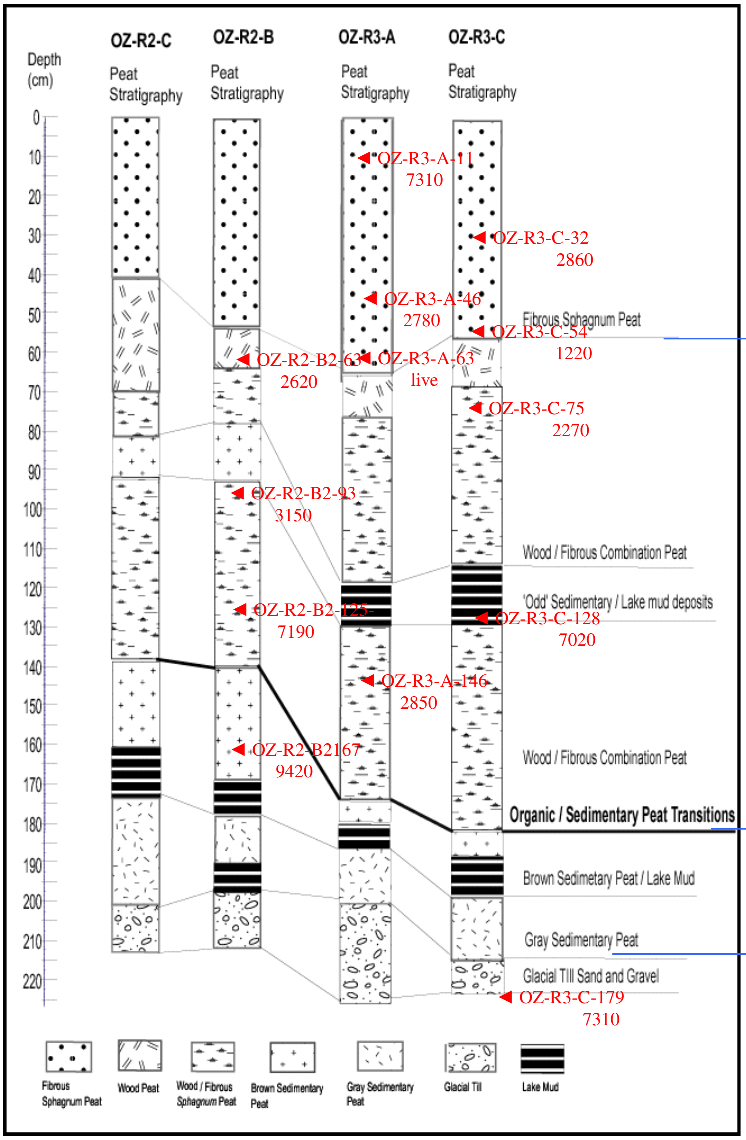
In the laboratory all cores were sliced lengthwise into two halves for detailed sedimentological descriptions. Peat stratigraphy was described using qualitative methods adapted from Rigg (1958) and Rigg and Richardson (1938). Their research compiled stratigraphic descriptions of peat profiles throughout Washington State. Peat types, soil descriptions, Munsell colors, charcoal layers, and distinctive properties were described for each stratigraphic unit. Rigg and Richardson (1938) identify twelve materials forming strata in Washington peatlands: lake mud, sedimentary peat (gray and brown), sedge peat, tule-reed peat, fibrous peat, reed peat, wood peat, charred remains, heath peat, muck, *Sphagnum* peat, and volcanic ash layers. Several wood samples were recovered from Ahlstrom cores and submitted for AMS radiocarbon dating. Sediments were examined for volcanic ash, but none were present, which is consistent with other wetland studies in the area (Rigg, 1938; Heusser, 1964; 1977). Loss on ignition was measured at 2 cm intervals to quantify the percentage of both organic and inorganic materials. Samples were oven dried at 40°C, placed in crucibles, then ashed in a muffle furnace at 500°C for 16 hours (Karam, 1993). The samples were weighed before and after ashing and percent weights of mineral and organic sediment were calculated. Particle-size distributions of inorganic sediments were measured with a laser particle size analyzer to interpret the sedimentary environment (Folk, 1974).

One continuous core from each site was sampled for macroscopic charcoal following methods adapted from Whitlock and Millspaugh (1996), Long *et al.* (1998), Brown and Hebda (2002), and Long and Whitlock (2002). $2.5cm^3$ samples were removed at 1 cm intervals, placed into clear petri-dishes, and soaked overnight in a 5% solution of sodium hexametaphosphate $(NaPO_3)_6$. After soaking, each sample was gently wet-sieved and charcoal fragments between 500 µm and 150µm were identified and counted using a stereo microscope. Samples were counted systematically at a 20X magnification (Brown and Hebda, 2002). Charcoal fragments larger than 500µm were noted for presence/absence and are indicators of local fire events as they cannot be transported by air more than tens of meters (Ohlson and Tryterud, 2000; Gavin *et al.* 2003A). Charcoal data were combined with linear sedimentation rates calculated from radiocarbon dated macrofossils. A detailed fire history or charcoal accumulation rate (CHAR) was calculated in $particles/cm^{-2}/year^{-1}$ using the methodology of Long *et al.* (1998). Though numerous assumptions were made, CHAR is a standard methodology for assessing fire histories from charcoal in sediment cores (Figueiral and Mosbrugger, 2000; see Gutchewsky [2004] for details).

Subsurface Stratigraphy: Reconstruction of Holocene Environmental History

The subsurface stratigraphies of the two peatlands were as dissimilar as their wetland characteristics and vegetation communities. Stratigraphy of Roose's prairie (Figure 12) showed deeper organic peat development, less inorganic sedimentary peat development, and less overall stratigraphic variation than Ahlstrom's (Figure 13). Average depths signified by (~) were used when discussing the stratigraphic boundaries between different cores. All cores recovered from Roose's peatland were composed of *Sphagnum* rich fibrous peat, wood-rich ligneous peat, and clastic-rich sedimentary peat. While some stratigraphic variability was noticeable between cores, a similar general sequence is obvious (Figure 12). The upper few centimeters of Roose's peatland are dominated by a fresh layer of *Sphagnum* mosses and other living plant materials including roots, stems, and leaves of surface vegetation. These materials are

Figure 12. Subsurface stratigraphy from Roose's bog. Note no dating has been done on this sequence. See Figure 1 for site location.



Peat Stratigraphy: (Roose's cores)

General Sequence:

Fibrous peat

(Sphagnum bog: modern envrionment)

ligneous peat

(Forested swamp)

sedimentary peat

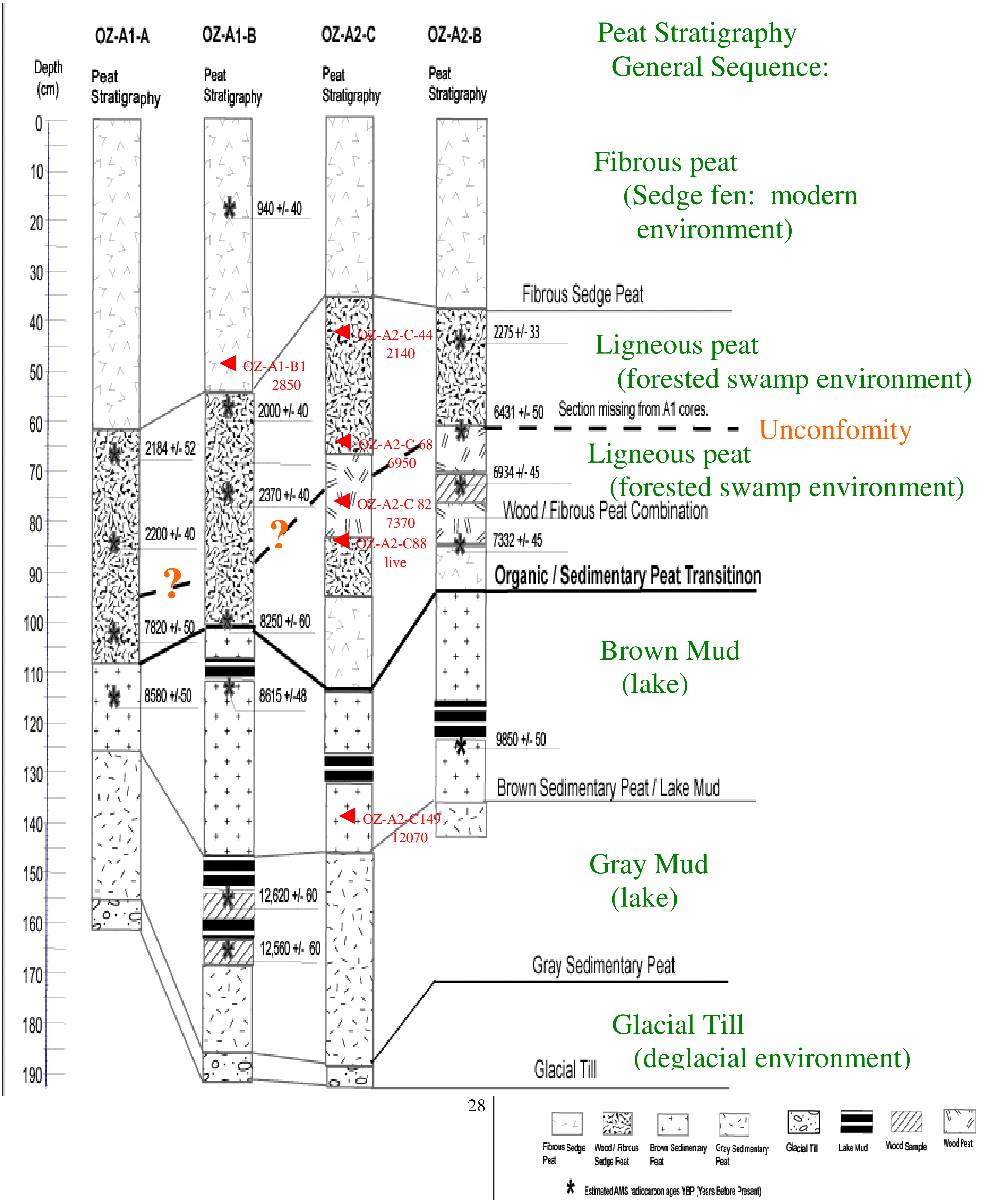
(lake)

Glacial till

(deglacial environment)

Fibrous peat
(Sedge fen: modern
environment)

ratigraphy from Ahlstrom's bog. Note radiocarbon ages are included. See Figure 1 for site location.



representative of the modern environment. Beneath the surface vegetation layers are slightly decomposed, very fibrous *Sphagnum* dominated peat units to depths of ~53 cm. Underlying the *Sphagnum* peat are thin deposits of pasty wood peat overlying combinations of *Sphagnum* and wood peat to depths of 140-170 cm. Underlying the wood peat are different lake sediment units, which become less organic with depth. Glacial till was deposited below ~200 cm in all cores (Figure 12).

Ahlstrom's prairie peat stratigraphies (Figure 13) were different from those observed in Roose's. The most pronounced difference in the sequences was the composition of fibrous macrofossils. The dominant constituents were roots, stems, and leaves of graminoids, where *Sphagnum* dominated Roose's fibrous strata. Radiocarbon ages are included in Figure 13 to show stratigraphic relations. The ages increase with depth in each core and are consistent among correlative units between cores. All four cores from Ahlstrom's prairie contained fibrous sedge dominated peat at the surface to depths of ~36-63 cm (Figure 13). Layered combinations of wood / fibrous sedge peat strata continue to a depth of about 100 cm. These units displayed increasing but variable concentrations of woody remains including tree wood, heath remains, and abundant charcoal. The A2-B core in Figure 13 shows a sequence dated between 6000–8000 yr. B.P. that is completely missing in the A1 cores. Underlying this wood peat are lake sediment units, which become less organic with depth. Several pieces of wood were recovered from this segment. Glacial till was deposited below ~155-185 cm in all cores (Figure 13).

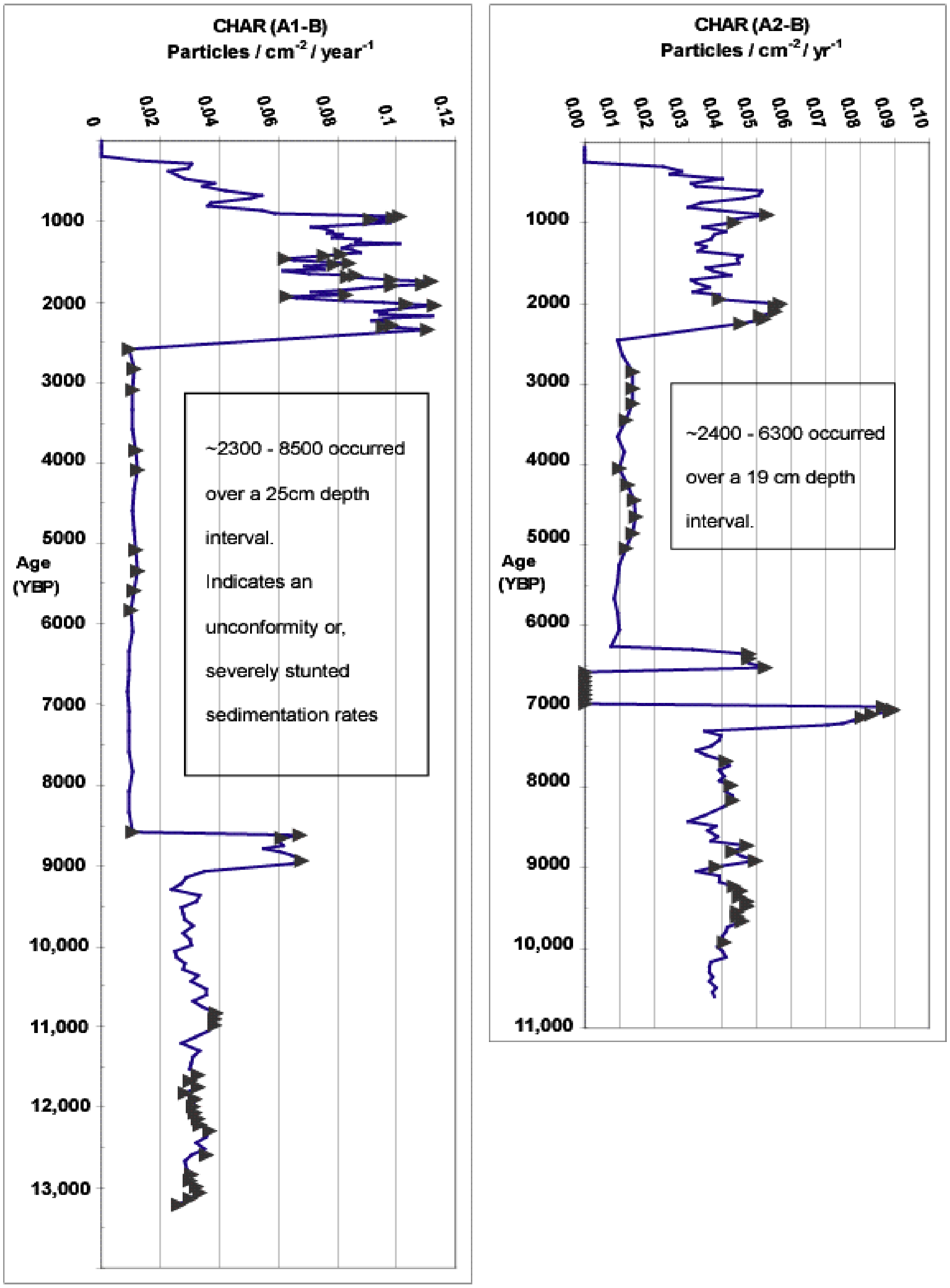
The dated sequence from Ahlstrom's provides a clear history of the sites. The bottom of all cores have undated glacial till (Figure 12 and 13). This must be older than the oldest date in the sequence of 12,620 years BP, thus probably correlates with the till dated 14,460 years BP sampled 10 kilometers to the east (Heusser, 1973). Lakes formed in depressions left by the retreating glacial ice, and persisted at the sites until sometime between 8580 and 8250 years BP (Figure 13). No evidence of marine sedimentation was observed. Given the elevation of ~47 m and the site's location at the edge of the ice sheet producing little isostatic depression, it seems unlikely that the site had been inundated by sea water. At that time the lake terrestialized, as the sediments transition from mineral dominated to organic dominated. A wooded swamp environment was present until after 2000 years BP. During this interval, fires were very frequent (see charcoal counts in next section). At least one large fire (and possibly many) removed (burned away) a significant portion of the peat during this interval. Organic sediments dated between 6431 and 7332 years BP are preserved in cores A2-B and -C, but are missing from cores A1-A and -B, where they were presumably burnt (Figure 13). The major wood component disappears from the record after 2000 years BP. A possible explanation for the disappearance of the wood is that it was burned away by repeated fires, and supported by the high incidence of charcoal just before this time period.

Subsurface Stratigraphy: Holocene Fire History

Coastal temperate rainforests are ecologically distinct from neighboring forests, which have drier climates (Agee, 1993; Lertzman *et al.* 2002). The long-term role of fire in these rainforests has only recently been studied (Agee, 1993; Brown and Hebda, 2002; Lertzman *et al.* 2002; Gavin *et al.* 2003A; 2003B; Hallett *et al.* 2003). A picture has begun to emerge of an infrequent incidence of fire, old and mixed-age stands, typically small (<0.25 ha) areas burned, and a high degree of topographic control (*i.e.* north vs. south slopes). Some north-facing slopes on Vancouver Island have not burned for over 6000 years (Lertzman *et al.* 2002; Gavin *et al.* 2003A). Only 45% of 83 sample sites had burned within the last 1000 years, most of which were on south-facing slopes (Gavin *et al.* 2003A). Time-since-fire in coastal temperate forests may exceed the ages of trees, making it difficult to accurately estimate fire frequency (Gavin *et al.* 2003A). Despite the larger annual precipitation totals, reduced seasonality, different stand structure and species dominance, the model of episodic, stand-replacing fires developed for coastal Douglas-fir forests has often been assumed [incorrectly] to apply to these wetter forests (Lertzman *et al.* 2002).

The Holocene fire history at Alhstrom's Prairie was reconstructed from counts of charcoal in sediment extracted from the wetland every 1 cm and converted to CHAR (Gutchewsky, 2004). The CHAR sequences from two cores show similar general age trends though their depth profiles (Figure 14). The erased/stunted sedimentation that occurred between ~2400 - ~7500 yr. B.P masks any CHAR peaks or specific fire events that might have occurred during that interval. It is important to note that this 20 cm thick section contained the largest overall concentrations of charcoal in the profiles. Therefore, any age-specific peaks older than 2400 years were not discernable from the CHAR data. However, background

Figure 14. Calculated CHAR using sedimentation rates to convert depths to ages and charcoal concentrations to log-transformed charcoal peaks representing potential local fires.



~2300 - 8500 occurred over a 25cm depth interval. Indicates an unconformity or, severely stunted sedimentation rates

~2400 - 6300 occurred over a 19 cm depth interval.

levels of charcoal are much higher in the late-Holocene than in the early-Holocene, suggesting that low intensity fires might have been more common in the late-Holocene. Climatically, the early-Holocene was more prone to fires (Heusser, 1964; 1973; 1977; 1983; Whitlock, 1992; Hebda, 1995; Gavin *et al.* 2001; Brown and Hebda, 2002).

The results of Ahlstrom's prairie 0-2400 year CHAR were presented in Figure 15. The upper 5 cm of both cores recorded no charcoal concentrations, suggesting no recent or modern fires have burned in Ahlstrom's prairie. There were 12 fire peaks distinguished from background threshold values of both analyzed cores between the present and ~2400 yr. B.P. (Figure 15). The presence of charcoal fragments >500µm were also included in Figure 15 as indicators of local fire events at the time they were deposited (Whitlock and Millspaugh, 1996). The background level of charcoal is relatively high, suggesting that low-severity fires were common throughout the record (Whitlock and Millspaugh, 1996). The twelve peaks in the two cores match up fairly well, within ~100 years considering that their sedimentation rates were slightly different. CHAR sequences also indicate less frequent burning over the last 900 years compared with 900-2400 yr. B.P. (Figure 15). The last 900 years of sediment show a decreasing number charred particles >500µm, number of CHAR peaks and background levels of charcoal. This trend could represent a period of annual or frequent burning by native peoples (Wray and Anderson, 2003). Three CHAR peaks distinguishable between 0-900 yr. B.P. in both cores, estimates an average fire frequency of ~266 years between events. This frequency could indicate that there have indeed been fewer fires in recent times. Or, considering the lack of woody materials among upper peat sequences it indicates a less abundant supply of woody fuels that would have been charred and deposited in the peat. Centuries of burning could have moved the forest boundaries away from modern day prairie centers where our samples were taken. According to radiocarbon estimates, the forest edge shift occurred sometime prior to 2000 yr. B.P. (Figure 13).

Between ~900-2400 yr. B.P., nine CHAR peaks were observed, indicating an average of ~166 years between fire events (Figure 15). Other fire frequency studies in similar areas using stand age dynamics, tree-ring data, fire scars, and soil charcoal determined fire frequencies of 1146-2380 years between events (Agee, 1993; Greenwald and Brubaker, 2001; Letzerman *et al.* 2002; Gavin *et al.* 2003A), intervals far greater than those observed in this study. The poor correlation of CHAR peaks between cores on Figure 15, as well as the inherent errors associated with radiocarbon dating, sedimentation rates, and inbuilt age limit this research in attempting to pinpoint the exact timing of fire events. The period of 900-2400 yr. B.P. might represent a time where natives were burning smaller than present prairies. Trees that created the charcoal found in the cores were more numerous and closer to the present day prairie centers where our sampling took place. As outlined in the previous section, paleoecological data suggest this period to be moist and cool with evidence of a declining incidence of fires (Brown and Hebda, 2002; Hallett *et al.* 2003).

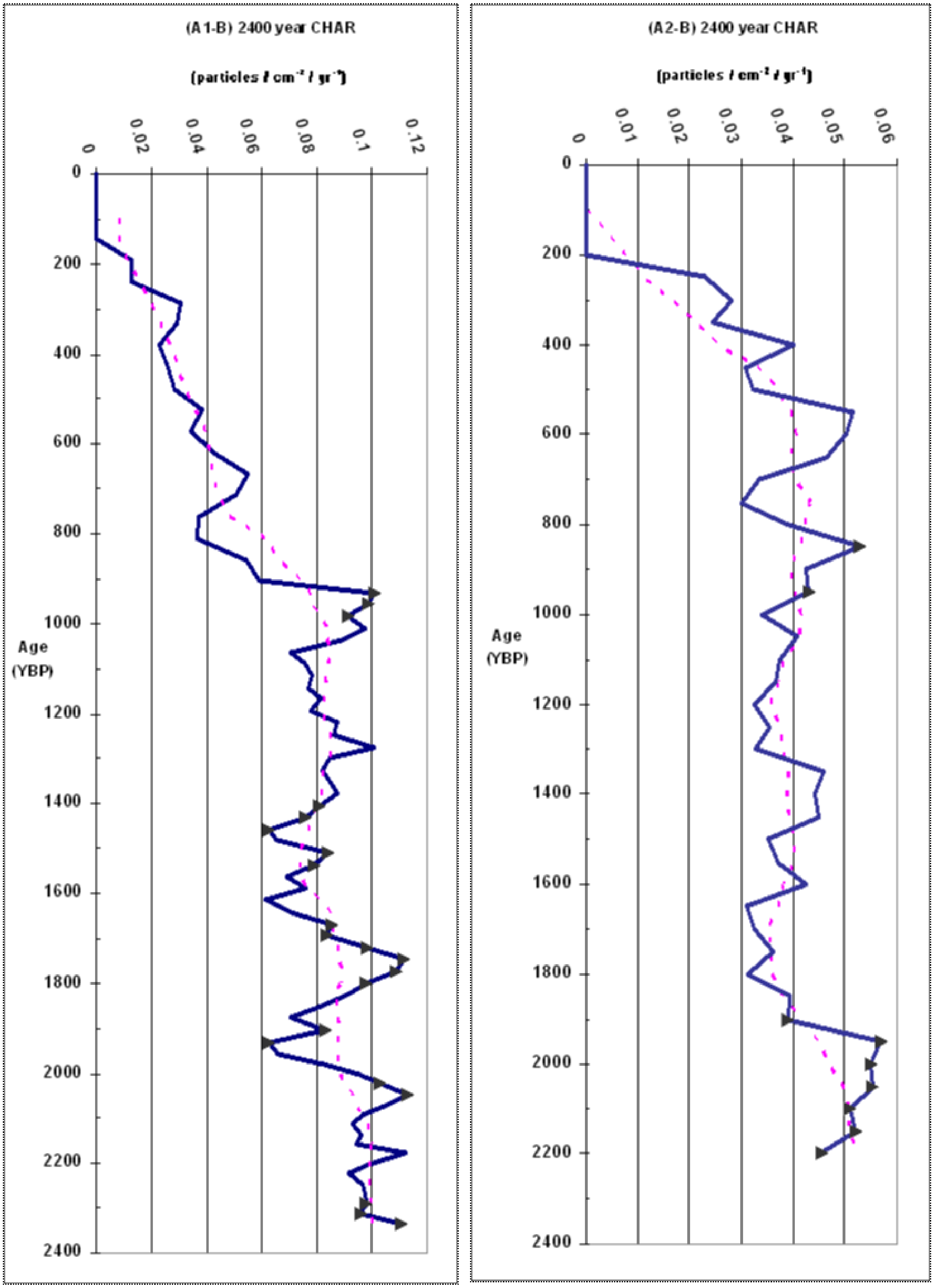
Overall, reported frequencies are likely conservative estimates of fire in the prairie for two reasons. First, the lack of woody materials for fuel amongst fibrous surface peats likely minimized the number of fire events recordable in upper layers of the peat sequences. Charcoal particles counted by this study were generally all deposited from woody sources. Charred sedges, grasses, or other non-woody herbaceous species burned in the prairies, were most likely not identified by this charcoal analysis. Second, the erasure effect could be masking fire events especially among wood peat units where a recent fire consumed the charcoal remains of earlier events hence combining two or more fire events into one.

We have presented stratigraphic charcoal data, forest age data, and soil data that all suggest fire has occurred relatively frequently at the Ozette Prairies. Studies of fire frequencies in analogous coastal temperate rainforests on Vancouver Island suggest that fires occur very infrequently. These environmental data, combined with ethnographic evidence (Wray and Anderson, 2003), strongly suggests a long history of human intervention in the fire regime.

Regional Paleoenvironmental History

Our paleoenvironmental record appears to fit with the regional framework quite well. Over the last 15,000 years, the global climate system has moved from a glacial state into the present interglacial period known as the Holocene. During this transition glaciers disappeared, sea-level rose world wide, land and

Figure 15: CHAR recording a 2400-year relative fire-frequency using a 300 year window-width for Ahlstrom's charcoal cores showing 10-12 likely fire events. Triangles indicate the presence of charcoal >500µm which are indicative of local fire events.



ocean surfaces warmed, and precipitation became redistributed (COHMAP, 1988). These global events created a series of adjustments to regional climates that caused changes in vegetation composition, and shifts in the distribution of species. In the Pacific Northwest, the areas formally covered with ice were colonized by vegetation from the unglaciated areas to the south, the exposed continental shelf, and in the mountains (Whitlock, 1992).

Chronologic data for paleoenvironmental changes in the coastal region of the Olympic Peninsula are limited. A detailed Puget Sound/interior British Columbia glacial chronology indicates that the Cordilleran ice sheet reached a maximum at ~14 ka (Heusser, 1977; Porter and Swanson, 1998; Kovanon and Easterbrook, 2002; Clague and James, 2002). Cascade Mountain glaciers reached a maximum extent earlier (~18 ka; Waitt and Thorson, 1983), and readvanced following the retreat of the ice sheet (Kovanon and Easterbrook, 2001). The glacial chronology of the Olympic Mountains is less well understood, but a similar asynchrony of glacier maxima appears to have occurred (Heusser, 1964; 1973; Thackray, 1996). The Ozette area, however, was outside the range of influence of alpine glaciers. Chronologic data from the Puget Lowlands (Porter and Swanson, 1998) and modeling (Clague and James, 2002) indicate that the ice sheet retreated from the Chehalis, WA area into British Columbia within 100-1000 years of the maxima. This rapid retreat was probably due to sea-level rise initiated by the decay of the Laurentide ice sheet (Clague and James, 2002). Since the Ozette area was at the margin of the ice sheet, it is unlikely that ice readvanced into the area. A radiocarbon date of 14,460 +/- 200 years was recorded within glacial till underlying Wessler bog ~10 km to the east (Heusser, 1973). Till under four other lakes/bogs in the region was dated between 12,020 – 13,380 years BP (Heusser, 1973).

During the glacial period the western Olympic Peninsula was covered with a mixture of tundra and parkland vegetation similar to modern subalpine forests (Heusser, 1964; 1973; 1977; 1983). Following deglaciation of the ice sheet, the landscape of the region was characterized by open pine woodlands (Heusser, 1973; 1977; 1983; Sugita and Tsukada, 1982; Whitlock, 1992; Hebda, 1995; McLachlan and Brubaker, 1995; Brown and Hebda, 2002). There is considerable inter-regional variation in paleoecological data, reflecting the mosaic of mesoscale (10-100 km) climates related to the complex topography of our region (McLachlan and Brubaker, 1995; Gavin *et al.* 2001; Lertzman *et al.* 2002). Especially notable is a west-to-east declining precipitation gradient. Whyac Lake, Vancouver Island, ~45 km NNW of Ozette, has a similar topographic setting and the same modern vegetation (Brown and Hebda, 2002), thus provides an analogy for our paleoecological reconstructions. The late-glacial pine forest at Whyak Lake is interpreted to be open, with a mix of other conifer species.

The early-Holocene (~10,000-7000 years BP) was a period of regional warming and drying in the Pacific Northwest, especially in the summer season (Heusser, 1964; 1973; 1977; 1983; COHMAP, 1988; Whitlock, 1992; Hebda, 1995; McLachlan and Brubaker, 1995; Gavin *et al.* 2001; Brown and Hebda, 2002). Most locations experienced an increase in Douglas-fir, but Whyak Lake saw spruce, western hemlock, and alder dominate in a closed forest (Brown and Hebda, 2002). Fires began to increase dramatically, reflecting a combination of warmer, drier conditions, and growing fuel loads. The increased occurrence of charcoal at Whyak Lake began about 10,300 years BP, 1000-2000 years earlier than the increase we measured (Figure 14).

The mid- Holocene (~7000-3000 years BP) was a period of moister, cooler conditions throughout the northwest, especially in the summer season (Heusser, 1977; Whitlock, 1992; Hebda, 1995; McLachlan and Brubaker, 1995; Brown and Hebda, 2002). Western hemlock and red cedar expanded into many areas. The expansion of cedar coincided with the development of massive woodworking technology by many native cultures (Hebda and Mathewes, 1984). At Whyak Lake western hemlock co-dominated with spruce by 7100 years BP, but red cedar did not arrive until ~5000 years BP. Whyak Lake and most other sites experienced a decline in fires in response to regional moistening (Sugita and Tsukada, 1982; Cwynar, 1987; Brown and Hebda, 2002). The charcoal record from Ahlstrom's shows this period had the highest occurrence of fire (Figure 14). An increased incidence of fire during a period of regional, climate-induced fire reduction suggests that humans might be responsible.

The late-Holocene (~3000 years BP - present) was a period when the climate of most areas approached the modern condition (COHMAP, 1988; Whitlock, 1992; Hebda, 1995; Brown and Hebda, 2002). The climate of Whyak Lake became wetter and a little cooler than the mid-Holocene, allowing western hemlock and red cedar to dominate over spruce, as seen in the modern forest (Brown and Hebda, 2002). It is important to note that no wet sites in the region experienced a warming or drying trend that might lead to in increased incidence of fires during the last 3000 years (Hebda, 1995; Gavin *et al.* 2001;

Brown and Hebda, 2002). Many, but not all, sites experienced a decline in red cedar during the latest Holocene, including Wessler bog (Heusser, 1973). It is speculated that the cedar decline is related to harvest and burning by indigenous groups (Turner, 1999; Brown and Hebda, 2002; Lepofsky *et al.* 2003). The charcoal record from Whyak Lake shows a fire free interval from ~4000-1500 yr BP associated with a moister climate and a slight increase in charcoal from 1500 yr BP to the present might reflect human activity (Brown and Hebda, 2002).

The charcoal record from Ahlstrom's shows an inverse pattern. Charcoal production was highest from the mid-Holocene through ~2400 yr BP, and remained relatively high until ~900 yr BP (Figure 14). Our interpretation is that fire activity was the result of humans burning the forested swamp in this period to encourage the understory plants to grow. The decline in charcoal after 900 yr BP does not reflect a decrease in fire activity, but a change in sample site vegetation from forest to fen, which did not have a wood source to produce charcoal.

Project Summary

This study has demonstrated that the Ozette Prairies have experienced and will continue to experience significant establishment of native trees. The two methods employed -- an air photo analysis combined with the use of a GIS and a model of prediction, as well as a field investigation utilizing vegetation transects and sampling for species frequency, height, diameter, and age -- combine to create an overall composite of spatial and temporal change. Both methods clearly show the invasion of trees onto the Ozette Prairies. The invasion of Roose's Prairie by trees began ~80 years ago, coinciding with the abandonment of the Roose homestead. Ahlstrom's Prairie did not experience tree invasion until ~50 years ago following Lars Ahlstrom's death. During the 36-year interval 1964-2000, Ahlstrom's Prairie decreased by 53.5% and Roose's by 32.7%. The timing of encroachment on each prairie coincides with changes in land management practices, including the cession of homesteader activities to wilderness protection.

The environmental history revealed from wetland sediments is consistent with regional paleoclimatic records. The area was deglaciated ~14,000 years ago, followed by lakes occupying the prairie sites. The lakes infilled and turned into forested swamps at about 8000 years BP. Fires occurred with an undetermined frequency during the 2400-6400 year era, burning away a portion of the organic record. At about 2000 years BP the forested swamp was replaced by the modern wetland vegetation. We speculate that this transition was the result of fires burning the forest edge away from the sample site. A fire return interval of ~266 years continued until ~900 years BP, which was subsequently replaced by a ~166 year return interval. This relatively frequent fire return interval and a high background level of charcoal particles in the record suggest frequent, low-intensity fires. A frequent, low-intensity fire regime is consistent with ethnographic evidence of contact-era Makah activities.

Analysis of soils and sediments deposited in the wetlands demonstrate that fire has occurred frequently on the prairies throughout the Holocene. Estimates of the fire return interval on the prairies over the last 2400 years are 166-266 years, while other studies in similar forest settings have found return intervals of 1000-6000 years. This significant difference in fire frequency strongly suggests anthropogenic activity. Since the prairies have experienced tree invasion since the cession of disturbance activities, we suggest that mitigation action, specifically prescribed fire, be taken in order to preserve the prairie vegetation communities that have existed for at least 2000 years.

Management Recommendations

The closer a forest system is managed to mimic the natural process in which it evolved, the more successful the management will be (Kauffman, 1990). Among our findings are three items which have management implications: The prairie wetlands in their current form have been present on the landscape for ~2000 years; a frequent fire regime was present during this time period, likely keeping trees from invading the wetlands; and modeling based on the rate of tree invasion since 1964 indicates that the prairies will infill with trees over the next 100 years. In order to maintain the prairies as openings, management intervention is recommended, specifically the reintroduction of fire. This is contrary to the recommendations of Agee (1993, p. 195), who states that fire has played a minor role in the development of these forests and that the suppression of fire "will not create significant 'unnatural' impacts in *Picea* *sitchensis* forests." He was speaking to the absence of fire in the coastal rain forest in general terms, and not to the site specific fire regime we have detailed here. The general lack of fire in these forests makes the prehistoric Ozette Prairie frequent fire landscape even more unique.

We do suggest however, that the reintroduction of fire be done carefully, on an experimental basis, following techniques used in similar habitats. Observations from a 20+ year study of prescribed fire reintroduction to native grasslands in the Puget Sound suggest using great caution in extrapolating results from either other burn studies, or from a few burn experiments on-site (Dunwiddie, 2002). In monitoring of burn experiments on Yellow Island, it has been difficult to predict the long-term effects of the reintroduction of a frequent, low-intensity fire regime that is thought to resemble what had sustained the grassland communities in prehistoric times. Following each of three burns, responses of different native species have been complex, varying in direction, magnitude and duration (Dunwiddie, 2002). One consistent finding is that non-native species usually establish more quickly than native species, and continue to dominate for many years. We have made this observation at the Roose homestead site, where brush piles were burned and non-native species have become established. We observed creeping bent grass, bull thistle, fox glove, velvet grass, hairy cat's ear, white clover, sheep's sorrel, and English plantain covering 10-75% of the areas burned under brush piles.

Since the life way of the butterfly species of concern on the prairies is unknown, we suggest that their biology be studied in detail. This will avoid the possible destruction of sensitive habitats, such as over-wintering habitats, or seasonal use habitats (*i.e.* larval stage). If intervention is not made into the tree invasion, the butterfly flight habitat will be greatly diminished in size (Figure 7), potentially reaching an extinction threshold.

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