Lepofsky, D., E. K. Heyerdahl, K. Lertzman, D. Schaepe, and B. Mierendorf. 2003. Historical meadow dynamics in southwest British Columbia: a multidisciplinary analysis. Conservation Ecology **7**(3): 5.
[online] URL: http://www.consecol.org/vol7/iss3/art5

Report

Historical Meadow Dynamics in Southwest British Columbia: a Multidisciplinary Analysis

Dana Lepofsky[1], Emily K. Heyerdahl[2], Ken Lertzman[1], Dave Schaepe[3], and Bob Mierendorf[4]

ABSTRACT. The recent encroachment of woody species threatening many western North American meadows has been attributed to diverse factors. We used a suite of methods in Chittenden Meadow, southwestern British Columbia, Canada, to identify the human, ecological, and physical factors responsible for its historical dynamics and current encroachment by woody vegetation. We evaluated three hypotheses about the origin and processes maintaining the meadow: the meadow is (1) of recent human origin; (2) of ancient human origin, maintained by aboriginal burning; and (3) of ancient non-human origin, not maintained by aboriginal burning.

Our data supported the idea that the meadow had ancient non-human origins and its recent history and current status have resulted from complex interactions among landform, climate, and fire. Soil properties (both horizonation and charcoal content) indicate that the meadow is of ancient, non-human origin. Tree ages in the meadow and surrounding forest indicate that encroachment is recent, not related to a variety of recent human activities, and is probably a result of increasing spring temperature and decreasing spring snow depth. Although ethnographic surveys and historical documents revealed indigenous use of the general area over millennia, including the use of fire as a management tool, we found little direct evidence of indigenous use of the meadow. However, there was no proxy record of fire frequency in the meadow that we could have used to determine the role of fire in maintaining the meadow in the past, or the role of humans in igniting those fires. Thus, the historical role of humans in the maintenance of the meadow by prescribed fire remains indeterminate. Based on these conclusions, we combined hypotheses (2) and (3) into an a posteriori hypothesis that reflects changing interactions among people, fire, and climate over time. Without management intervention, we expect that tree encroachment will continue.

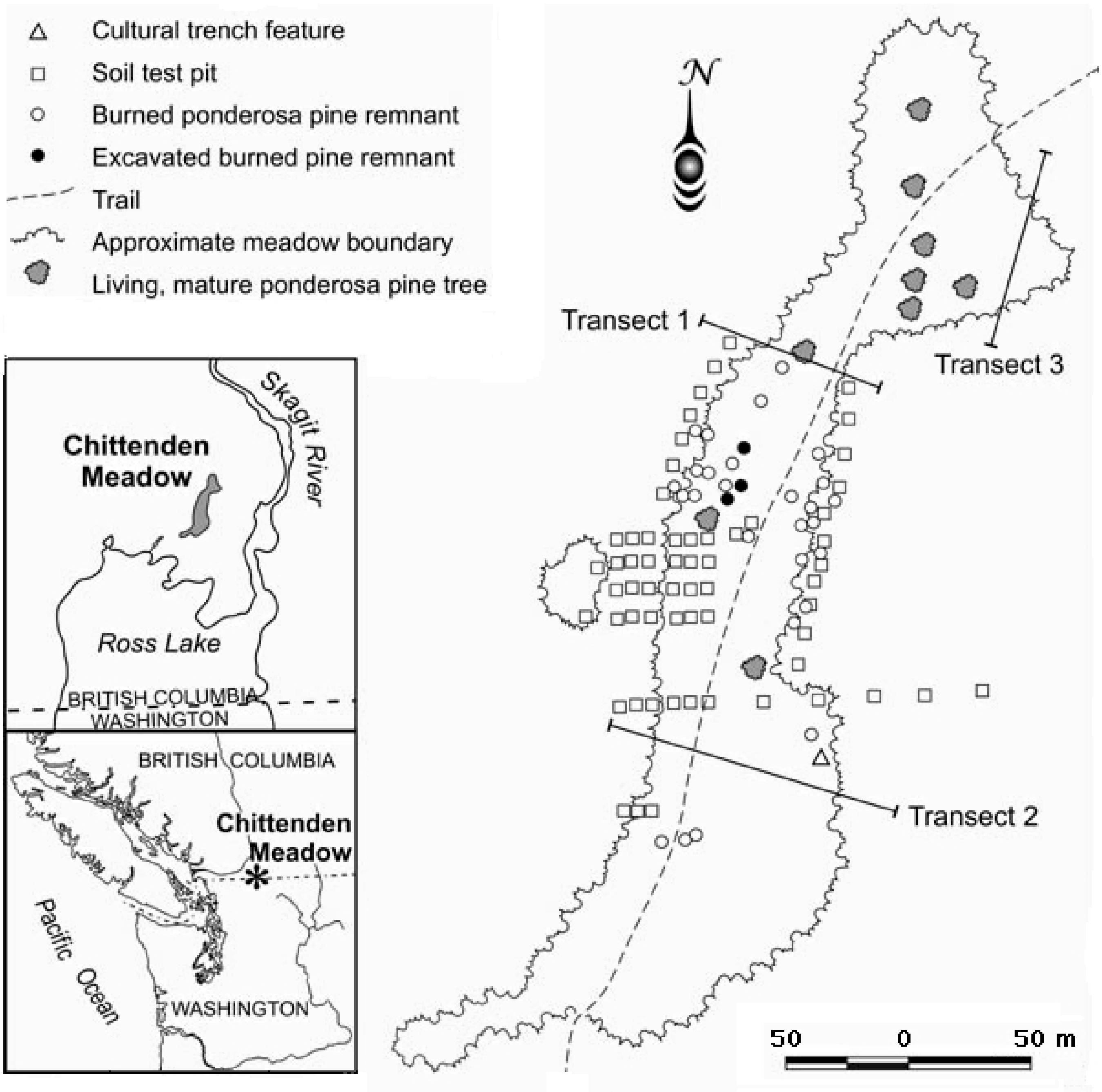
Several general lessons emerge from our study of Chittenden Meadow. A single modern ecosystem condition may result from diverse antecedents, but ecosystems may not carry a memory of all the processes driving their historical dynamics. The historical role of indigenous reource management activities may be one such process: despite millennia of human occupation and resource use in the region, local First Nations left only a light footprint on Chittenden Meadow. Finally, there is value and challenge in integrating data and perspectives from different disciplines.

INTRODUCTION

Many modern ecosystems result from complex interactions among ecological, physical, and anthropogenic processes. For example, some meadows in western North America were historically maintained within forested landscapes by a combination of fire (Arno and Gruell 1986, Magee and Antos 1992, Hadley 1999, Tveten and Fonda 1999), domestic livestock grazing (Vale 1981), or substrate (Hadley 1999). Other meadows, particularly subalpine meadows, were maintained by climate or by interactions between climate and fire (Vale 1981, Agee and Smith 1984, Butler 1986, Taylor 1990, Dyer and Moffett 1999). Many meadows are currently threatened because of recent changes in these processes. This often has resulted in woody vegetation encraoching into meadows, similar to the encroachment of fire-intolerant species into open ponderosa pine forests (*Pinus ponderosa;* our authority for plants is Hitchcock and Cronquist [1973]). One goal of managing these open forests and meadows is to restore them to their pre-encroachment condition, but this requires one to identify the relative importance of the factors that historically controlled their dynamics (Swanson et al. 1993, Landres et al. 1999). Further, such restoration often will require an understanding of the unique history of individual ecosystems.

[1]Simon Fraser University; [2]USDA Forest Service; [3]Stó:lo Nation; [4]North Cascades National Park Service Complex

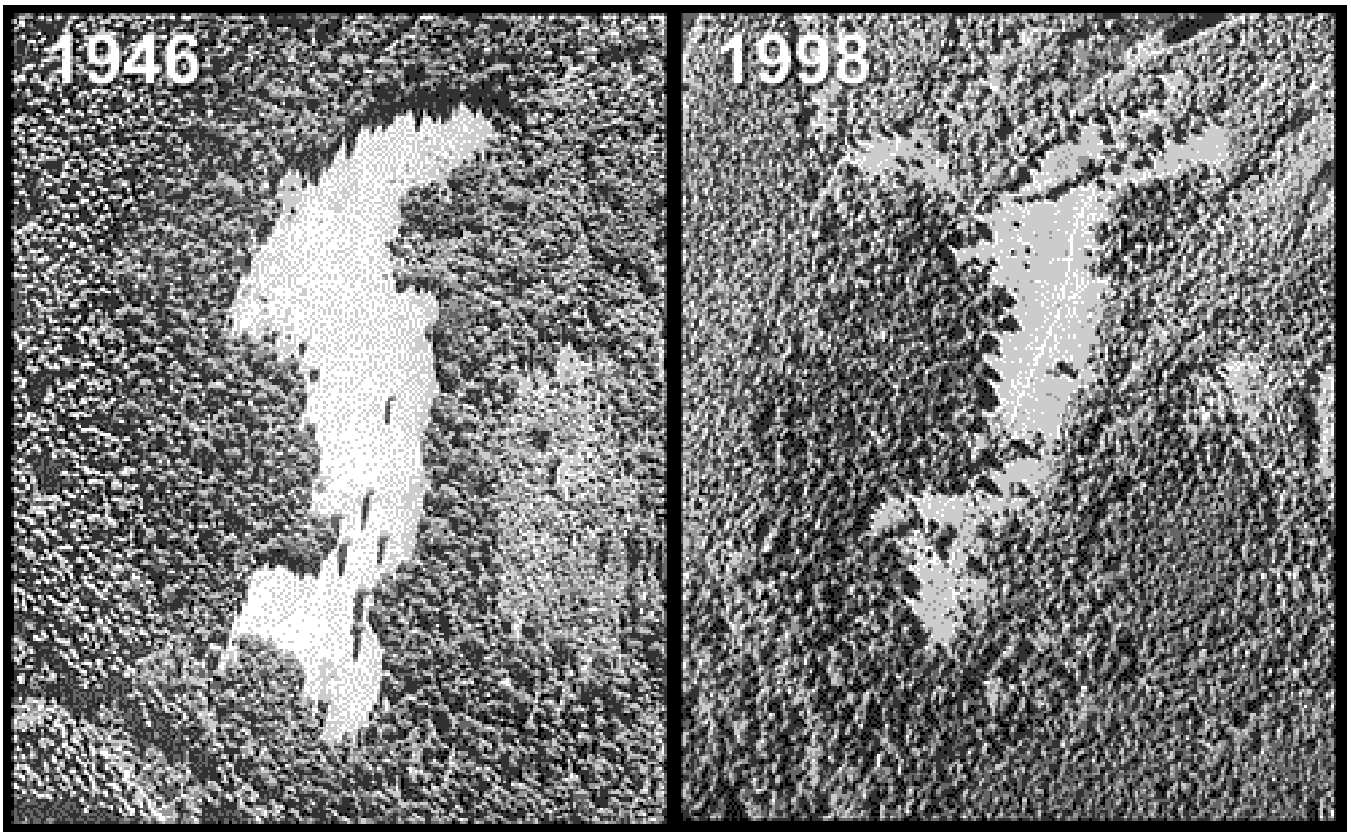
Fig. 1. Chittenden Meadow, British Columbia, Canada, showing the location of sampling sites for archaeological (soil test pits and cultural trench feature), ecological (transects), and geomorphological evidence.



In exploring historical ecosystem dynamics, ecologists often seek supporting data from other fields such as archaeology, ethnography, climatology, and geology, but less commonly collaborate with researchers in these disciplines to develop synthetic, multidisciplinary perspectives of ecosystems (but see Delcourt et al. 1998, Hörnberg et al. 1999, Alcoze and Hurteau 2001). Sometimes we consider only ecological explanations for historical ecosystem dynamics, and may consider only a single driving factor. Studying the historical dynamics of meadows in this way has resulted in different studies of the same meadow ascribing different primary processes (Dyer and Moffett 1999). In this paper, we present the results of a multidisciplinary collaboration to examine the human, ecological, and physical processes responsible for the historical and current state of a meadow in southwestern British Columbia, Canada.

Chittenden Meadow appears similar to ecosystems elsewhere in western North America, where frequent surface fires historically maintained meadows and open ponderosa pine forests (Agee 1998). However, this small meadow (<10 ha) is located on the floodplain of the Skagit River, in a matrix of riparian vegetation and more mesic coastal and coastal–interior transition forests (Fig. 1). Consequently, these floodplain forests probably experienced fires that were less frequent and more severe than those that historically sustained forests dominated by ponderosa pine elsewhere in the region (Agee et al. 1990). Today, conifer trees, mostly Douglas-fir (*Pseudotsuga menziesii*) and grand fir (*Abies grandis*), are establishing in Chittenden Meadow, suggesting a change in the factors that maintained it historically (Fig. 2).

Fig. 2. Aerial photos of Chittenden Meadow in 1946 and 1998, showing the recent encroachment of trees.



Chittenden Meadow has evidence of a range of factors that are known to drive meadow dynamics elsewhere. First, there is evidence of past fires in and around the meadow. Mature ponderosa pines with charred bark and fire scars in Chittenden Meadow, but not in the surrounding forest, suggest that perhaps fire was more frequent in the former, as we would expect if fire were important in maintaining the meadow. Lightning strikes the area during the fire season (Morris 1934, British Columbia Forest Service 1995*a*). However, historical fires in the meadow also may have been ignited by aboriginal people, who have used the Skagit Valley for at least 8000 years (Willig and Aikens 1988, Mierendorf 1993, Carlson 1997, Mierendorf et al. 1998, Franck 2000). They ignited fires to maintain open ecosystems into the early 20th century, although this practice was restricted after contact with European settlers (Collins 1974, Turner 1999, Lepofsky et al., *in press*). If humans were igniting the fires that maintained the meadow, we would expect to find evidence of human use of the meadow and a change in the fire regime of the meadow around the time when aboriginally set fires were restricted.

Second, there is evidence of recent human activity that may have created or maintained Chittenden Meadow. A late 19th century homestead suggests that the meadow may have been created by logging and subsequently maintained by grazing. In this case, we would expect the mature pines in the meadow to have established in the open conditions that prevailed after the existing forest was cleared; the recent encroachment of trees could be a consequence of the cessation of grazing. Alternatively, fire suppression, or the logging and flooding of nearby forests to create Ross Lake Reservoir, may have led to this encroachment.

Table 1. Our hypotheses about the origin and maintenance of Chittenden Meadow, British Columbia, showing potential findings. Our actual findings are in boldface, whereas those that we could not test are in italics.

Hypothesis	Mature ponderosa pine in meadow	Fire frequency, meadow vs. forest	Record of aboriginal use		Soil profile, meadow vs. forest	Soil charcoal, meadow vs. forest	Modern encroachment of trees synchronous with:
			Ethnographic	Archaeologic			
A) Recent human origin	postdate modern human activity	*same*	none	none	similar	similar	cessation of grazing
B) Ancient human origin, maintained by aboriginal burning	**predate modern human activity**	*more frequent*	**use of fire**	**use of meadow**	**different**	**different**	abandonment of aboriginal burning
C) Ancient non-human origin, not maintained by aboriginal burning	**predate modern human activity**	*same or more frequent*	none	none	**different**	**different**	**climate change;** mid-20th C fire exclusion; Ross Lake flooding
Sources of data	establishment dates of mature pine	fire scars on trees	archival records	archaeologic survey, excavation	soil horizona-tion	soil charcoal	archival records; tree rings; modern climate

Third, climate, interacting with fire, may have played a role in maintaining Chittenden Meadow, as it has in some other meadows (Vale 1981, Agee and Smith 1984, Butler 1986, Taylor 1990, Dyer and Moffett 1999). Since the mid-1970s, spring temperature has increased across the Northern Hemisphere, resulting in a decrease in spring snow cover across North America, including the upper Skagit Valley (Karl et al. 1993, Cayan et al. 2001). This decrease may have favored the establishment of Douglas-fir and grand fir in the meadow. In the upper Skagit Valley, the survival of Douglas-fir and grand fir seedlings, which germinate in the spring after the winter snowpack melts, is limited by midsummer moisture stress and heating from solar insolation (Foiles et al. 1990, Herman and Lavender 1990). Earlier melting of the snowpack would allow trees to germinate earlier in the year, when moisture stress and solar insolation, the major limits to seedling survival, are lower than they are near the end of the growing season. If climate were historically important in maintaining the meadow, we would expect the recent encroachment of trees to be synchronous with the recent change in climate in the study area.

We tested three alternative hypotheses to determine if Chittenden Meadow is of ancient or recent origin and to identify the relative importance of the factors that have maintained it. First, we hypothesized that the meadow is of recent origin and was maintained by recent human activities (Table 1, Hypothesis A). Second, we hypothesized that the meadow is of ancient human origin and was maintained by aboriginal burning (Table 1, Hypothesis B). Third, we hypothesized that the meadow is of ancient, but non-human, origin, and that it was maintained by some combination of non-aboriginal fire, climate, and substrate. To address the meadow's origins, we considered soil horizonation, age of mature ponderosa pines in the meadow, and fire frequency. To address the factors maintaining the meadow, we considered soil charcoal, ethnographic records of human use of fire, archaeological evidence, changes in fire frequency through time, and the timing of tree encroachment relative to changes in climate and recent human activities.

We will show that the meadow is of ancient origin and that its recent history and current status reflect a complex interaction among fire, soil, and climate variables. We conclude by proposing a fourth, a posteriori hypothesis that we believe reflects this interaction. The role of fire in the meadow and the influence of aboriginal people in igniting those fires, remain unclear because the meadow has retained no detailed proxy record of fire frequency. Our study reveals some of the challenges of extracting historical causality from patchy records of complex ecosystem dynamics.

STUDY AREA

Physical and ecological setting

We studied a 1 km^2 area in and around Chittenden Meadow, west of the crest of the Cascade Range in the upper Skagit Valley (500 m; latitude 49°00' N, longitude 121°03' W; Fig. 1). Most precipitation falls as snow in winter, and snowpack generally persists into April or May. However, the study area lies in the rain shadow of the Pickett Range and receives less precipitation (mean annual 790 mm; International Joint Commission [1971]) than other areas at similar elevations in the western Cascade Range. Consequently, in the upper Skagit Valley, mesic coastal forests are juxtaposed with dry interior forests (Agee and Kertis 1987). For example, ponderosa pine is generally uncommon west of the Cascade crest, but occurs in the meadow and some nearby forests. The meadow is in the Interior Douglas-fir zone (warm wet subzone: “IDFww” of British Columbia’s Biogeoclimatic Classification system; Meidinger and Pojar 1991), but is bordered by coastal forests to the north and west (Coastal Western Hemlock zone, moist submaritime and dry submaritime subzones: CWHms1 and CWHds1) and interior forests to the east, mostly Engelmann Spruce–Subalpine Fir zone (moist warm subzone: ESSFmw). Our meadow is unique in this area. Aerial photos, historical documents, and early historical maps reveal only one other large meadow in the upper Skagit Valley, one that probably originated with tree clearing to establish the Whitworth ranch in 1904 (S. Apted, *personal communication*).

Cultural history of Chittenden Meadow and vicinity

Aboriginal use of the upper Skagit Valley, including the vicinity of Chittenden Meadow, is well documented over the past 8400 years. There are 31 known archaeological sites within 5 km of the meadow (Mierendorf et al. 1998, Franck 2000), most of which were used seasonally. They include hearths (for warmth and cooking meat, fish, and berries) and drying trenches for processing large quantities of berries (Franck 2000). Most of the artifacts from the vicinity of the meadow are utilitarian, but a bird effigy stone bowl found in the south end of the meadow indicates that people may also have used the area for rituals. During the early contact era (roughly AD 1782–1858), four First Nations, the Stó:lô, Nlaka'pamux, Nooksack, and Upper Skagit, used the upper Skagit Valley for a wide range of activities including seasonal subsistence (e.g., hunting, fishing, and plant-food gathering), gathering of non-food resources (e.g., quarrying of raw materials for stone tools), intercommunity trade, transportation, and communication via travel routes through the region (Franck 2000). This area is currently rich in animal and plant species that traditionally were important to aboriginal people, such as black bear (*Ursus americanus;* our authority for animal names is Banfield [1975]); white-tailed and mule deer (*Odocoileus virginianus* and *O. hemionus*), starflowered false Solomon's-seal (*Smilacina stellata*), tiger lily (*Lilium columbianum*), chocolate lily (*Fritillaria lanceolata*), kinnikinnick (*Arctostaphylos uva-ursi*), bracken fern (*Pteridium aquilinum*), Nootka rose (*Rosa nutkana*), and saskatoon (*Amelanchier alnifolia*, Turner et al. 1990, Turner 1995, 1998).

Non-aboriginal people also have used the study area over the past 120 years. The Cawley homestead was occupied in Chittenden Meadow from 1883 to 1904. The remains of a corral at the north end of the meadow are visible on a 1933 map, suggesting that livestock may have grazed the meadow during this time (Map No. S-1019 "Skagit Project, Key Map of Ruby Reservoir," City of Seattle, Lighting Department, 21 March 1933; S. Apted, *personal communication*). Later, in the 1940s–1950s, the valley bottom along the upper Skagit River was logged to within 1 km of the south end of Chittenden Meadow to create Ross Lake reservoir (Pitzer 1978; Fig. 1). Curly Chittenden, the logging supervisor, recognized the meadow's uniqueness and prevented logging of the forest immediately surrounding it, although logging roads and camps were built nearby and some logging roads crossed the meadow (S. Apted, *personal communication*). The water in the reservoir reached its northern extent, near the southern end of the meadow, in 1952. British Columbia Parks designated parts of the upper Skagit Valley, including the meadow, a Recreation Area in 1973 and a Provincial Park in 1997. They are concerned about the recent encroachment of Douglas-fir and grand fir trees into the meadow and are considering options for restoring the meadow to its historical extent.

METHODS

Mature ponderosa pine in the meadow

To (1) determine the timing of establishment of the mature ponderosa pine trees relative to the origin of the meadow and (2) identify any fire scars on these trees that could provide evidence of low-severity fires that occurred before or after the origin of the meadow, we located all such trees in and around the meadow on aerial photos and the on ground. We examined each tree for fire scars, measured tree height and diameter at breast height (dbh, 1.3 m high), and removed increment cores near the ground (mean height above ground = 40 cm) to determine the establishment date.

Records of aboriginal use

Ethnographic evidence of prescribed fire. To locate any documented uses of prescribed fire by aboriginal people near Chittenden Meadow, we searched ethnographic reports and historical documents pertaining to the Stó:lô, Nlaka'pamux, Nooksack, and Upper Skagit First Nations.

Archaeological evidence of meadow use. To determine the spatial and temporal extent of aboriginal use, we surveyed the meadow for surface and subsurface cultural features. We inspected the surface for features that were potentially cultural in origin, such as depressions, stone artifacts, structural remains, or culturally modified trees, although our survey at the north end of the meadow was hampered by shrubs (mostly *Rosa* spp.) that obscured the surface. We excavated and drew a stratigraphic profile of four of the depressions thus identified. From one of these features, which subsequently proved to be cultural in origin, we also collected two samples of charcoal from 25–30 cm below the surface to determine the plant species that had burned and for radiocarbon dating (via accelerator mass spectrometry). We surveyed for subsurface cultural features by digging 60 small test pits (40 cm in diameter; Fig. 1), 26 of them on a grid at the western meadow–forest boundary, 11 on an east–west transect across the meadow and into the surrounding forest, and the remaining pits within the forest near the meadow–forest boundary. We excavated each pit to the C horizon, glacial sediment, and screened the excavated soil through 6-mm mesh to retrieve any small artifacts.

Soils

Profiles of meadow vs. forest soils. To determine the stability of the current meadow–forest boundary, we compared the soils of the meadow with those of the surrounding forest along transects that crossed the meadow–forest transition. Soil horizonation can provide information about the time period over which meadow vegetation has been present. In general, A horizons, zones of decayed organic matter, accumulate below grasses and shrubs but not under forests (Birkeland 1984, Singer and Munns 1991, Mierendorf 1993, Buol et al. 1997). In contrast, forest soils generally lack an appreciable A horizon but do have a thick O horizon, composed of forest litter, underlain by a weathered, reddish, often illuvial B horizon, where weathering products, such as iron oxide, accumulate. Although A horizons may develop in less than 100 years under optimal conditions (Brady and Weil 1999), they typically require 200–400 years to develop under the conditions present in our study area (Ellis and Mellor 1995, Buol et al. 1997; L. Lavkulich, *personal communication*). Thus, a distinct A horizon under Chittenden Meadow would indicate that the meadow was of ancient origin (Table 1, hypotheses B and C).

We recorded soil profiles in 35 of the archaeological test pits (16 in the meadow, 12 in the forest, and seven under the encroaching trees), noting in particular the thickness of any O and A horizons, the composition of the C horizon, and the presence of macroscopic charcoal. Using a chi-square test of association, we tested whether the association of A horizons or charcoal with either meadow or forest soils was statistically significant. Elsewhere, remnant eluviated horizons may indicate past forests (Brady and Weil 1999), but we did not survey for these horizons because they are rare in the upper Skagit Valley, even under mature, low-elevation forests (R. Mierendorf, *personal observation*).

Soil charcoal. To date fires that burned the meadow in the past, we radiocarbon-dated (via accelerator mass spectrometry), and identified to species, charcoal from one of the test pits that we dug in the meadow. This pit had well-defined stratigraphy and we took samples from three charcoal layers (2, 14, and 19 cm below the ground surface) in the A and B horizons.

Modern tree encroachment

Reconstructing the timing of encroachment. To determine the timing of modern tree encroachment into the meadow, we determined the species and date of establishment of all trees, and the height of most trees (74%), in three belt transects crossing the meadow and extending a short distance (20 m) into the surrounding forest at each end (Fig. 1). The transects are 132–152 m long and 15 m wide, although small trees (<20 cm diameter) were only sampled in a band 10 m wide. For each tree, we estimated establishment date in one of three ways. For large trees (57% of trees), we removed increment cores near the ground (mean height 18 cm). For trees too small to be cored (<5 in diameter), we either counted branch whorls (34%) or we removed complete disks (9%). For the older trees (>50 yr old, 17% of trees), we assigned calendar years to tree rings using visual crossdating of ring widths (Stokes and Smiley 1968). We dated young trees (<50 yr old) by counting rings on increment cores or disks because they could not be crossdated with confidence.

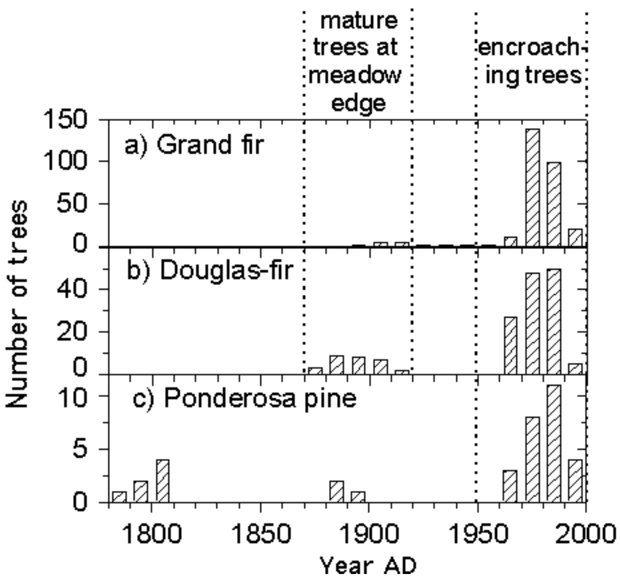
To estimate establishment dates, we applied one, and sometimes two, corrections to the date of the innermost ring sampled on increment cores and disks. First, to account for the number of years required for each tree to reach sampling height, we subtracted one calendar year from the pith date for every 10 cm or 14 cm between ground level and coring height for grand fir and Douglas-fir or ponderosa pine, respectively. These corrections were determined by regressing tree height and age for the small trees cut at ground level and the trees with counted whorls. Second, for cores that did not intersect the pith (45%), we estimated the number of rings to the pith based on the curvature of the innermost rings sampled (mean correction 3 years; Applequist [1958], Duncan [1989]).

Timing of encroachment relative to historical and recent human activity. To determine if historical or recent human activities have affected the factors that maintained the meadow in the past, we determined whether tree encroachment was synchronous with these activities. Specifically, we compared the timing of tree encroachment to the timing of modern fire exclusion in the region, of the flooding of Ross Lake reservoir, and of possible domestic livestock grazing of the homestead in the meadow.

Timing of encroachment relative to climate variation. To determine if climate variation played a role in the encroachment of woody vegetation into the meadow, we determined whether this encroachment was synchronous with changes in spring snow depth, temperature, and precipitation. Spring snow depth was measured in early May (1948–1998, missing 1953 data) at Beaver Creek Trail, North Cascades National Park (22 km south of Chittenden Meadow; *public communication* Natural Resources Conservation Service, ftp://162.79.124.23/data/snow/snotel/snothist/, accessed 1997). This site is approximately the same elevation as the meadow (670 m), and the variation in snow depth measured there is similar to that at nearby sites. Spring precipitation and temperature are for Washington State climate division 5 (1948–1998, with no missing data; *public communication* National Climatic Data Center, http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftppage.html, accessed 2002). If a change in climate were responsible for the encroachment of trees into Chittenden Meadow, we would expect the encroaching trees to have established roughly synchronously over this small area, because

Douglas-fir and grand fir seeds from trees in the surrounding forest are probably dispersed across the entire meadow (Foiles et al. 1990, Herman and Lavender 1990).

Fig. 3. Establishment dates of trees by species in 10-year age classes, sampled in three transects across Chittenden Meadow, and extending a short distance (20 m) into the surrounding forest (see Fig. 1).



RESULTS

Mature ponderosa pine in the meadow: results

We found nine mature ponderosa pine trees in the meadow (Fig. 1), six of which established within a few years of 1800. They currently average 44 m in height and 115 cm dbh (Fig. 3). The remaining mature pines established about 1890 and currently average 31 m in height and 65 cm dbh. There were several fire scars on one of these trees, as well as on several western redcedar (*Thuja plicata*) north of the meadow. However, we could not reconstruct the historical frequency of surface fires in the meadow from so few scars (Fall 1998).

Records of aboriginal use: results

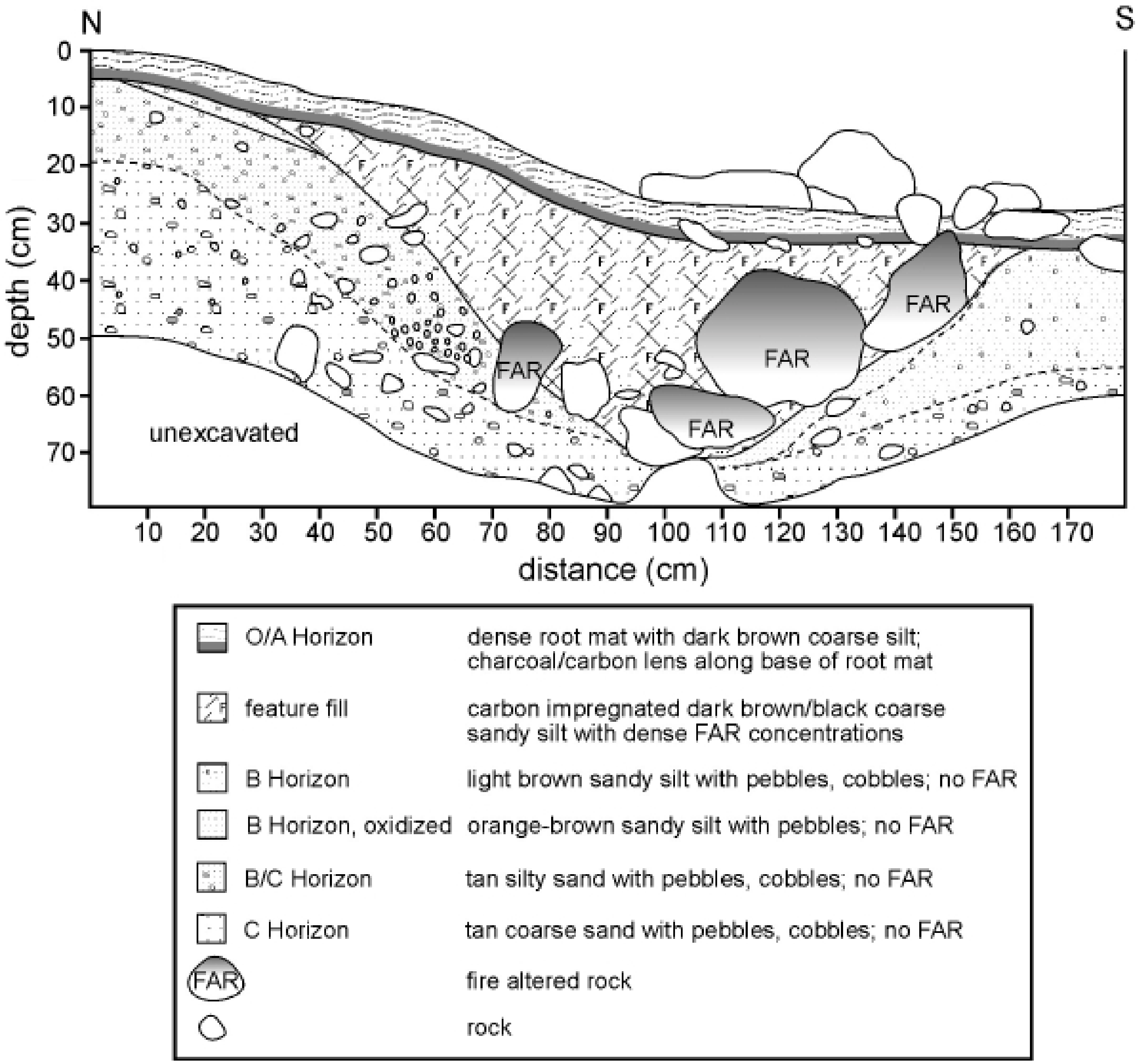
Ethnographic evidence of prescribed fire. We found one reference to aboriginally ignited fire near the meadow. In 1859, Henry Custer, surveying for the U.S. Boundary Commission, followed aboriginal trails in the upper Skagit Valley with the aid of aboriginal guides. He observed a fire about 12 km north of the meadow and noted the general use of prescribed fires by aboriginal people in the area:

> *On this side of the stream [Skagit River] we found the whole forest burned by late fires, ignited by persons lately encamped here. Smoke was still arising in all directions from numerous footlogs and trees ect. [sic]. Fires are very frequent during the sumer [sic] season in these Mountain forests and are often ignited purposely by some of the Indian [sic] hunting in these Mountain regions, to clear the woods from underbrush & make travel easier. Once ignited, they generally burn the whole summer, and only the drenching rains of the fall are able to check their further spread.* (Custer 1866:20).

This reference is consistent with what we know about the use of prescribed fire among the Stó:lô, the Nlaka'pamux, and the Upper Skagit in general (Collins 1974, Turner 1999, Lepofsky et al., *in press*), and suggests that fire may have been used as a land management tool near Chittenden Meadow in the early contact era.

Archaeological evidence of meadow use. Our survey of the meadow surface yielded 31 potentially cultural features, only one of which proved to be distinctly cultural after it was excavated. This feature is a linear trench filled with thermally altered rock and charcoal-rich sediment, adjacent to a linear mound of earth (5.5 x 0.75 m; Figs. 1 and 4; Borden site number DgRg18). The structure of this feature shares attributes with archaeological drying and roasting features from sites near Chittenden Meadow (Franck 2000) and in western Washington (Mack and McClure 2001). Fires were probably lit in these trenches to heat rocks that would dry or roast berries, roots, or meat placed on wooden racks above the trench. This interpretation is supported by the large charcoal fragments and abundant thermally altered rock indicating that this feature sustained low-intensity heat in an oxygen-rich (i.e., open-air) environment. The mixed internal stratigraphy of this feature indicates that it was used repeatedly. The two charcoal samples that we removed were Douglas-fir and ponderosa pine, and dated to 970 ± 40 years before present (BP) and 140 ± 40 BP (uncalibrated; CAMS 61989 and CAMS 63441, respectively). The feature’s current morphology (e.g., distinct edges) is consistent with last use about 140 BP.

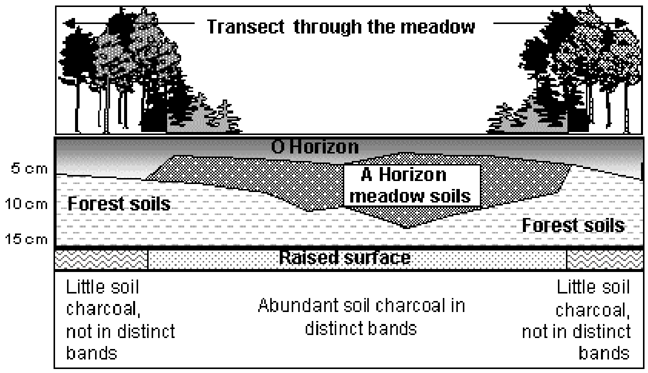
Fig. 4. Cross section of the cultural trench feature, showing its mixed stratigraphy, charcoal, and fire-altered rock (FAR). See Fig. 1 for the location of this feature in the meadow.



The remaining 30 surface features are shallow, roughly circular depressions (0.9–3.2 m diameter, mean 1.7 m; Fig. 1). Our excavation of three of these features revealed that they are not cultural, but are rather the charred remains of ponderosa pine roots and lower boles that were consumed by smoldering fires. They have diffuse boundaries and contain abundant charred and uncharred ponderosa pine bark and wood, but no thermally altered rock. They all have a similar gross morphology and the uncharred wood is in a similar stage of decay, so they appear to be of similar age.

None of the 60 test pits that we dug yielded evidence of subsurface cultural features. However, most of these test pits were in the middle of the meadow, so there may be additional cultural features or burned ponderosa pine remnants elsewhere, such as in the north end where shrubs obscured the meadow surface.

Fig. 5. Schematic cross section of the meadow and surrounding forest, summarizing the soil and ecological surveys. The meadow soils had shallow O horizons but contained A horizons, whereas the forest soils had relatively thick O horizons but lacked A horizons.

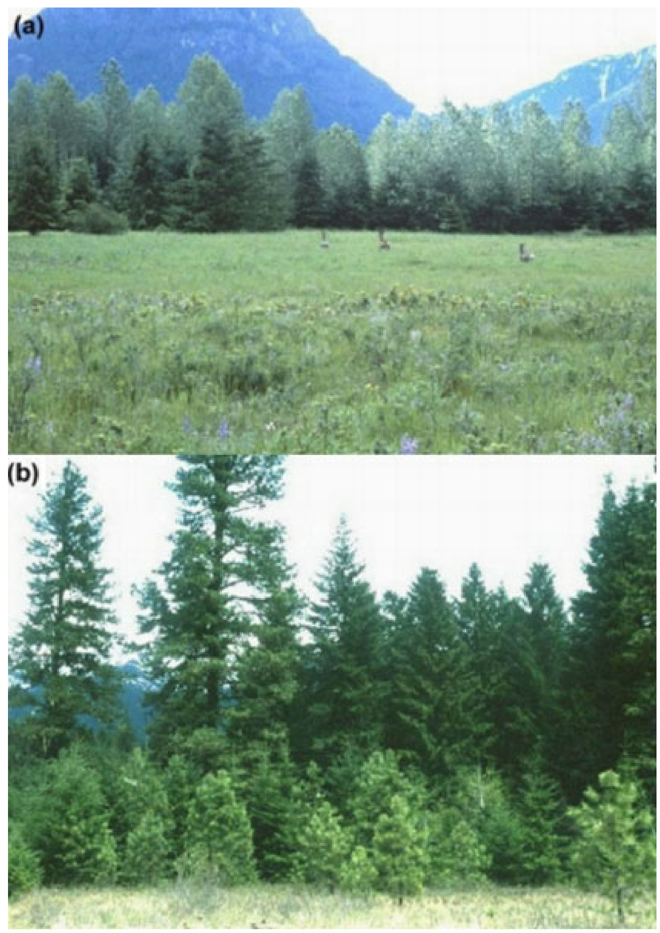


Soils: results

Profiles of meadow vs. forest soils. Based on differences in soil profiles between the forest and the meadow, the boundary visible in the 1946 aerial photo (Fig. 2) has been stable for a relatively long time, at least several hundred years. During this time, the area currently occupied by the meadow probably had a fire regime distinct from that of the surrounding forest. Neither the A horizons nor the macroscopic charcoal were randomly distributed among the test pits that we examined, but rather were significantly associated with pits in the meadow (Pearson chi-square; $P<0.001$ for A horizons, $P<0.05$ for charcoal; Fig. 5). Specifically, all 16 meadow profiles had A horizons (4–12 cm thick) and relatively shallow O horizons. In contrast, only two of the 12 forest profiles had A horizons (both 10 cm thick), but all had well-developed O horizons. In addition, most of the meadow profiles (10), but only a few of the forest profiles (2), contained macroscopic charcoal. The seven profiles underlying the encroaching trees were similar to those in the meadow, with well-developed A horizons (6–13 cm thick) but relatively shallow O horizons, and four of these profiles had abundant charcoal.

Our examination of soil profiles in test pits, as well as our archaeological survey, revealed that the meadow surface is raised slightly above the surrounding modern floodplain. The C horizon under both the meadow and the surrounding forest is glacio-fluvial outwash and till. This indicates that the raised surface of the meadow is probably one bar in the system of extinct bar-and-channel formations that surround the meadow and date from the early Holocene. As a consequence, the meadow soils were probably better drained than the soils of the surrounding forest, which is at slightly lower elevation.

Fig. 6. Chittenden Meadow, showing the vegetation and its context. (a) The dense shrubs of the meadow (Nootka rose (*Rosa nutkana*), common snowberry (*Symphoricarpos albus*), and tall Oregon-grape (*Mahonia aquifolium*) and whitetailed deer in the foreground; the meadow–forest edge in the middle ground; and surrounding mountains in the background. (b) The encroaching woody vegetation at the meadow–forest boundary. The small trees visible in the foreground are Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and ponderosa pine (*Pinus ponderosa*). The purple flower is silky lupine (*Lupinus sericeus*).

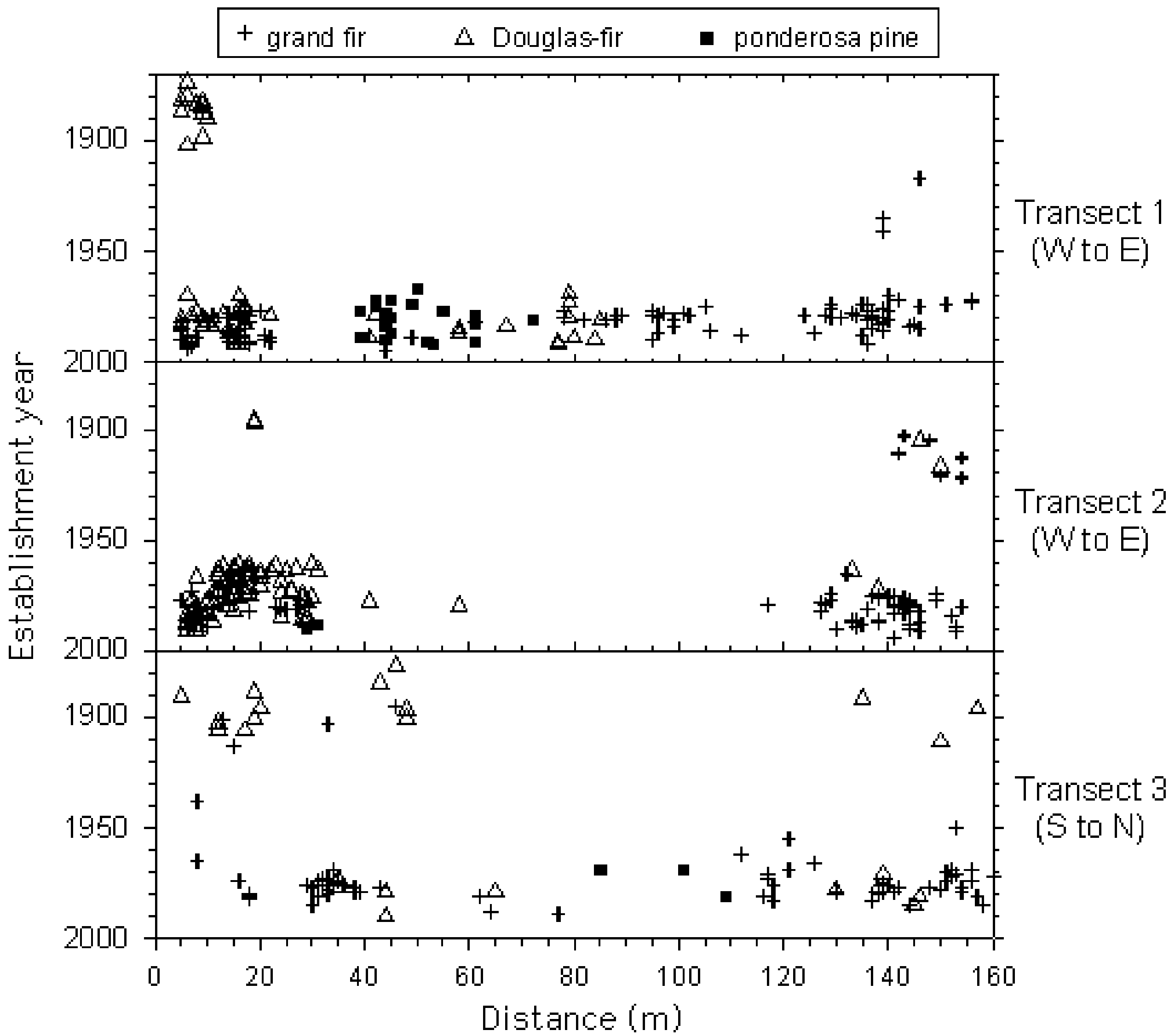


Soil charcoal. All three of the charcoal samples that we dated from the archaeological test pit were ponderosa pine and of recent radiocarbon age (110 ± 40 BP, 70 ± 40 BP, and modern, CAMS 61986, 61987, 61988, respectively).

Modern tree encroachment: results

Reconstructing the timing of encroachment. Most of the encroaching trees are grand fir (60% of 477 sampled trees) or Douglas-fir (33%) with the remainder being ponderosa pine (6%), western redcedar (<1%), or western hemlock, *Tsuga heterophylla* (<1%; Fig. 6). Grand fir is more common on the mesic western edge of the meadow, whereas Douglas-fir and ponderosa pine are more common on the drier northern and eastern edges (Fig. 7). The age of the encroaching trees does not decrease with distance from the meadow–forest boundary, but rather, these young trees all established about the same time (Fig. 3, Table 2). The mean date of establishment across the three dominant species is 1980 (1 SD = 7.3 years), and most trees established after 1970 (81%; Fig. 3, Table 2).

Fig. 7. Age structure of encroaching trees along transects in the meadow, showing that the age of encroaching trees does not decrease with distance from the meadow–forest edge. The *y*-axis is inverted. See Fig. 1 for the location of the sampling transects in the meadow.



The mature forest surrounding the meadow is relatively even-aged and dominated by Douglas-fir and grand fir, but western redcedar and western hemlock also occur. Most trees established between about AD 1880 and 1910 (Fig. 3). In combination with the stability of the meadow–forest boundary that we have already inferred, this modern even-aged forest suggests that, in the late 1800s, a severe disturbance killed the forest that surrounded the meadow at that time, after which the modern forest established.

Table 2. Encroachment of the three major tree species in Chittenden Meadow since the 1946 aerial photo.

Species	No. trees	Calendar year			Standard deviation (yr)
		Minimum	Maximum	Mean	
Grand fir	287	1950	1995	1980	6.5
Ponderosa pine	26	1967	1992	1981	8.0
Douglas-fir	132	1961	1992	1978	8.4
Total	445	1950	1995	1980	7.3

Timing of encroachment relative to historical and recent human activity. The abrupt initiation of tree encroachment into the meadow in the 1970s was not synchronous with any of the historical or recent human activities that we hypothesized may have affected establishment in the meadow. These activities are: the abandonment of aboriginal burning between the late 19th century and the early 20th century, early 20th century abandonment of the homestead and cessation of grazing, and the mid-20th century suppression of fire and flooding of Ross Lake reservoir.

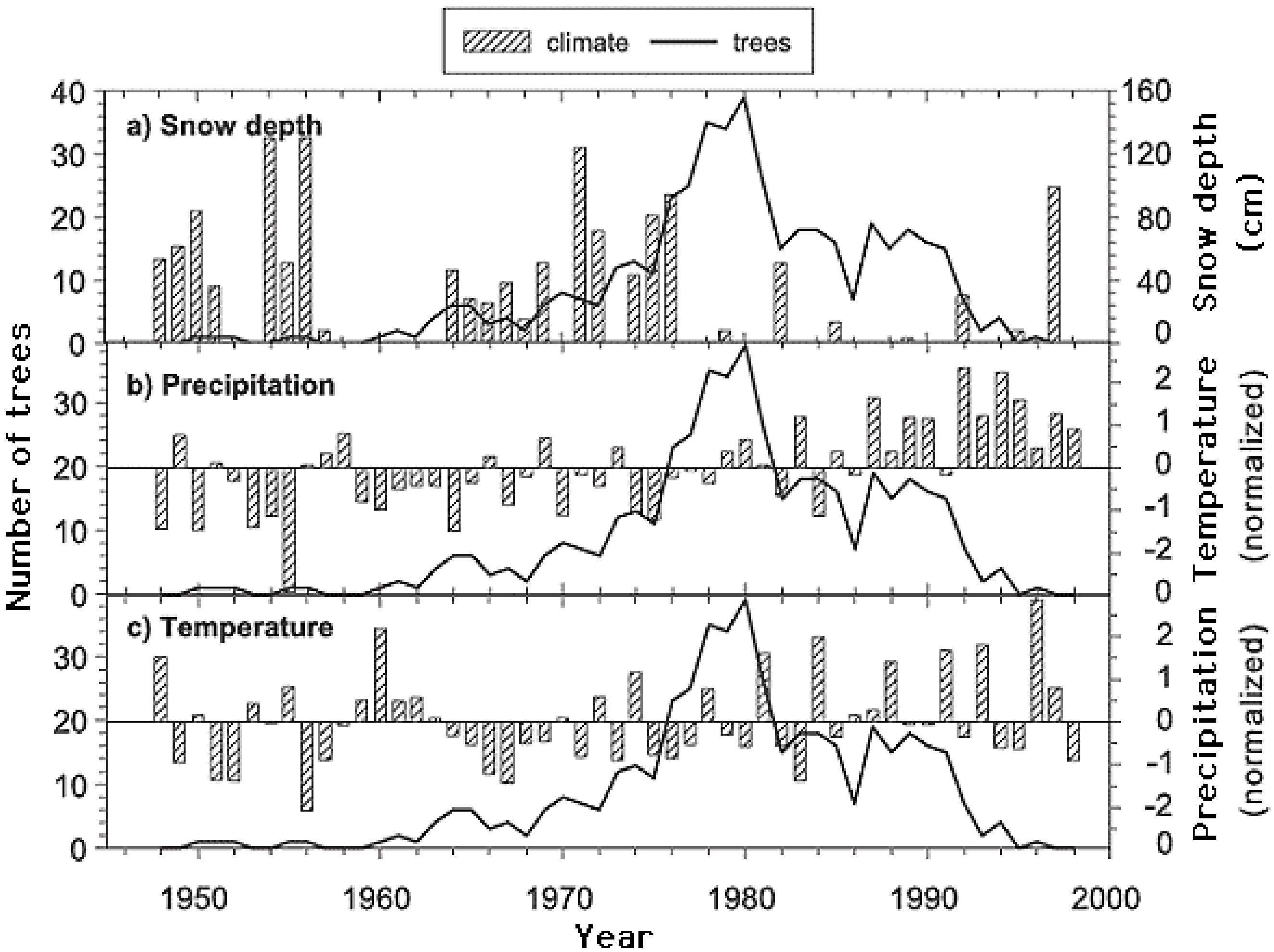
Fire. Any major changes in fire regimes in the upper Skagit Valley, including both cessation of aboriginal burning and mid-20th century fire suppression, predated the encroachment of trees into the meadow. First, aboriginal burning in southwestern British Columbia was restricted by European colonists with passage of the Bush Fire Act in 1874, although this act was not widely enforced until the early 1900s (MacDonald 1929; J. Parminter, *personal communication*). Consistent with this, fires generally became smaller and somewhat less frequent after the late 1800s in similar forests 10 km south of Chittenden Meadow (Agee et al. 1990), and we assume that the area surrounding the meadow probably experienced a similar change in fire at about this time. However, this inferred decrease in fire occurrence was unlikely to have resulted in the encroachment of trees into Chittenden Meadow, because it predates that encroachment by many decades. Second, modern fire suppression became effective in the upper Skagit Valley in the 1940s or 1950s (J. Parminter, *personal communication*). Only a few small fires burned in the Skagit Valley between 1940 and 1970, and there is no record of modern fires occurring within the meadow since it was protected by British Columbia Parks in 1973 (J. Parminter, *personal communication*; British Columbia Forest Service 1995*b*). Thus, modern fire suppression also predates encroachment of the meadow by several decades and, consequently, probably did not result in the encroachment of trees.

Flooding. Ross Lake reservoir reached its maximum extent in 1952, preceding significant tree encroachment by several decades. Furthermore, although there is a distinct band of wetland vegetation adjacent to the northern margin of Ross Lake, this vegetation is separated from Chittenden Meadow by several hundred meters of forest.

Grazing. Encroachment of the meadow does not appear to be the result of a cessation of grazing because trees did not begin encroaching for at least 60 years after the Cawley homestead was abandoned.

Timing of encroachment relative to climate variation. In the mid-1970s, early May snow depth decreased markedly, probably in response to an increase in April/May temperature, synchronous with the major pulse of tree establishment (Fig. 8a, b). May snow depth during 1948–1977 was relatively deep (average: 41 cm/yr) and few trees established (average: 5 trees/yr). In contrast, after this time (1977–1998), snow depth was significantly less deep (average: 10 cm/yr) and many more trees established (average 15 trees/yr; *t* test with unequal variances, P = 0.009, df = 30.7).

Fig. 8. Spring climate (bars) and the number of trees establishing in the meadow (line). Spring climate is (a) early May snow depth (not recorded in 1953); (b) normalized precipitation (April and May); and (c) temperature in Washington climate division 5.



DISCUSSION

Status of the a priori hypotheses

Our evidence allows a clear rejection of the hypothesis that the meadow is of recent, human origin (Table 1, Hypothesis A). The meadow is a slightly raised landform with soil horizonation distinct from that of the surrounding forest. These differences, and evidence of a previous generation of ponderosa pine trees, indicate that the meadow has been distinct from the surrounding forest for at least hundreds of years and, consequently, predates recent human activities. Furthermore, the encroachment of trees into the meadow was not synchronous with the cessation of grazing, the flooding of Ross Lake, or mid-20th century fire exclusion. Instead, like other low-elevation meadows in the Pacific Northwest (Hadley 1999, Leopold and Boyd 1999), Chittenden Meadow has existed for a long time.

Although we can confidently reject hypothesis A, distinguishing between hypotheses B and C (Table 1) is more complex. The meadow appears to be a distinct landform and, at least in part, the distinct vegetation occupying it probably has an ancient, geomorphic origin unrelated to human activities. Thus the meadow's *origins* are most consistent with hypothesis C. Our data, however, are less clear regarding the processes *maintaining* the meadow. There is abundant evidence that fires burned the meadow in the past (soil charcoal, burned pine root systems, a few fire scars in the meadow, and even-aged cohorts of trees in the surrounding forest) and that the fire regime and vegetation of the meadow were different from those of the surrounding forest (with abundant charcoal in meadow soil, but not in forest soil). However, we lack a detailed proxy record of fire frequency from which we could quantify differences in fire frequency between the meadow and forest, or changes in fire frequency through time. Ethnographic reports indicate that aboriginal people used prescribed fire in the upper Skagit Valley, and the trench feature that we found in the meadow suggests that they used the meadow itself. However, there is no direct evidence that fire was used as a land management tool in Chittenden Meadow. In light of these results, we combined hypotheses B and C into an a posteriori hypothesis that explains the origins and maintenance of the meadow as a consequence of landform, climate, and fire.

Empirical, a posteriori hypothesis of the history of Chittenden Meadow

We propose three periods in the history of the meadow that could account for the plant community that we see today:

Period 1. Ponderosa pine parkland. The meadow appears to have been an open ponderosa pine parkland from an undetermined time in the past until the late 19th century, based on burned remnants of ponderosa pine trees, abundant charcoal in the meadow soils, the age of trees surrounding the meadow, and radiocarbon dates of soil charcoal. The number and distribution of burned remnants indicate that ponderosa pine trees were denser in this parkland than they are in the meadow today (30 remnants vs. nine live pines), but open enough to maintain meadow soils. It is likely that this parkland was maintained by fire, because fire is a keystone process in most ponderosa pine systems (Agee 1998). Ethnographic reports suggest that aboriginal people may have ignited some of these fires, and we hypothesize that this was the case during period 1, although we have no direct evidence for this in Chittenden Meadow. Young trees probably established in the parkland during climatically favorable periods, but Douglas-fir and grand fir seedlings have thin bark and are easily killed by fire when young (Howard and Aleksoff 2000). Thus we infer that fire was frequent enough to prevent the long-term survival of species other than ponderosa pine. We expect that high- or mixed-severity fires burning in the surrounding forest could not burn as crown fires in the widely spaced pine of the meadow, but rather burned only the surface of the meadow. Furthermore, the raised surface of the meadow relative to the surrounding floodplain forest would have protected the plant community there from repeated flooding by the Skagit River.

Period 2. Transition to meadow. At some point, most of the mature ponderosa pine in the meadow died (30 burned remnants vs. nine mature pines alive today), converting this area from an open parkland of large ponderosa pine to a meadow with relatively few scattered pines. Based on radiocarbon dates of soil charcoal and the establishment dates of some of the mature ponderosa pine (Fig. 3), a fire appears to have burned the meadow about 120 years ago and may have killed many of the mature pine alive at that time. In addition, most of the trees that we dated from the surrounding forest established at about this time, indicating a severe disturbance there as well. However, we did not date sufficient charcoal from the burned ponderosa pine remnants to determine whether they were killed by this fire or a prior disturbance. These trees may have been felled and the area burned to create the Cawley homestead, which was established about this time. The meadow appears to have remained open and largely free of successful tree establishment until the shift in climate in the 1970s. This is the open meadow that was recognized as significant by Curly Chittenden in the mid-20th century and was protected by British Columbia Parks.

Period 3. Meadow with encroaching trees. The encroachment that we see in the meadow today is probably due to a combination of variation in climate and lack of fire. In the mid 1970s, changes in spring climate (higher temperature and lower snowpack) were coincident with similar changes in climate across North America and with the pulse of tree establishment in the meadow. Before this time, conifer seedlings probably germinated in the meadow but were unable to survive the region's hot, dry summers, or did not survive the periodic fires that burned in the meadow.

What are the general lessons from this study?

Diverse antecedents exist for a single modern condition. Whether or not our a posteriori hypothesis is correct, the ecological history of the meadow clearly is not explained by any single factor. Yet simple, single-factor explanations (e.g., cessation of aboriginal burning or fire suppression) are sometimes considered by management agencies as a basis for restoring ecosystems to a pre-European state. We expect that, in many such cases, management actions such as prescribed fire are indeed appropriate, but we caution against applying them without careful consideration of other ecological and cultural factors that historically maintained specific sites. Furthermore, not all factors act at the same scale: our meadow was affected by both landform processes acting at the scale of tens of hectares and probably also by climate variation driven by processes acting at the hemispheric scale.

Ecosystems may not carry a "memory" of all that we wish to know. The historical drivers of an ecosystem are often critical input to management decisions. Unfortunately, not all ecosystems retain sufficient evidence of their dynamics to allow us to distinguish among potential drivers. Some events may not be recorded and more recent events may edit the record of the past. In this study, we were particularly frustrated with our inability to tease out the role of aboriginal people in the history of fire during Period 1. A fire scar record of past fire frequency may have been lost when the mature ponderosa pine trees in the meadow were killed in the late 19th century. Such a record might have given us insights into the role of aboriginal burning in maintaining the meadow. As well, some historical processes may not leave evidence for us to find: prescribed fires that are so frequent that woody vegetation does not have time to develop may not leave charcoal for radiocarbon dating. Similarly, the use of a meadow for hunting or plant gathering may not leave an archaeological record if the processing was done elsewhere.

Uncertain role of aboriginal resource management activities. The degree to which aboriginal people affected historical ecosystem dynamics has been the subject of much polarized debate. Some authors see them as significant "agents of environmental change," whereas others focus on the "light footprint" of their activities (Denevan 1992, Vale 1998, Vale 2002). Our study illustrates the challenge of finding evidence that clearly identifies the actual intensity of human management of a specific ecosystem. For Chittenden Meadow, we are tempted to come down on the side of the "light footprint," because there is substantial archaeological and ethnographic evidence of sustained and intensive use of the area around the meadow over thousands of years. However, if humans managed Chittenden Meadow intensively, they left little direct evidence of the environmental impact of their activities.

There is value and challenge in integrating data and perspectives from different disciplines. As in other multidisciplinary projects in which we have participated (e.g., Lepofsky et al., *in press*, Lertzman et al. 1996, Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995), we reached different conclusions collectively than we would have individually. Although a focus on soil processes and geomorphology was common to the ecologists and archaeologists in our group, other elements of the study were not. The ecologists in our group did not recognize the trench feature or the depressions that were later identified as burned ponderosa pine remnants. Likewise, the archaeologists did not consider the role of recent climate variation in driving tree encroachment. Furthermore, the value of this study goes beyond revealing the specific historical dynamics of Chittenden Meadow that we report in this paper, because contact with researchers in different fields has changed the way each of us perceives ecosystem dynamics.

Beyond the problems of non-overlapping technical language, the central challenge that we encountered in combining perspectives from different disciplines was in reconciling differences in the nature of evidence and the standards of proof and belief. This was especially true where we combined qualitative historical data with quantitative physical data. Within both environmental archaeology and historical ecology there are strong traditions of multidisciplinary perspectives (e.g., Butzer 1982, Reitz et al. 1996), yet in our experience, the quantitative/qualitative divide remains challenging.

Provide a clear recommendation for managers. It is our responsibility to provide clear management recommendations, despite our uncertainties about historical processes. The managers of Chittenden Meadow are responsible for an ecosystem that is departing from the condition for which it was protected. How should it be managed? Our best historical reference condition for the meadow is the open ponderosa pine parkland of the pre-1880 period.

We recommend developing a management plan that returns the meadow community to that condition by reducing the encroachment of young Douglas-fir and grand fir and encouraging the establishment of scattered ponderosa pine. Mechanical treatment could eliminate the encroaching trees and would be the best option if prescribed fire is not feasible, or if managers are very risk averse regarding the use of prescribed fire. However, simply removing the encroaching trees would not reduce the dense shrubs that currently inhibit ponderosa pine establishment. Thus we recommend that the meadow be burned to reduce the density of young Douglas-fir, grand fir, and shrubs, and to encourage the establishment of scattered ponderosa pine. Furthermore, we recommend that tree and shrub mortality and establishment be monitored to determine the success of burning in returning the meadow to its desired condition.

Responses to this article can be read online at:
http://www.consecol.org/vol7/iss3/art5/responses/index.html

Acknowledgments:

We thank Chris Tunnoch, of British Columbia Parks, for her assistance with the bureaucratic end of the project. Stu Apted (B.C. Parks) and Kelly Bush helped to compile the background information on the history of Chittenden Meadow. Larry Commodore, Chris Ferris, Doug Hopwood, Riley Lewis, and the Simon Fraser University 1999 Archaeology Field School students assisted with fieldwork. We thank Bruce Freet and others at the USDA National Park Service for logistical support. Tina van Gaalen, Laura Fowler, and Leeanna Rhodes helped with graphics. We thank Les Lavkulich (University of British Columbia) and Ray Weil (University of Maryland) for help interpreting soil development. We thank John Parminter (B.C. Ministry of Forests) for the record of modern fire in the meadow. Field and laboratory research for this project were funded by the Skagit Endowment Environmental Commission (SEEC, Project CA99-09). Global Forest provided financial support for the publication of the paper (Contribution No. GF-18-2000-101). We thank J. Agee, D. Hopwood, J. Parminter, S. Sutherland, and one anonymous reviewer for comments on the manuscript. We dedicate this paper to Curley Chittenden, who protected Chittenden Meadow for all of us to enjoy.

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