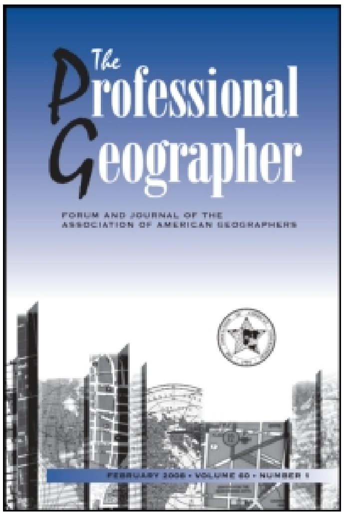

The Professional Geographer
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t788352615

Change in Extent of Meadows and Shrub Fields in the Central Western Cascade Range, Oregon

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First Published on: 05 August 2008

Change in Extent of Meadows and Shrub Fields in the Central Western Cascade Range, Oregon*

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We examined change in areal extent of mountain meadows and fields of deciduous shrubs and conifer saplings in the central western Cascade Range of Oregon, based on analysis of aerial photographs taken in 1946 and 2000. These nonforest vegetation patches are distinctive habitats in dominantly forested landscapes, such as the Cascades, and change in extent of these habitats is of interest to scientists and land managers. We mapped and dated even-aged forest stands of probable postfire origin around the nonforest patches, using tree-ring analysis and interpretation of aerial photographs. We used these and archival data to interpret possible influences of past wildfire and sheep grazing on the extent of nonforest patches. The total area of nonforest vegetation patches decreased from 5.5 percent of the study area in 1946 to 2.5 percent in 2000. Significantly more cases of contracted patches were observed for mesic and xeric meadows which have adjacent forest established after wildfire in the approximately 150 years preceding 1946. A higher proportion of mesic (47 percent, $n = 47$) than xeric (17 percent, $n = 115$) meadows contracted between 1946 and 2000. Broad-leaved shrub fields were unchanged, probably because of topo-edaphic controls, dense cover of shrubs, and snow effects; but all fields of conifer saplings underwent succession to forest. We observed no strong influences of sheep grazing on the extent of meadows. **Key Words: Cascade Range, forest fire, landscape scale, meadow contraction, sheep grazing.**

我们分析 1946 年和 2000 年空中拍摄的照片，来研究俄勒岗州卡斯卡德草原中央西部的地面变化程度，其中包括山区草地，落叶灌木和针叶树苗木等。这些非森林植被斑块是森林为主的景观的鲜明的栖息地，如卡斯卡德。这些栖息地所产生的变化吸引科学家和土地管理者前来研究。我们用树木年轮分析和空中拍摄的照片，将非森林补丁周围的林火后期相等年龄的树林注明日期，并呈现在地图上。我们利用这些和档案数据来解释过去野火和绵羊放牧对非森林补丁所可能产生的影响。非森林植被斑块总面积，从 1946 年的 5.5%下降至 2000 年的 2.5%。在 1946 年以前的大约 150 年，在野火后有毗邻森林生成的中湿和干生草地有更多的植被斑块缩小的情况。中湿草地（47%，每组 47 个），比干生（17%，每组 115）草地在 1946 年至 2000 年间的缩小程度较高。阔叶灌木领域则维持不变，可能是因为土壤控制，包括密集的灌木和积雪的影响，但各个领域的针叶树苗木经历了到森林的演替。我们观察到羊放牧对草场没有强烈的影响。>**关键词：卡斯卡德草原，森林大火，景观尺度，草甸收缩，绵羊放牧。**

Examinamos el cambio en la extensión del área de praderas de montaña y campos de matorrales deciduos asi como de árboles jóvenes de coníferas en la región medio occidental de la Cordillera de las Cascadas en Oregón, basándonos en el análisis de fotografías aéreas que se tomaron entre 1946 y 2000. Estas áreas de vegetación no forestal son hábitats diferentes en paisajes dominantemente forestales, como las Cascadas, y el cambio en la extensión de estos hábitats es de interés para los científicos y administradores de tierras. Mapeamos y fechamos rodales de edad uniforme que probablemente se originaron después de un incendio alrededor de zonas no forestales, usando el análisis de los anillos de crecimiento y la interpretación de fotografías aéreas.

*This research was supported by USDA Forest Service, Pacific Northwest Research Station; Oregon State University; the Long-Term Ecological Research program at the H. J. Andrews Experimental Forest supported in part by the National Science Foundation; and Senshu University, Japan. We thank J. Jones for help with statistical analysis and ecological considerations, and C. Halpern, J. Jones, J. Rice, and P. Weisberg for helpful comments on earlier drafts.

The Professional Geographer, 60(4) 2008, pages 1–14
Initial submission, April 2007; revised submission, December 2007; final acceptance, February 2008.
Published by Taylor & Francis Group, LLC.

Usamos estos datos y material de archivo para interpretar las posibles influencias de incendios forestales pasados y el pastoreo ovino en la extensión de las zonas no forestales. El área total de las zonas de vegetación no forestal disminuyó en la zona de estudio del 5.5 por ciento en 1946 al 2.5 por ciento en 2000. Se observaron significativamente más casos de zonas reducidas en las praderas mésicas y xéricas con bosques adyacentes establecidos después de un incendio forestal aproximadamente 150 años antes de 1946. Una mayor proporción de praderas mésicas (47 por ciento, $n = 47$) que xéricas (17 por ciento, $n = 115$) disminuyeron en área entre 1946 y 2000. Los campos de arbustos de hoja ancha permanecieron inalterados, probablemente debido a controles topo-edáficos, la densa cubierta de los arbustos y los efectos de la nieve; pero todos los árboles jóvenes de coníferas experimentaron una sucesión a bosques. No observamos influencias fuertes del pastoreo ovino en la extensión de las praderas. **Palabras clave: Cordillera de las Cascadas, incendio forestal, escala del paisaje, contracción de praderas, pastoreo ovino.**

Extensively forested landscapes, such as the Cascade Range of the Pacific Northwest in the United States, contain nonforest vegetation patches of varied origins, persistence, and vegetation structure and composition. These nonforest patches are small and dynamic components of the Cascade landscape, but they contribute substantially to biological diversity, such as the herb flora and associated species-rich butterfly communities (Miller, Hammond, and Ross 2003). The temporal and spatial patterns of nonforest patches have received much less study than forested systems in this region.

The nonforest patches include fields of conifer saplings, broad-leaved shrub fields, and mesic and xeric herb-dominated meadows (Hickman 1976; Halpern, Smith, and Franklin 1984; Franklin and Halpern 1999). Some of these patches are created and temporarily maintained solely by forest disturbance, such as fire and domesticated animal grazing; they are ephemeral and gradually return to forest. Others are maintained in a nonforest state for long periods of time by topo-edaphic conditions. The dynamics of still other nonforest patches reflect the interaction of these factors. Thus, disturbance processes may affect the presence and persistence of many types of nonforest patches (Hadley 1999).

Several studies have reported that extensive tree invasion into meadows took place during the twentieth century at many locations (Brubaker 1986; Franklin and Dyrness 1988; Taylor 1990; Rochefort et al. 1994; Miller and Halpern 1998; Hadley 1999; Haugo and Halpern 2007), and have examined effects of disturbances, such as wildfire and grazing (Franklin et al. 1971; Dunwiddie 1977; Vale 1981; Agee and Smith 1984; Taylor 1990; Miller and Halpern 1998) and volcanic eruptions (Taylor 1990), on dynamics of meadows in the Pacific Northwest. Most of these studies interpreted temporal relationships between tree regeneration and site disturbance histories based on the age structure of trees invading meadows. Climate variability, wildfire, grazing, and other factors have been considered as possible influences on the extent of meadows, but these factors commonly affect meadows simultaneously and, therefore, are difficult to distinguish. In addition, nonforest patches may have distinctive histories and sets of environmental conditions. To obtain better understanding of spatial and temporal dynamics of nonforest patches, it is useful to examine a large population of them representing different characteristics, as Miller and Halpern (1998) have done for meadows.

The objective of our study is to better understand patterns in time and space and possible causes of change in extent of nonforest openings at the landscape scale. To quantify the pattern and possible causes of landscape change, we examined effects of disturbance, especially wildfire and sheep grazing, on the dynamics of more than 500 meadows and shrub and sapling fields distributed over a 356 km^2 area in the central western Cascade Range of Oregon. We focused on spatial patterns of vegetation change between 1946 and 2000 for four types of nonforest patches, using interpretation of aerial photographs. This work can provide a broad framework for subsequent, more detailed analysis using historical reconstruction, dendrochronological analysis, and other techniques to learn more about specific timing, rates, and causes of change.

Several different patterns of change in extent of nonforest patches can occur. Contraction of patches may proceed inward from the margin. Tree invasion may be scattered throughout a nonforest area, leading to development of forest patches that may fragment the nonforest parts of the area. Forest establishment may occur simultaneously over the entire area, causing it to convert to forest uniformly. For simplicity, we use the single term *contraction* to refer to reduction in the size of individual nonforest patches. Expansion of nonforest patches may occur by mortality of adjacent forest, which may permit two or more nonforest patches to merge.

Study Area

Our study area includes portions of the Blue River watershed and some adjacent areas of the central western Cascades in the McKenzie River drainage, east of Eugene, Oregon (Figure 1). Elevation of the study area ranges from 420 to 1,620 m. The maritime climate is characterized by warm, dry summers and mild, wet winters. Average daily air temperature is 17.8°C in July and 0.6°C in January at a meteorological station (426 m elevation) in the H. J. Andrews Experimental Forest, located in the study area (Bierlmaier and McKee 1989). Mean annual precipitation is 2,300 mm at that low-elevation station; approximately 70 percent falls from November through March. A seasonal snowpack generally develops above 1,000 m elevation and persists longer on north-facing than south-facing slopes.

Forest vegetation in the study area is classified into two major zones (Franklin and Dyrness 1988). The western hemlock zone covers the lower slopes of this mountainous area below approximately 1,000 m, and the Pacific silver fir zone occurs above that elevation. The nonforest vegetation patches occurring in both zones include meadows, shrub and sapling fields, and rock outcroppings. These patches are scattered throughout the landscape, but are commonly interspersed among higher elevation forests where environmental conditions are more stressful for trees and rock outcrops are more common (Franklin and Halpern 1999).

Various aspects of the geology, topography, and soils of the study area influence the distribution of nonforest patches. Bedrock at lower elevations is composed of Oligocene–lower Miocene volcanic rocks of various origins, whereas that at higher elevations is composed mainly of Miocene and younger lava flows (Swanson and James 1975). A steep, deeply dissected landscape has been created by fluvial, glacial, and mass movement processes over the last four million years. Cirques have been formed on north- and northeast-facing slopes below ridgelines that exceed 1,400 m

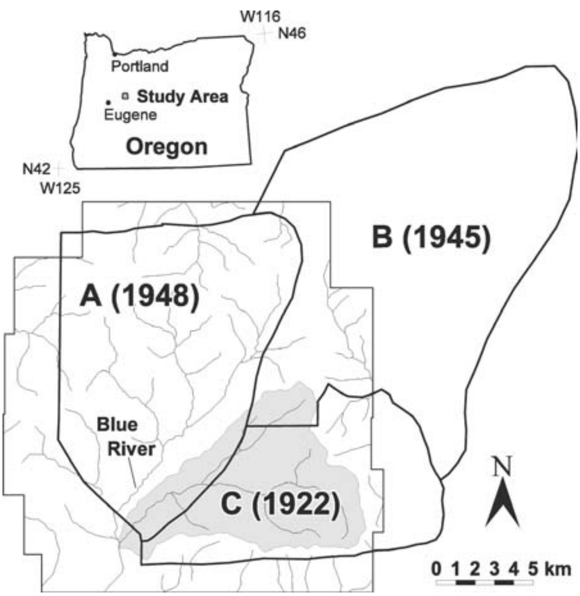

Figure 1 *Study area. Shaded area is the H. J. Andrews Experimental Forest. Areas A, B, and C indicate historic grazing allotments with dates of cessation of grazing (Burke 1979).*

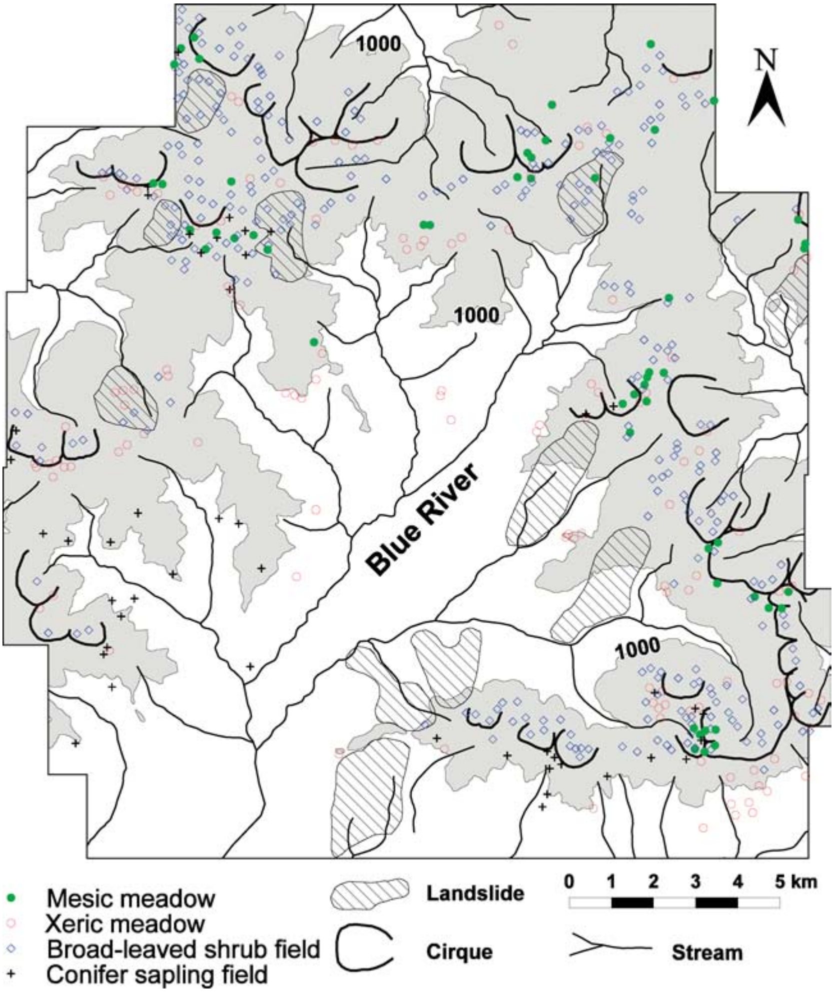

Figure 2 *Distribution of nonforest patches in 1946. Area above the 1,000 m elevation contour is shaded. Landforms creatd by large, slow-moving landslides are from Swanson and James (1975) and Walker and MacLeod (1991).*

(Figure 2). Large landslides have created cliffs forming head scarps, boulder fields, and poorly drained depressions without forest cover on the landslide deposit surface (Figure 2; Swanson and James 1975; Walker and MacLeod 1991). Soils derived from the diverse types of volcanic bedrock commonly have loamy surface horizons. In general, soils are thinner and more immature at higher elevations, where air temperatures are lower and parent material is young.

Reconstructions of fire history, based on tree-ring analysis of tree establishment dates and fire scars, reveal that wildfire has been a major disturbance agent in this study area and the region over the past millennium (Teensma 1987; Morrison and Swanson 1990; Agee 1993; Weisberg 1998; Cissel, Swanson, and Weisberg 1999; Hadley 1999; Giglia 2004). The mean fire return interval for sample sites in the Blue River area was 151 years and ranged from 9 to 394 years across the diverse topographic settings (Cissel, Swanson, and Weisberg 1999). Periods of extensive fire occurred in the 1500s and 1800s, perhaps due to favorable climatic conditions (Weisberg and Swanson 2003). Native people may have influenced fire occurrence before 1850, but their effect on the fire regime of this area is poorly known (Burke 1979; Boyd 1999; Whitlock and Knox 2002). Since about 1850, various land uses by European settlers and travelers in the study area and along adjacent, major drainages probably increased fire ignitions (Burke 1979; Hadley 1999). Fire suppression has been a significant factor since the early 1900s and has probably been most effective in the latter half of the 1900s, when a forest road system and modern technology for fire detection and fighting were developed (Weisberg and Swanson 2003). Only a few forest stands larger than 0.1 ha burned between 1946 and 1977 (Burke 1979), and no fires of this size or larger have occurred in the study area since 1978.

Sheep were brought into the Cascade Range of Oregon for summer pasturage in late 1800s (Coville 1898; Burke 1979). Mountain meadow vegetation, including bunchgrass communities dominated by *Festuca viridula*, provided excellent forage for summer sheep grazing. Grazing activity in the central western Cascades continued well into the early 1900s. Grazing allotments were established in 1905 to protect the range from overuse. Closure of allotments in the study area occurred between 1922 and 1948 (Figure 1), and sheep grazing largely ceased by 1949 (Burke 1979).

Logging, mainly by clearcutting with broadcast burning (prescribed fire over most of the cut area), was an important disturbance process in the study area mainly between 1950 and 1990, resulting in about 25 percent of the area being converted from natural forest to young conifer plantations stocked with planted seedlings.

Methods

Mapping Nonforest Patches

Nonforest patches larger than 0.2 ha were mapped and classified into four cover types based on interpretation of aerial photographs taken in 1946 (black and white, 1:20,000) and field observations in 2003 (Figure 2). We mapped nonforest areas that had tree-canopy cover less than 30 percent, and we observed isolated trees in some nonforest patches on both 1946 and 2000 photographs but could not detect tree seedlings and small saplings that were established shortly before the date of a photograph. Almost all nonforest patches, especially broad-leaved shrub patches, displayed distinct boundaries, but interpretation was subjective in the few cases exhibiting complex patterns of forests and mesic and xeric meadows. Boundaries of the nonforest patches were delineated by stereoscopic analysis of aerial photographs and then digitized on ortho-photographs produced by USDA Forest Service from black-and-white, 1:40,000 aerial photographs taken in 2000.

The four mapped cover types—mesic and xeric meadows, broad-leaved shrub fields, and conifer sapling fields (Figure 3)—could be distinguished on aerial photographs. Meadows were classified into mesic and xeric types by tone on the aerial photographs: Dark tone was interpreted as mesic and light tone as xeric. Field observations indicated that vegetation in mesic meadows is characterized by herbs and ferns on slopes having deep, loose soils. Xeric meadows consist of sparse grasslands with some inclusions of dwarf shrubs on shallow, stony soils; exposed bedrock with little grass; and boulder fields with scattered shrubs. Vegetation types within the xeric type could not be distinguished from one another with aerial photograph interpretation. Broad-leaved shrub fields identified in the aerial photographs were dominated by Sitka alder (*Alnus crispa* ssp. *sinuata*) and vine maple (*Acer circinatum*). Conifer sapling fields were covered mainly with small Douglas fir and noble fir trees, which we estimate to be generally less than about 5 m tall, based on field observations, comparison with the height of broad-leaved shrub fields, and observation of canopy texture in aerial photographs.

By comparing photographs taken in 1946 and 2000, changes in spatial extent during this period were examined for each nonforest patch except those that were adjacent to logged stands. Contraction and expansion were recorded when the detected change in area was at least 10 percent. Nonforest patches with adjacent clearcuts created in the period between 1946 and 2000 were counted in the 1946 photographs; we observed no cases of logging adjacent to nonforest openings before 1946, when logging was just beginning in this area.

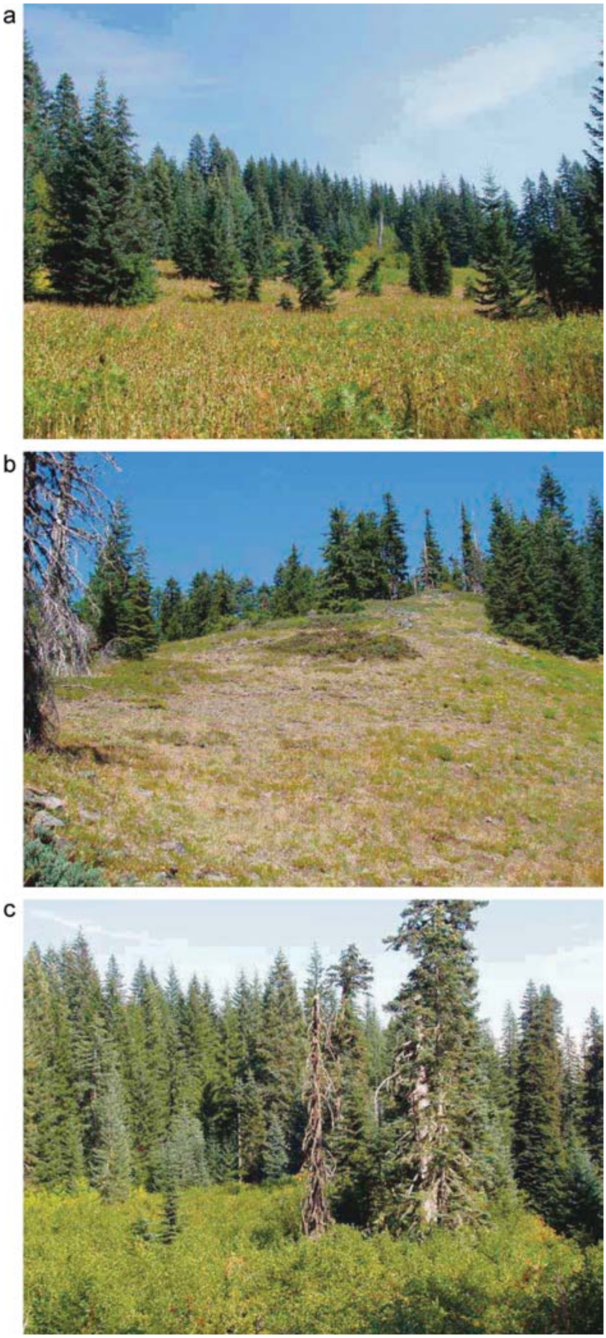

Figure 3 *Physiognomy of the cover types of nonforest patches: (a) mesic meadow, (b) xeric meadow, and (c) broad-leaved shrub field.*

We excluded nonforest patches with adjacent clearcuts from assessment of change in patch size, however, because the boundary of such patches may have been modified directly or indirectly by logging; some trees that had invaded the meadow may have been cut during logging; and site disturbance by logging could affect forest establishment in both the meadow and the adjacent area, complicating interpretation of natural processes. Meadow contraction could be explained by two types of change: (1) growth of trees present, but not large or not visible, in the 1946 photographs, and (2) establishment of trees after 1946. These two types of change could not be distinguished in the aerial photographs.

History of Fire in Forests Adjacent to Nonforest Patches

We interpreted the occurrence of recent fire by mapping postfire stands adjacent to nonforest patches using several types of evidence. We mapped young forest stands with uniform, fine-textured canopy observed in the 1946 photographs. These fine-textured canopies of stands contrast with the coarser texture of old-growth forests. We considered the possibility that disturbance processes other than fire, such as windthrow and landslides, might be responsible for establishment of these even-aged stands, but several lines of evidence, including spatial arrangement and char on the boles of residual trees and snags, pointed to fire as the overwhelmingly dominant disturbance agent. Young forest stands have a wide range of canopy heights, including sites with small trees, which we termed conifer sapling fields.

We use these interpretations of occurrence of fires in adjacent forest stands in the following analyses. Most of these adjacent forest stands were estimated to have established after burning in the 1800s and early 1900s, based on tree-age data collected from 159 stands by Morrison and Swanson (1990) and Weisberg (1998) and with archival data compiled by Burke (1979), including USDA Forest Service maps of fires from 1910 to 1977.

Spatial Analysis

A 10-m digital elevation model (Oregon 10m DEM created by the U.S. Geological Survey) was used to produce maps of elevation, slope, aspect, and distance to ridge using geographic information systems (GIS; TNT-mips). Because aspect is a circular variable, it was translated to a continuous north–south gradient (northness) and an east–west gradient (eastness) using the following equations: northness = cosine (aspect); eastness = sine (aspect; Beers, Dress, and Wensel 1966). Distance to ridge was calculated as the horizontal distance to the nearest watershed boundary created with a 50-m DEM by TNTmips.

Environmental conditions inferred from these maps were used to analyze the distribution of nonforest patches. Slope can affect soil and snow stabilities, and aspect can cause spatial variation in soil moisture and snow-free period. Distance to ridge can be an indicator of windy and dry conditions.

Logistic regression analysis was conducted for mesic and xeric meadows to identify site variables that best discriminated between contracted and stable meadows, using SPSS for Windows version 12.0. Predictors included terrain variables (elevation, slope, northness, eastness, and distance to ridge), fire history, and grazing period. Terrain variables were calculated as means of the 10-m $\times$ 10-m cells contained within the patch boundary. Fire history and grazing period were coded as dummy variables: for fire, 0 = unburned in the 1800–2000 period and 1 = burned; for grazing, 0 = grazing continued until 1940s and 1 = until 1920s. Logistic regression is appropriate for dealing with a binary (0 or 1) dependent variable and cases where the parameters of the fitted model lend themselves to interpretations using odds ratios, which are useful in interpreting the patterns of occurrence of variables.

Results

Change in Area of Meadows and Shrub and Sapling Fields

A total of 521 natural, nonforest vegetation patches were detected in the 1946 photographs (Table 1, Figure 2). These areas covered about 1,950 ha or about 5.5 percent of the study area. In 1946, 57 percent of nonforest patches were broad-leaved shrub fields, 24 percent were xeric meadows, 10 percent were mesic meadows, and 9 percent were conifer sapling fields.

Table 1 *Area and number of nonforest patches by type of change in patch area between 1946 and 2000; area in 2000 was calculated on the presumption that patches with "unknown" natural change in size (those with adjacent clearcuts) were stable*

	Area (ha)		Number of nonforest patches					
Cover type	**1946**	**2000**	**Contracted**	**Stable**	**Expanded**	**Subtotal**	**Unknown**	**Total**
Mesic meadow	133	66	22	22	3	47	6	53
Xeric meadow	265	223	19	96	0	115	8	123
Broad-leaved shrub field	605	601	2	213	1	216	84	300
Conifer sapling field	946	6	45	0	0	45	0	45
Total	1,949	896	88	331	4	423	98	521

The conifer sapling fields averaged 19.1 ha ($SD = 6.8$ ha) in size, and the average size of the other three cover types was about 2.2 ha ($SD = 0.1$ ha).

The geographic distribution of the cover types mapped on the 1946 photographs was controlled in part by terrain conditions (Figure 4). Mesic and xeric meadows and broad-leaved shrub fields were most common above an elevation of 1,000 m, whereas conifer sapling fields occurred in both lower and higher elevations. Xeric meadows and conifer sapling fields were more common on steeper slopes than were mesic meadows and broad-leaved shrub fields. Broad-leaved shrub fields were most common on north-facing slopes but also occurred on south-facing slopes. Distances to ridge were smaller for mesic and xeric meadows and conifer sapling fields than for broad-leaved shrub fields; the former

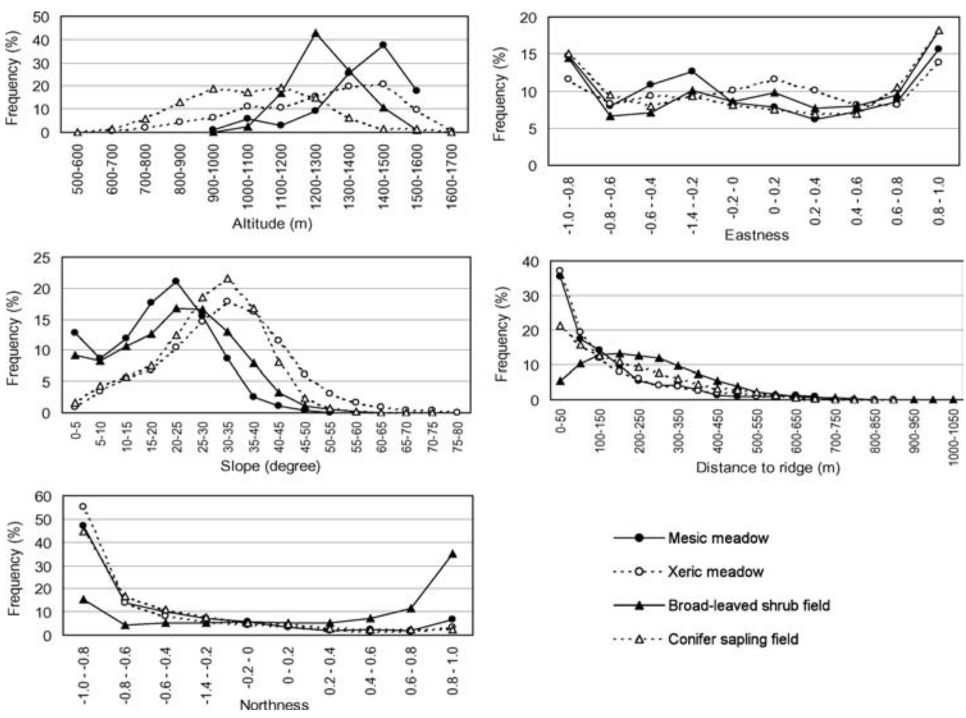

Figure 4 *Distribution of the cover types of nonforest patches in relation to terrain conditions.*

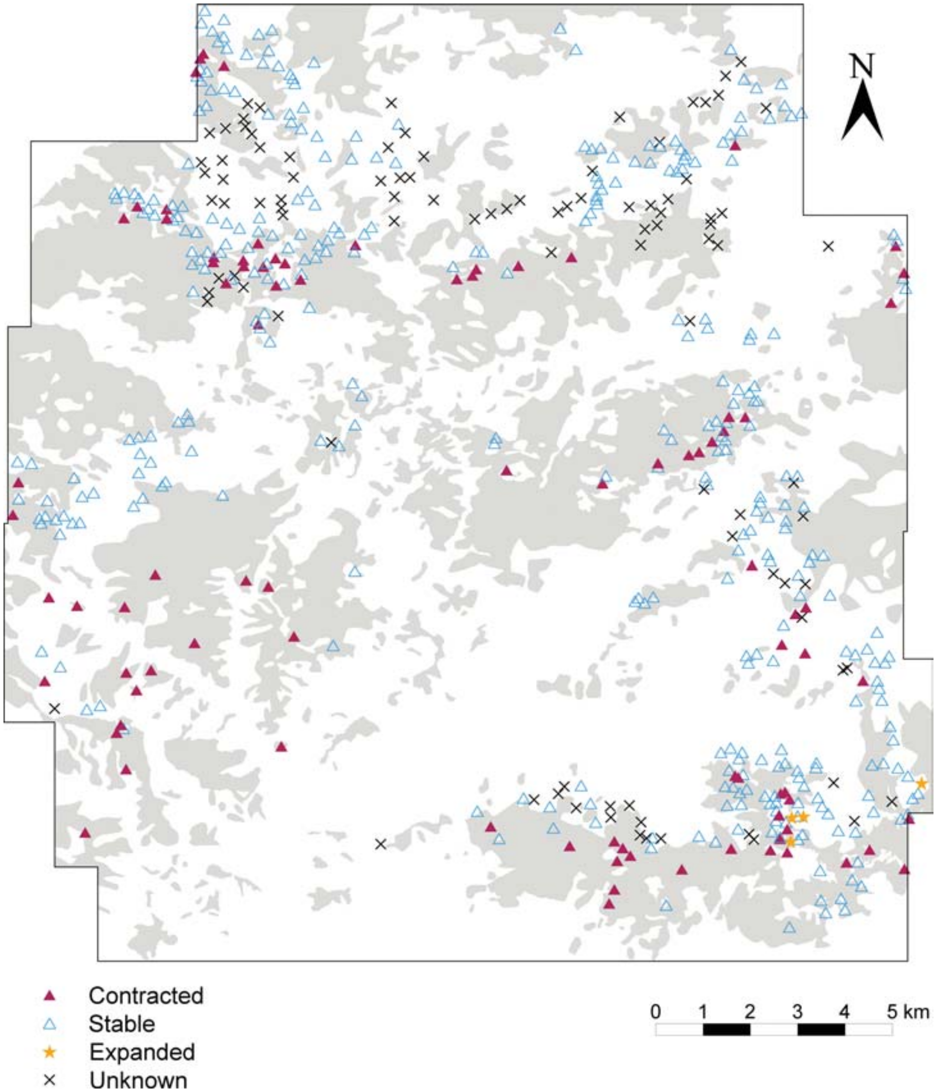

Figure 5 *Map of meadows and shrub and sapling fields distinguished by the type of change they experienced between 1946 and 2000. Shading indicates the distribution of forest stands established between 1800 and 1946, and unshaded area is older forest. Unknown refers to nonforest patches adjacent to logged sites.*

commonly occurred along upper slopes and occasionally on ridge crests. Broad-leaved shrub fields tended to occur in glacial cirques and on large landslide areas at higher elevation (Figure 2), and xeric meadows were common on the upper headwall of cirque basins.

Nonforest patches covered 896 ha in 2000, 2.5 percent of the study area. The stability of nonforest patches between 1946 and 2000 was determined for 423 nonforest patches with neighboring forests that were free from the influence of logging (Table 1, Figure 5). Four of the nonforest patches expanded between 1946 and 2000, eighty-eight contracted (20.8 percent), and the remainder had no detectable change in area (Table 1). The extent

Table 2 *Number of meadows that contracted and were stable between 1946 and 2000 in burned and unburned sites*

Cover type	Fire history	Contracted	Stable	
Mesic meadow				$\chi^2(1) = 10.476,\ p = 0.002^*$
	Burned	20	10	
	Unburned	2	12	
Xeric meadow				$\chi^2(1) = 6.003,\ p = 0.014^*$
	Burned	19	72	
	Unburned	0	24	
Broad-leaved shrub field				$\chi^2(1) = 2.456,\ p = 0.155$
	Burned	2	95	
	Unburned	0	118	

Note: "Burned" indicates meadows and shrub and sapling fields adjacent to young forests established after wildfire in the 1800–1946 period.
$^*p < 0.05$.

of change varied with cover type: twenty-two of forty-seven mesic meadows (46.8 percent) contracted, whereas 83.5 percent of xeric meadows and 98.6 percent of broad-leaved shrub fields were stable. Almost all of the areas classified as conifer sapling fields in 1946 were forested in 2000. In ninety-eight cases (19 percent) change in size of nonforest patches could not be determined because adjacent forest was clearcut between 1946 and 2000. Other than clearcuts and roads, no new inventoried openings were created between 1946 and 2000.

The distribution of patch types and patch-size stability exhibited some correlations with fire history of adjacent stands before 1946 (Table 2). Mesic and xeric meadows were observed more frequently adjacent to areas burned in 1800 to 1946 than were broad-leaved shrub fields: 64 percent of mesic meadows and 79 percent of xeric meadows occurred adjacent to burned areas, versus 45 percent of broad-leaved shrub fields. Significantly more cases of contracted patches were observed for mesic ($p = 0.001$) and xeric ($p = 0.014$) meadows adjacent to forest that experienced stand-replacement fire in the approximately 150 years preceding 1946.

A total of 356 patches occurred within grazing allotments A, B, and C (Figure 1), and thirty-eight of them were contracted meadows and broad-leaved shrub fields. No statistically significant relationship was detected between the timing of closure of allotments and change in patch extent (Table 3).

Logistic regression analysis for forty mesic meadows and eighty-nine xeric meadows inside the grazing allotments indicates that contraction of mesic meadows is related to fire history, but contraction of xeric meadows is related to topography and grazing (Tables 4 and 5). Mesic meadows adjacent to areas that burned in the preceding 150 years were about thirty-three

Table 3 *Number of meadows that contracted or were stable between 1946 and 2000 in each grazing allotment*

Cover type	Allotment	Contracted	Stable	
Mesic meadow				$\chi^2(1) = 0.666,\ p = 0.414$
	A and B	14	17	
	C	6	4	
Xeric meadow				$\chi^2(1) = 0.471,\ p = 0.493$
	A and B	9	49	
	C	7	26	
Broad-leaved shrub field				$\chi(1)^2 = 3.073,\ p = 0.080$
	A and B	0	114	
	C	2	73	

Note: Sheep grazing continued until the 1940s in allotments A and B and until the 1920s in C.

Table 4 *Effects of site characteristics on contracted mesic meadows determined by logistic regression analysis*

					95% Confidence interval	
	Coefficient	***SE***	***p* Value**	**Odds ratio**	**Lower**	**Upper**
Elevation	0.003	0.005	0.596	1.003	0.992	1.013
Slope	–0.019	0.063	0.764	0.981	0.868	1.110
Northness	–1.084	0.769	0.158	0.338	0.075	1.526
Eastness	–0.744	0.730	0.308	0.475	0.114	1.989
Distance to ridge	0.004	0.004	0.331	1.004	0.996	1.013
Fire history	3.496	1.337	0.009*	32.994	2.402	453.206
Grazing period	1.835	1.339	0.171	6.266	0.454	86.467

*$p < 0.05$.

times more likely, based on the odds ratio, to contract than meadows with older adjacent forest, and meadow contraction was not related to other environmental variables (Table 4). However, contracted xeric meadows were about six times more likely to be on east-facing slopes than on other aspects and about five times more likely to have experienced earlier cessation of grazing (Table 5).

Discussion

Patterns of Change in Extent of Nonforest Patches

The total area of nonforest vegetation patches other than clearcuts in the study area decreased substantially between 1946 and 2000, although the four cover types differed greatly in extent over time (Table 1). Nonforest patches may exhibit four possible trends over time: stability, contraction or disappearance, expansion, or creation of new patches. Contraction and disappearance can be caused by ecological succession, natural environmental change, human influences (e.g., fire suppression), or some combination of factors. The majority of inventoried patches in the study area and period were either stable or contracted; very few expanded; and none was newly created by natural processes. Some small forest gaps were created by processes such as small landslides and patches of bark beetle mortality, but these were below the minimum size of our patch delineation.

The broad-leaved shrub fields and conifer sapling fields exhibited quite different trends in change of areal extent over time (Table 1). All forty-five conifer sapling fields present in 1946 contracted or disappeared by 2000. Almost all of them were classified as forest in 2000, suggesting succession to forest after wildfire.

Table 5 *Effects of site characteristics on contracted xeric meadows determined by logistic regression analysis*

					95% Confidence interval	
	Coefficient	***SE***	***p* Value**	**Odds ratio**	**Lower**	**Upper**
Elevation	–0.004	0.002	0.035*	0.996	0.992	1.000
Slope	0.005	0.053	0.930	1.005	0.906	1.114
Northness	–1.996	1.112	0.073	0.136	0.015	1.200
Eastness	1.841	0.777	0.018*	6.305	1.375	28.922
Distance to ridge	–0.006	0.003	0.044*	0.994	0.987	1.000
Fire history	20.325	8479.682	0.998	6.718e+8	0.000	—
Grazing period	1.629	0.797	0.041*	5.098	1.069	24.319

*$p < 0.05$.

Although we excluded this vegetation type from the spatial analysis, it is worth noting the extent of ephemeral conifer sapling patches in the prelogging landscape, because historically it was a significant component of landscape and served as important wildlife habitat (Bunnell 1995). Plantations created by clearcutting and burning in the period from 1950 to 1990 might have provided this habitat, but the reduced rate of harvest since then combined with decreased frequency of fire may limit its future extent in the study area.

The broad-leaved shrub fields remained relatively stable between 1946 and 2000. Many of these patches have sharp boundaries and occupy distinctive topo-edaphic conditions, such as boulder fields, which are not conducive to tree establishment. Deep snow packs and snow creep may also maintain the broad-leaved shrub fields (Franklin and Dyrness 1988). The 3- to 5-m-tall Sitka alder and vine maple in the shrub fields had stems that were bent downslope at the base, suggesting chronic snow creep on the steep slopes common to this vegetation type. Also, the dense cover of these long-lived shrubs discourages conifer tree establishment.

Meadows had more complex patterns of change. Most xeric meadows remained stable over the study period, whereas mesic meadows were evenly split between stable and contracted conditions (Table 1). This complex pattern suggests that diverse factors, such as disturbance, topographic, and soil properties (Hadley 1999) affect meadows, even of a particular type, and that meadows are generally more stable on xeric sites. Large geographic gradients in climate caused very different patterns of invasion in xeric and mesic sites on the Olympic Peninsula (Woodward, Schreiner, and Silsbee 1995; Peterson, Schreiner, and Buckingham 1997). This study showed that the same variety of patterns occurred among different types of sites within a small area.

Natural, recent expansion of nonforest patches was uncommon. Only three mesic meadows and one broad-leaved shrub field expanded between 1946 and 2000. Fallen dead trees appear in the area of mesic meadow expansion in the 2000 aerial photographs. These areas of expansion were probably caused by tree mortality in response to an outbreak of balsam woolly adelgid in the 1950s (Whiteside 1958). The broad-leaved shrub field may have been enlarged by a snow avalanche, a process that is rare in the elevation range and wet snow conditions of the study area.

Factors Affecting Changes in Nonforest Patches

Environmental change involving fire, climate, and grazing potentially affects the dynamics of meadows. Contraction of both mesic and xeric meadows is linked to disturbance by fire, based on chi-square tests (Table 2), but the importance of disturbance depends on the type of meadow. A majority of mesic meadows adjacent to areas that experienced fires between 1800 and 1946 underwent contraction in the subsequent half-century, whereas fires were less commonly associated with contraction of xeric meadows (Tables 2, 4, and 5).

The stronger effect of fire on mesic meadows may reflect the more favorable sites for tree establishment in the deeper, moister soil of mesic meadows. Several stressful conditions may discourage tree establishment in xeric meadows (Hadley 1999). Soils in these sites were poorly developed, and the sites include areas of very shallow, stony soils and patches of boulders and bedrock outcrops. The high-elevation environment and soil erosion in response to fires and intensive livestock grazing also may have contributed to poor soil conditions and little tree establishment. In addition, fire has limited ability to spread through sites of low, discontinuous fuels, which is more likely to be the case in xeric meadows.

Slope aspect did not make a large difference in tree-invasion histories in the study area (Tables 4 and 5), although Miller and Halpern (1998) observed aspect effects in the subalpine zone (1,600–2,000 m) of the central Cascade Range. Slope aspect can influence snow-free period and summer-drought susceptibility. However, the rather short period of snow cover in this study area (Bierlmaier and McKee 1989) probably limits snow effects on tree invasion.

No strong correlation was detected between closure of sheep grazing allotments and the presence of contracted meadows (Tables 3, 4, and 5), although contraction of xeric meadows was more likely in sites with earlier cessation of grazing. This may partly reflect the limitations of detecting changes in meadows by aerial photograph interpretation. The difference in timing of invasion between grazing allotments A and B (1920s) and allotment C (1940s) may be too small to be detected by observation of seedlings and saplings on the aerial photographs. Another possible reason is that grazing disturbance may not have been intense in the study area, particularly in the later years of grazing. Meadow–tree interactions in some areas depend on grazing intensity (Savage 1991). In the nearby Three Sisters Wilderness Area, timing of tree invasion corresponded most closely with cessation of grazing where grazing disturbance had been most intense (Miller and Halpern 1998). Drought in the 1930s in the western Cascades may also have suppressed potential differences among these allotments.

Changes in disturbance factors, including fire and grazing, raise important conservation issues in the extensively forested landscape of the central western Cascades Range. These nonforest habitats and the great diversity of flowering plants within them contribute to the biological diversity of a landscape dominated by forest cover (Miller, Hammond, and Ross 2003).

Fire suppression is a possible cause of lower wildfire extent in the twentieth century than in the several preceding centuries (Weisberg and Swanson 2003). Suppression of fire may limit both expansion of meadows and maintenance of recent meadows and also facilitate tree invasion into some of the meadows. However, another possible explanation is that infrequent (every few centuries) large fires have not been suppressed, but simply occur at intervals long enough to permit widespread meadow contraction during the interludes between these events that create extensive nonforest openings.

Some types of nonforest patches appear to be susceptible to change, whereas others are stable (Table 1); attempts to manage nonforest patches would probably be most effective in the relatively unstable mesic meadow type. A coordinated program of extensive surveys, such as this one, intensive reconstruction of site histories, long-term monitoring, and experimental manipulations, using processes such as fire, would greatly advance our understanding of the mechanisms driving the dynamics of the nonforest patches and provide a foundation for future conservation practices. ■

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