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Conifer Invasion of Subalpine Meadows, Central Lemhi Mountains, Idaho

Abstract

Ages of invasive trees in three subalpine meadows were determined with an increment borer. Climate change, forest fire history, and grazing pressures have all influenced the histories of meadow invasion. Invasive limber pine (*Pinus flexilis*) gave way to Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*) during the period of major climate-caused invasion around 1895-1915. Invasions into the meadows in 1920-1940 were a result of drier climatic conditions, the possible influence of grazing, and a forest fire. Heavy grazing prevents present-day invasion in at least one meadow.

Introduction

The determination of periods of climate change, and knowledge about the geographic extent of such changes, provide the basis for an increased understanding of the potential impact of future climatic fluctuations. Unfortunately, many areas in the American west suffer from a paucity of widespread, long-term climatic data which could document such changes. Surrogate data become significant in such locations.

In the mountains of the western United States, subalpine forest environments are difficult sites for tree establishment (Agee and Smith 1984). When trees do become established in locations such as above present treeline or in subalpine meadows, the establishment is often attributed to some form of climate change which has made conditions more amenable for tree survival (Franklin *et al.* 1971, Schimpf *et al.* 1980, Kearney 1982, Ostler *et al.* 1982, Winter 1984). Other factors, particularly land-use practices, must also be examined as possible causative factors in successful tree establishment at formerly inhospitable sites (Dunwiddie 1977, Vale 1981b).

A recent study from the Lemhi Mountains of east-central Idaho (Figure 1) revealed a major historic treeline advance, initiated in the 1920s (Winter 1984). This advance was correlated with a broad climatic warming and drying that occurred across western North America during the same period, and which has also been identified by examination of the ages of invasive trees in subalpine meadows (*e.g.*, Franklin *et al.* 1971, Nisle 1981, Agee and Smith 1984). Other studies in western mountain meadows have also identified successful tree establishment in the same period, but did not directly attribute these tree invasions to climate change (Koterba and Habeck 1971, Vale 1981a).

The present study was concerned with 1) identifying the period(s) of successful tree invasion into mountain meadows in the central Lemhi

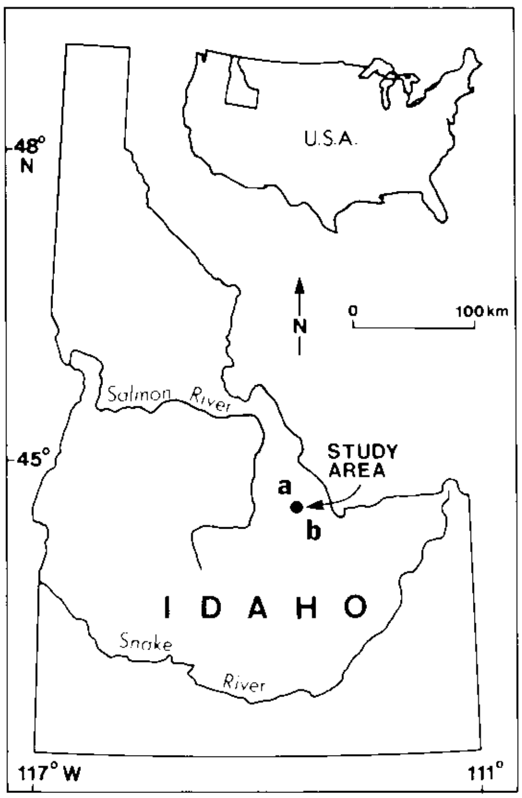

Figure 1. Location of the study area in east-central Idaho. A and B are the locations of Winter's (1984) upper treeline study sites in the Lemhi Mountains.

Mountains of Idaho, 2) comparing the period(s) of meadow invasion to the period of treeline advance in the same range, identified by Winter (1984), and 3) attempting to identify causal factors which allowed the meadow invasions to occur.

The Study Area

Geology and Geomorphology

The Lemhi Mountains rise abruptly from the northern edge of the Snake River Plain, and extend approximately 160 km in a northwesterly direction. The range crest has a mean altitude of 3,050 m (Knoll 1977). The mountains are composed of highly deformed Paleozoic sedimentary rocks and quartzites, with a few granitic and dioritic intrusives exposed.

The Lemhis are incised by a system of glacially-scoured valleys which are oriented roughly perpendicular (*i.e.*, southwest-northeast) to the crest of the range. Glacial recession and deposition during the late Pleistocene and Holocene have produced complex patterns of moraine and kettle topography in many valleys (Knoll 1977; Butler 1984a,b,c; Butler *et al.* 1983, 1984). Tree-ring studies illustrate that the last stage of the Neoglacial terminated later than in the southern Rockies, in the 1905-1910 period (Knoll 1977, Butler 1983).

Soils

Soils in the valleys are generally thin and stony. Many Holocene glacial/boulder deposits have soil profiles with poorly developed O/A/C horizons. B-horizon development is restricted to soils forming on Pinedale-aged (and older) glacial moraines, or in subalpine meadows (Butler 1984c).

Climate

No climatic data exist for the valleys of the eastern Lemhi Mountains. It is estimated, however, that the eastern front of the range receives about 40-45 cm of precipitation annually. Precipitation at higher elevations may total as much as 75 cm, much of that in the form of snow (Gallup 1962). Modern-day mean annual temperature along the front of the mountains is estimated at 4-6°C. Periods of above-average precipitation in the state of Idaho as a whole were recorded in 1892-1897, 1905-1915, 1940-1950, and 1968-1972. Periods of low rainfall were 1886-1890, 1899-1905, 1920-1940, and 1950-1965 (Nisle 1981).

Vegetation

Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) occupy the lower two-thirds of most valleys. These species give way to subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), limber pine (*Pinus flexilis*), and whitebark pine (*Pinus albicaulis*) at higher elevations. Lodgepole pine (*Pinus contorta*) is a major successional species at low to middle elevations. Upper treeline elevation ranges from about 2,800 to 3,100 m (Winter 1984).

Specific Study Sites

In several of the glaciated valleys of the east-central Lemhi Mountains, subalpine meadows are located along the central axes of the valleys, in positions immediately upvalley of arcuate mid- and late-Pinedale readvance moraines. The meadows are comprised of varying thicknesses of fine-grained sediments which were impounded by the damming action of the moraines. These sediments in some cases record complex environmental fluctuations which accompanied deglaciation and post-glacial recovery (Butler 1984b, 1985; Butler *et al.* 1984). The thickness of the dammed sediments is a function of the proficiency with which the arcuate meadows acted as dams.

Meadow Selection

Three subalpine meadows in the central portion of the Lemhi Mountains, First, Harry's, and Deer Creek, were chosen for this study. The three meadows are located roughly half-way between the two sites examined in Winter's (1984) treeline study (Figure 1), offering a basis of comparison of periods of meadow invasion vs. treeline advance. They have been spared logging of larger trees; other meadows in the south-central portion of the range near Winter's southern study site were heavily logged. Each meadow possesses similar elevations, orientations, and terrain characteristics (Table 1), and each is within or adjacent to valleys for which records of late Neoglacial climatic fluctuations are available (Butler 1983, 1984a). Grazing records, necessary for evaluating grazing effects as a possible causal agent of meadow invasion, were available for the valleys in which the meadows are located.

Location, Soils, and Vegetation

First Meadow (FM) and Harry's Meadow (HM) are located in the Mountain Boy Valley. Butler *et al.* (1983, 1984) mapped and described them. Deer Creek Meadow (DCM) is located in Deer Creek Valley, about 2 1/2 km to the northwest. Soils in the meadows (sampled by backhoe- and hand-trenching) are relatively similar (Table 1), in spite of the varying thicknesses of the fine-grained impounded parent material.

Vegetation surrounding the meadows is largely mature Douglas-fir forest. Several isolated limber pine are scattered along the crest of the moraine which dams FM, and some dead limber pine snags are in close proximity to the living specimens. The meadows themselves are conspicuous on aerial-photos and the ground, because of the general absence of mature, large trees. Vegetation in the meadows is primarily sheep fescue (*Festuca ovina*) or Idaho fescue (*F. idahoensis*), with very little bluebunch wheatgrass (*Agropyron spicatum*). Bluegrass (*Poa secunda*) is a secondary species (U.S. Forest Service 1964). Sagebrush (*Artemisia* spp.) is found in all three meadows (Figure 2). Various members of the aster family (Compositae) are found in all three meadows.

Figure 2. Invasive conifers in First Meadow. The arrow points to a portion of the moraine which dammed the sediments comprising the meadow. Sagebrush and grasses dominate the understory vegetation in the foreground.

Grazing History

Grazing records on file in the U.S. Forest Service office in Leadore, Idaho, indicate that all three meadows were grazed by cattle and horses during an unspecified "early part" of the 20th century. Winter (1984) stated that grazing began in 1919 on an allotment immediately to the north of, and more accessible than, the present study area. It is reasonable to assume, then, that grazing did not begin in the meadows before about 1920. In Winter's study area, the number of grazing animals peaked in 1930, decreased sharply (a 33 percent reduction) until 1935, and increased again until 1951, when a 60 percent reduction was imposed because of severe overgrazing. Since the mid-1960s, the present study area has had approximately 200 cattle grazing for periods of 1-2 months for three consecutive summers followed by a summer of rest from grazing. The field season of 1984 immediately followed the period of grazing in Deer Creek Valley. DCM was laden with cow manure, and the soil was heavily disturbed by cattle hoof prints.

Fire History

Fire records for the three meadows are unavailable, as no fire data are available for the Lemhi Mountains prior to the mid-1960s (Winter 1984). One tree in DCM, however, was fire scarred; a tree-ring core was extracted at the scar, and the year of occurrence was dated at 1938. This fire followed the severe drought of 1934-36, revealed by tree-ring analysis of Douglas fir growing on dry mountain slopes adjacent to the East Fork of the Salmon River (B. R. Butler 1978). Charcoal was recovered from the surface soils in both FM and HM, and was radiocarbon-dated as "modern" (beta 3657 and beta 3655, respectively). Nonetheless, no evidence exists on the surface of these meadows that would indicate extensive fire occurrence.

Nature of Invasion

Approximately five large stumps are located in HM, associated with the construction of a log cabin there. This is the only evidence of tree removal from any of the three meadows, and is not considered to have biased the HM age sampling described below. Small invasive conifers, noticeably smaller than in the surrounding

TABLE 1. Terrain and Soil Characteristics of the Sampled Meadows

Meadow	Elevation, Upvalley end	Elevation, Downvalley end	Meadow Dimensions	Average Slope	Meadow Orientation	Surface soil pH	Color (Dry Munsell)	Texture % Sand	Texture % Silt	Texture % Clay
FM	2,438 m	2,426 m	100mx300m	5°	NE-SW	6.9	10YR 3/3	40	38	22
HM	2,487 m	2,463 m	70mx240m	6-8°	NNE-SSW	7.3	10YR 4/3	48	27	25
DCM	2,365 m	2,347 m	65mx260m	5-7°	NE-SW	7.0	10YR 3/3	47	30	23

TABLE 2. Characteristics of Trees Sampled

Meadow	Total Population	Limber Pine	Lodgepole Pine	Douglas-fir	Subalpine Fir	Engelmann Spruce
First Meadow						
Sample Number	66	6	31	29	0	0
Average Tree Age	64yr	87yr	62yr	61yr	---	---
Average dbh	18cm	22cm	23cm	13cm	---	---
Average Height	9m	11m	11m	6m	---	---
Average Distance from Forest Margin	41.0m	52m	26m	22m	---	---
Harry's Meadow						
Sample Number	32	14	0	10	8	0
Average Tree Age	79 yr	93yr	---	72yr	62yr	---
Average dbh	16cm	12cm	---	25cm	9cm	---
Average Height	8m	7m	---	11m	6m	---
Average Distance from Forest Margin	14.2m	19.m	---	7m	4m	---
Dear Creek Meadow						
Sample Number	23	2	1	11	1	8
Average Tree Age	47yr	79yr	42yr	42yr	47yr	45yr
Average dbh	16cm	11cm	13cm	12cm	6cm	24cm
Average Height	8m	6m	6m	7m	4m	11m
Average Distance from Forest Margin	12.3m	10m	8m	14m	7m	12m

mature forests, dot the surface of each of the three meadows (Figure 2). FM is undergoing the most widespread invasion, and DCM the least. It is these small invasive trees that are the subject of the present study.

Methodology

Tree rings were sampled to determine the period or periods of the onset of tree invasion into the three meadows. A standard increment borer was used to core the invasive trees. Trees were defined as those specimens with a dbh of at least 5 cm, and a height of at least 150 cm.

The main purpose of this study was to determine the period of invasion onset. Young seedlings were, therefore, not sampled. Only one seedling was found in DCM, and less than ten were found in HM. More seedlings are present in FM.

Every tree in HM and DCM (32 and 23, respectively) was cored. The greater number of trees in FM, and time constraints, dictated a more restricted sampling scheme. A sample of 66 trees was cored in FM. All trees were cored in the NE, SE, and SW quadrants of the meadow, where numbers of invasive trees were limited. In the NW quadrant, many invasive trees were present, and a 5 m-wide belt transect was used for sampling. The transect extended from the mature forest margin into the geographic center of the meadow. All trees within the transect were cored.

Every tree was cored 8-10 cm above ground level. A growth factor of 3 yr was added to the total age of each core, following the procedure of Vale (1981b). Cores were stored in plastic straws to protect them during transport. Before counting rings, the cores were dried, mounted, and sanded. Ring counting was done under a 10-60x zoom microscope. Each core was counted twice for accuracy of age determination. The age of establishment for each tree was then categorized by pentad (Figure 3). Species, dbh, estimated height, and distance from the forest/meadow boundary were recorded for each tree sampled.

Results

Average tree age varies considerably among the three meadows (Table 2, Figure 3). Nevertheless, the ages of the invasive trees from all three meadows are considerably younger than mature trees in the surrounding coniferous forest. On the ridge of a nearby well-drained glacial moraine in Mountain Boy Valley, 27 of 35 sampled mature trees cored at breast height exceeded 130 years in age, with 16 of the 35 being more than 200 years old (Butler 1983). On the crest of the moraine which dams FM, a stump (cut during jeep trail construction) revealed 305 annual rings.

Few trees existed in either FM or HM prior to 1880, and none did in DCM (Figure 3). Invasion into FM began in earnest in the mid-1890s, and continued at relatively equal levels until ap-

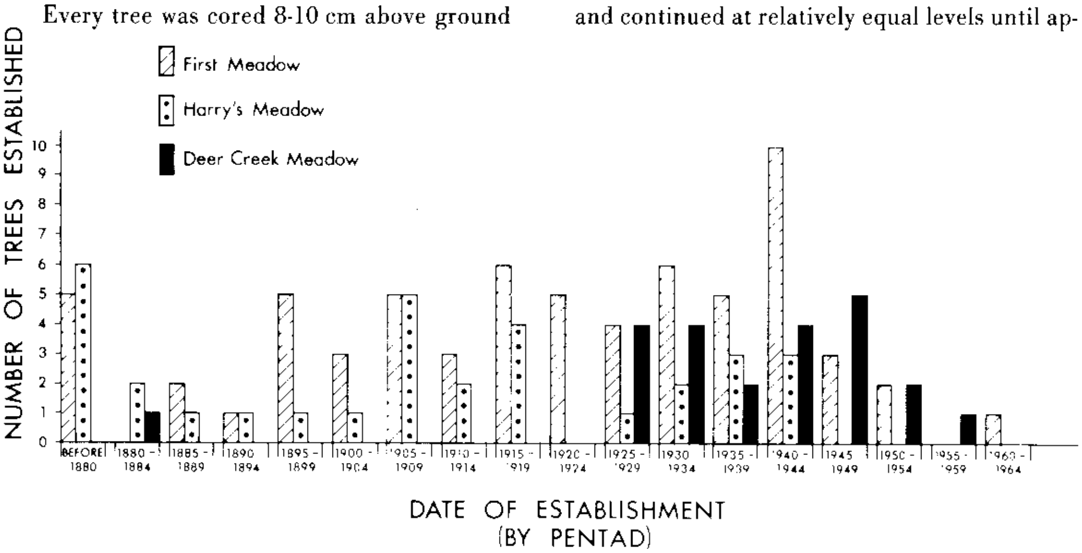

Figure 3. Number of trees established in each meadow, by pentad.

proximately 1950, except for a distinct peak in the early 1940s. Two separate periods of maximum invasion occurred in HM, 1905-1919, and 1925-1945. Invasion has almost ceased in HM, with only the few undated seedlings post-dating 1945. In DCM, all but one tree invaded after 1925, and 55 percent of those invaded after the forest fire of 1938. Invasion ceased after 1959, with only one undated seedling having become established there in the last 25 years.

Definite differences in species age occur in each of the three meadows. In all three, limber pine averages at least 21 years older than the next oldest species. Average age of other species within each individual meadow varies little; only a one year difference between average age of the other two species in FM, and five years or less in DCM (Table 2). Differences in average heights and dbh of sampled trees among the three meadows were not statistically significant. The greater average distance from the mature forest margin in FM may at first glance seem an anomaly, but is accounted for simply by its greater size compared to HM and DCM (Table 1).

Little correlation exists between tree age and height, tree age and dbh, or tree age and distance from forest margin. Simple linear regressions, with tree age as the independent (predictor) variable and tree height (by species within each meadow), tree dbh (by species within each meadow), or distance from forest margin (by species within each meadow) as the dependent variable, were calculated. No R^2 values in excess of 0.25 resulted for the tree age/height, tree age/dbh, and tree age/distance from forest margin calculations; except for a 0.55 R^2 for limber pine dbh as a function of age in FM, and a 0.66 R^2 for subalpine fir distance from forest margin as a function of age in HM. This latter result may be a function of extension into the meadow through sucker-shoot reproduction.

Discussion

Periods of invasion vary among the three meadows, suggesting that 1) no one causal agent is responsible for invasion, or 2) the same causal agent operated at different times in each meadow. Suggestions as to the causal agents in each meadow are outlined below.

In DCM, initial invasion correlates temporally with the dry period of 1920-1940, and with the period of introduction of grazing. Other studies in the region have shown that warmer and drier conditions during these decades produced longer snow-free periods in subalpine meadows, drying the meadow soils and therefore allowing tree invasion (Franklin *et al.* 1971, and Agee and Smith 1984, in the Pacific northwest; Ostler *et al.* 1982, in the Uinta Mountains of Utah; and Schimpf *et al.* 1980, in the northern Wasatch Mountains of Utah). This same period also saw an upper treeline advance at least partially attributable to milder climatic conditions (Winter 1984), so it is reasonable to assign climate as one of the most likely causal agents for the onset of the tree invasion.

Cessation of grazing has been cited as conducive to tree invasion in some studies (Vale 1981a, 1981b), whereas other work suggests that moderate levels of grazing result in abundant tree invasion, by reducing competition with meadow vegetation (Dunwiddie 1977). The introduction of grazing around 1920, at an initially moderate level, probably assisted the establishment of seedlings in DCM. As grazing pressures increased, however, seedling establishment declined except during the immediate post-fire period. Although reduced grazing was recommended in 1950 and imposed in 1951, DCM continues to experience severe grazing disturbance in most summers. This grazing probably precludes continuing invasion of the meadow, in that seedlings are trampled and destroyed before they can become well established and sufficiently large to survive. Cessation of grazing would probably result in a renewed initiation of seedling invasion.

The two periods of pronounced invasion in HM, 1905-1919 and 1925-1945, are probably climate related, with a possible grazing influence in the second period. The first period correlates with the termination of cold, late Neoglacial climatic conditions in the Lemhi Mountains (Knoll 1977, Butler 1983). Snow retention into the summer season was therefore reduced, allowing for the initiation of meadow invasion. The second peak of invasion probably represents a continuation of the invasion process, favored by the drought conditions prevalent in that time period. The onset of grazing in the 1920s may have contributed further to the second phase of invasion.

The period of initial invasion in HM coincides with the cessation of limber pine establishment in all three meadows, suggesting climate change as the primary invasion instigator. Post-1905 trees in the meadows represent species such as Douglas-fir and lodgepole pine (Table 2), species which are more tolerant of warmer and drier conditions. The limber pine is a tree frequently found near upper treeline (Winter 1984), and is associated with cold climatic conditions. Given the change from late Neoglacial to post-Neoglacial conditions about 1905 in the Lemhis, it is not surprising that limber pine was no longer able to successfully invade and compete in the warmer and increasingly drier meadow environments.

Meadow invasion has essentially ceased in HM, with no tree present (except for the few unsampled seedlings mentioned above) younger than forty years in age (Figure 3). Reasons for this are unclear, in that no grazing has been observed in this meadow in five summer field seasons, nor is the soil of the meadow churned and disrupted as in the heavily-grazed DCM. Fire has not been a factor, nor has human disruption, although a small, sporadically-utilized miner's cabin is located on the fringe of the meadow. No evidence of cutting or stump removal of small trees is present. The total absence of grazing (associated with an absence of seedlings) may lend support to the theory that moderate (but not heavy) grazing levels assist in tree establishment.

Invasion in FM predates the invasion in HM by approximately ten years. In the absence of grazing or fire corroboration, climate remains the most likely causal agent for invasion. FM is more exposed and sunny than HM, and 50 m lower in elevation. These factors may have allowed warming and drying, and subsequent meadow invasion, to begin sooner in FM than in HM.

Once begun, the invasion in FM has remained steady, except for a surge in the 1940-1944 pentad. Although no fire scars were located on trees in FM, the presence of modern charcoal suggests that this surge could be a result of post-fire succession. The large number of invasive lodgepole pine also suggests fire succession. Invasion since the 1940-1944 peak has continued; the decline in number of invasive trees in FM on Figure 3 is an artificial misrepresentation, resulting from the absence of sampling of the many invasive trees which were smaller than the established minimum dbh of 5 cm and height of 150 cm.

Concluding Remarks

Previous studies of invasion of trees into subalpine meadows have cited several possible causal agents. In this study, the influences of these same causal agents have interacted in a complex fashion. Some periods of invasion onset or cessation are attributable to climate changes, whereas others are a result of forest fire succession, or are related to changing grazing pressures interacting with climate change. Each meadow examined had its own unique history, depending on which potential causal agents had interacted in that meadow. Common to all three meadows was the cessation of limber pine establishment around the turn of the 20th century, as milder climatic conditions began to favor the establishment of such species as Douglas-fir, lodgepole pine, and (to a lesser extent) Engelmann spruce and subalpine fir. The climatic causal agent was apparently not limited to the two valleys containing the three study meadows. Climate change was geographically widespread enough to affect meadow establishment in the central portion of the Lemhi Mountains, while at the same time allowing upper treeline expansion to the north and south, over a geographic distance of at least 75 km. Other studies have also shown the geographically widespread distribution of temporally-coincident climate change in the Lemhi Mountains (Knoll 1977, Butler 1984a, 1984b). Reason exists to believe that future climate changes in the area will also be widespread.

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