Shifting Forests

Historical Grazing and Forest Invasion in Southwestern Montana

Kathy Hansen, William Wyckoff, and Jeff Banfield

Forest distribution often changes as a result of land use disturbances. In southwestern Montana we suspected, based on visual evidence and on knowledge of the region's historical land use, that livestock grazing caused changes in forest tree distributions, specifically tree invasions into grasslands and shrublands. To test that theory we undertook this study to look at the historical changes in grazing and in the distribution of the forest. The study's conclusions could assist in a better analysis of management options, allowing both for conservation of environmental resources and for sustained grazing. In this study, we reconstructed the history of livestock grazing for the region, documented climate changes, measured the extent and the timing of forest changes, and then tested for associations among the data.

Coniferous trees in southwestern Montana have migrated into lower-elevation grasslands and shrublands over which domestic livestock have grazed for the last eighty to one hundred thirty years (see figure 1). These changes in tree distribution have become exaggerated with time,

Figure 1 *Coniferous trees have invaded the lower grass/shrublands on the western slope of the Madison Range in Montana that domestic livestock have grazed over the last eighty to one hundred thirty years. All figures accompanying this article were provided by the authors.*

creating what are now obvious shifts in the forest. Prior to 1940 several observers reported large-scale invasions of woody vegetation in western North America.[1] Studies in various settings have described invasions as common, widespread, and substantial, but few have alluded to or measured its geographic extent.[2]

United States Forest Service (Forest Service) range managers and longtime residents have reported these changes in tree distribution at least since 1960, but a controversy over cause and effect has fueled recent and heightened awareness of this biogeographic change.[3] Previous studies suggest causes that include grazing and climatic changes; none have closely correlated changes in grazing with the forest distributional changes, and no previous studies have been conducted in the area of Montana that this study investigated. Studies conducted elsewhere indicate that domestic livestock grazing during the spring season reduces competing grasses and forbs to the benefit of invading tree seedlings.[4] Tree invasion elsewhere has been restricted by competing grasses that were not overgrazed.[5] Although livestock trampling has significantly hindered tree seedling establishment in some areas, grazing animals' hooves have also broken open the sod and facilitated tree seedling root penetration.[6]

 Vol 39 No 2

Increases in the average precipitation where available moisture has typically been low has assisted tree invasion in other regions.[7] By contrast, however, under different scenarios a dry climate pattern seems to have favored invasion.[8]

Some of the possible consequences of forest distributional changes include alterations in plant and wildlife diversity and an increase in woody species, which would create an optimum habitat for deer and thus a population eruption.[9] Some studies also cite an increase in competition between domestic livestock and wild ungulates for grazing forage, thus concentrating the animals in areas where forage is available and creating sites of heavy trampling and grazing.[10]

The Madison Range Study Area and the Methodology Used in the Study

Our study area was within the narrow corridor of the forest-grass/shrubland ecotone along the lower forest border of the western slope of the Madison Range in southwestern Montana (see figure 2). By comparing photographs taken in 1927 with photographs taken in 1981 we saw clear evidence of substantial increases in the geographic extent of trees along the lower forest border of this range.[11] The area is an ideal setting to study historical relationships between grazing practices and forest alteration because the grazing intensity, type, and seasonality have changed considerably during the twentieth century. Prior to these twentieth-century changes, the distribution of trees along the lower forest border in the region was stable for perhaps several hundred years.[12]

The Madison Range is a north-south trending mountain range with a sharply defined western front bordering the Madison Valley. The forest-grass/shrubland ecotone varies in elevation from 1,890 meters to 2,190 meters. Regional vegetation types are controlled by elevation.[13] The lower elevation forest is composed predominantly of Douglas-fir, limber pine, and Rocky Mountain juniper.[14] Fire has been essentially eliminated along this lower forest border since the 1920s and 1930s when fire suppression efforts became successful.

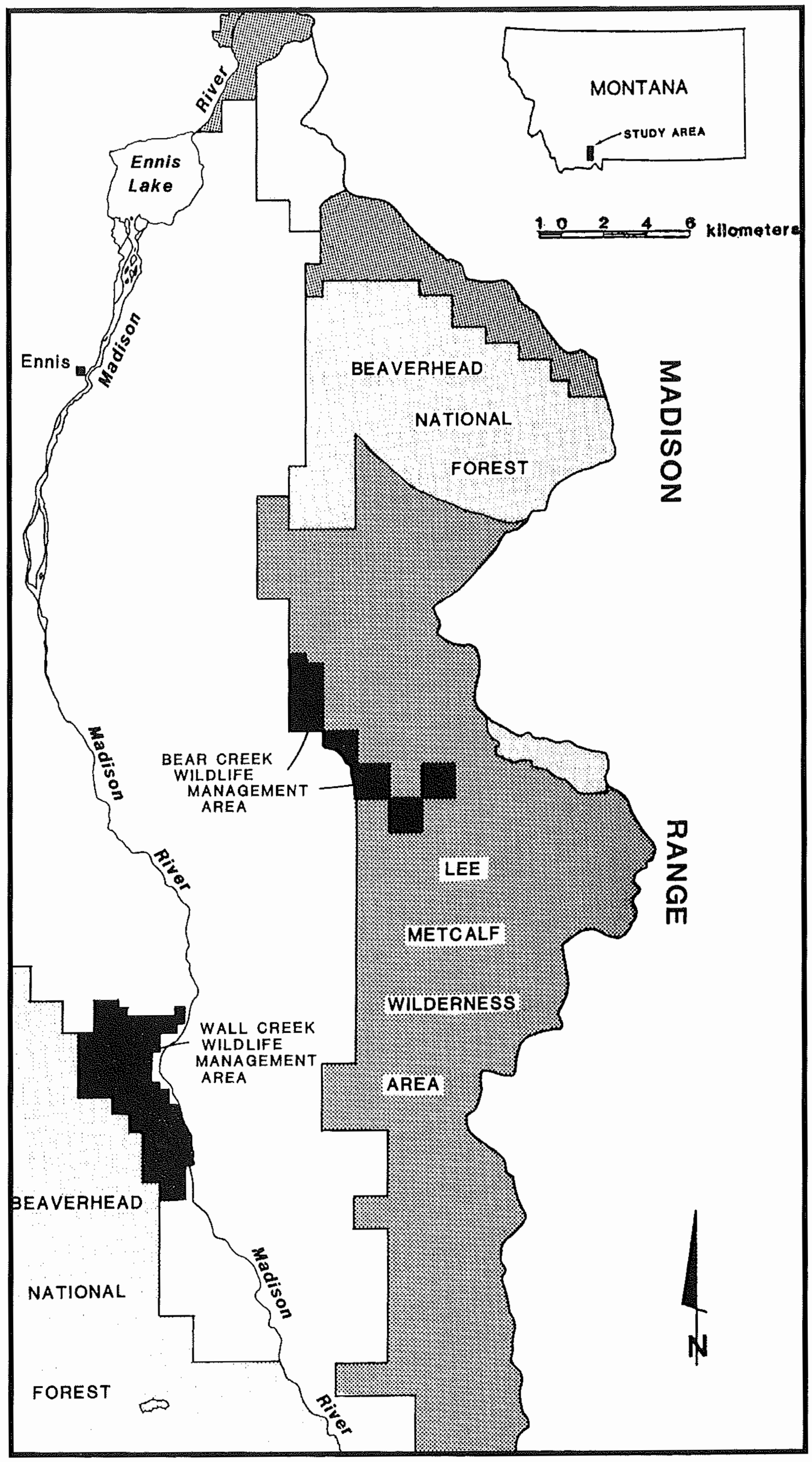


Figure 2 *The study sites lie along a narrow ecotonal belt, immediately downslope from the western flank of the Madison Range and are adjacent to the Beaverhead National Forest, the Bear Creek Wildlife Management Area, and the Lee Metcalf Wilderness Area.*

History of Land Use and Climate

We reconstructed domestic livestock grazing histories for each geographic section of land in the study area. The data we compiled were on:

1. type of domestic grazing animal: for example, cattle, horse, or sheep
2. timing of grazing: when grazing began, when shifts occurred from sheep to cattle, etc., and when grazing ceased
3. the seasonality of grazing: whether it was spring to fall, summer, etc.
4. the intensity of grazing: such as specific years of overgrazing, long trends in grazing intensity, etc.

The study area straddles a public-private land ownership boundary. As a result, we used different research methodologies to address the complex problems of land use reconstruction. For privately controlled acreage, we reconstructed past land ownership patterns from county land records, and also contacted and interviewed the surviving members of ranching families. Interview questions addressed the family's own land management techniques as well as those of others in the study area. We asked each interviewee to provide the names of other people we might interview. Overall, the study included thirty-four local residents who were involved in ranching. Local histories and unpublished material collected by the federally sponsored Works Progress Administration program in the 1930s also provided data on land use history.

To gather material for reconstructing grazing patterns on public lands, we used four types of Forest Service archival records. First were annual grazing reports summarizing general patterns of grazing conditions that Forest Service personnel filed at the district and supervisor levels. Second were historical grazing allotment maps that displayed allotment names and boundaries that had changed over time. These maps, also showing earlier grazing patterns, facilitated the reconstruction of site-specific land use histories. Third were grazing permits and related applications and correspondence files, available at district or supervisor offices, that offered the most consistent and detailed data on grazing type, seasonality, and intensity. Fourth were records filed by grazing allotment that contained long-term management plans, maps, and occasional photographs that traced land use activities in each allotment. Interviews with current and former Forest Service personnel provided other valuable data. We also reviewed records from a small number of Bureau of Land Management tracts.

There are some caveats to note about using these methods of historical reconstruction. Because the study area contained both public and private lands, it was difficult to build a consistent reconstruction based on a single data source. Also, both written records and oral interviews were much less helpful in supplying detailed, highly site-specific data for the pre-1920 time period than for post-1920. Early land use records were inherently subject to more uncertainty than recent evidence and were likely to be more general than the very detailed records made in recent years. Another concern affects all of the data, even when collected within a single section or parcel of land. That concern is that management and herding strategies, topography, and varying distributions of grasses and shrubs can produce significant variations in the impact a given number of livestock grazing in a particular season over a period of years might have. Thus the data can serve only as an approximation of the actual impact. The final caveat is that partial dependence on oral interviews for data creates opportunities for error, confusion, and subjectivity. Wherever possible, we used interview data only when other written records or additional interviewees confirmed the information.

In order to determine whether climatic factors played an important role in invasion timing, we checked historical departures from averages for various periods during the year (i.e., spring temperatures, summer precipitation). We obtained records of temperature and precipitation for 1920 to the present from the United States Weather Bureau station at nearby Ennis, Montana, and smoothed the data so it could be compared with grazing and invasion history.[15]

History of Tree Invasion

To reconstruct the timing of tree invasion, we developed a new method to determine accurately the age of the invading trees. We collected age data along thirty-seven transects within separate geographical sections of the study area. Circular plots with a five meter radius were sampled at equal intervals (thirty-three meters apart) along a randomly chosen, elevational transect. These were positioned perpendicular to the closed-canopy, mature forest boundary and ran downslope through the invaded forest-grass/shrubland ecotone into the non-invaded grass/shrubland regions below. We counted all the trees within the circular plots. To assess tree age, we cored those trees that had a trunk diameter greater than 2 centimeters (which meant the tree had a trunk large enough to core with an increment borer without damaging the tree) at 20 centimeters above the ground surface.[16] This was as close to the ground as we could get and still maintain the required turning radius of the increment borer. Core surfaces were properly prepared and ring counts were made to the center of the pith on the core. We used cross-dating of the ring width patterns to identify missing rings before we assigned accurate ages to the cores.

Rather than adding an estimated number of years, as some studies have done, we developed a procedure to improve the accuracy of estimating tree age.[17] This seemed particularly appropriate within our ecotonal study area since varied stress factors contributed to large variations in annual rates of tree growth. We cut randomly selected trees (considered the training sample) located outside the sample plots at their base, and then counted their rings both at the base and at 20 centimeters up the trunk.[18] Growth rates were determined for each major species by using ring counts between 0 centimeters and 20 centimeters. From these samples we estimated the number of years it takes a tree to grow from 0 centimeters to 20 centimeters.[19] For example, the distribution of the time it takes a Douglas-fir to reach a height of 20 centimeters is skewed (see figure 3), with most of the probability between zero years and ten years, although some trees took as many as sixteen years to grow to 20 centimeters. Rather than simply adding an average number of years to the age of the core sample, we used the entire growth rate distribution to spread the tree's probable germination date over several years. This permitted direct incorporation of the uncertainty of such measurements into the age distributions for the forest stand.[20] Based on this methodology for determining the ages of invading trees, we estimated a smoothed distribution of the probability of tree invasion over time for each individual site (shown in figure 4 for one site). The height of the curve for any given year is an empirical estimate of the probability that a tree, chosen at random from the site, would have germinated in that year.

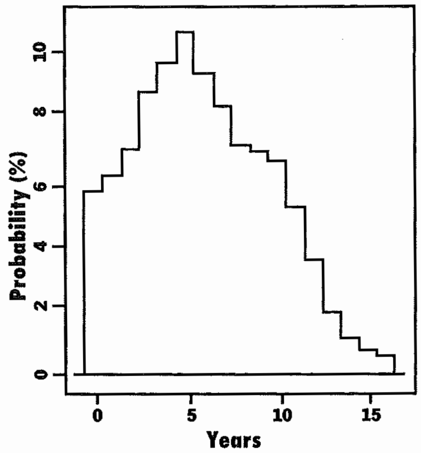


Figure 3 *Probability distribution for the time it takes a Douglas-fir to reach 20 centimeters in height (mean = 5.15 years; standard deviation = 5.34; sample number = 120) along the western slope of the Madison Range, Montana.*

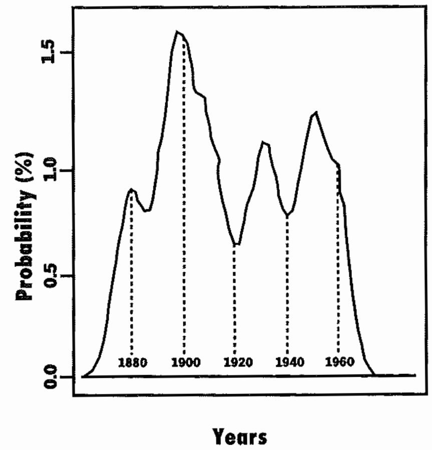


Figure 4 *Smoothed distribution of the probability of tree invasion over time for one study section (Hawk Heaven [HH]) along the western slope of the Madison Range.*

Extent of the Area of Invasion

We measured the extent of the area that trees invaded by using paired aerial photographs taken in 1947 and 1981. First we identified open, non-forested areas on the 1947 photographs. These were refined to areas that could have been invaded by trees from the forests upslope. Invadable areas included those that existed between the lower limit of the closed forest on the 1947 photographs and the lower limit of the forest on the 1981 photographs. We transferred these invadable areas (scale-corrected) to United States Geological Survey 1981 orthophotos. Measurements from the orthophotos included:

1. the entire invadable area
2. the area that had actually experienced tree invasion at densities of 50 percent or more.

Using the 50 percent criterion produced a measurement of substantial tree invasion versus the occasional tree in an open grass/shrubland environment. The difference between these two measurements yielded an absolute measure of invasion.

Causal Relationships

To analyze the relationships among the histories of the tree invasions, the grazing, and the climate, we worked at two scales: regional scale and local scale. The regional scale looked at climate and the regional invasion, and the local scale looked at the individual section's grazing history and invasion. We gathered comprehensive data on invasions and grazing history at fourteen sites.

We based our analysis on a disparate set of variables. The climate data were a continuous time series, the age distributions were empirical probability density functions, and the periods of invasion were defined as the modes of the age distributions. As a result, the analysis did not fit into any standard statistical framework. We did, however, analyze the data using graphical data analysis and computer simulations.[21]

Grazing and Land Use History

Native American inhabitants periodically traveled through the region, establishing seasonal hunting camps. Shoshoni and Bannock tribes were dominant immediately prior to non-Native incursions.[22] European-American settlement of the region dates from the discovery of gold in the 1860s.[23] As demand for beef increased nationally, most of the study area by 1890 felt the effects of increased horse and cattle usage (see figure 5). By that time established ranchers in the region grazed their livestock not only on their own acres but also on portions of the unregulated public domain located in the southern valley and in the nearby mountains. Two important changes occurred between 1890 and 1920. First, the government initiated formal attempts to regulate grazing on the Madison National Forest lands in 1906 with the establishment of grazing districts and an annual permit system. In reality these early efforts did little to curb periodic abuse of the range.[24] Second, while horse grazing lessened in importance, high wool prices between 1915 and 1926 encouraged ranchers to bring large numbers of sheep into selected portions of the northern and central valley as well as a variety of subalpine meadows in the summer.[25]

Between 1920 and 1935, a rapid deterioration of range conditions was apparent as overuse, especially by sheep, combined with significant drought.[26] By 1940 domestic grass varieties had replaced over 90 percent of the native grass species.[27] After 1935 the number of sheep in the valley dropped dramatically. Drought conditions and low sheep prices spurred the declines, and

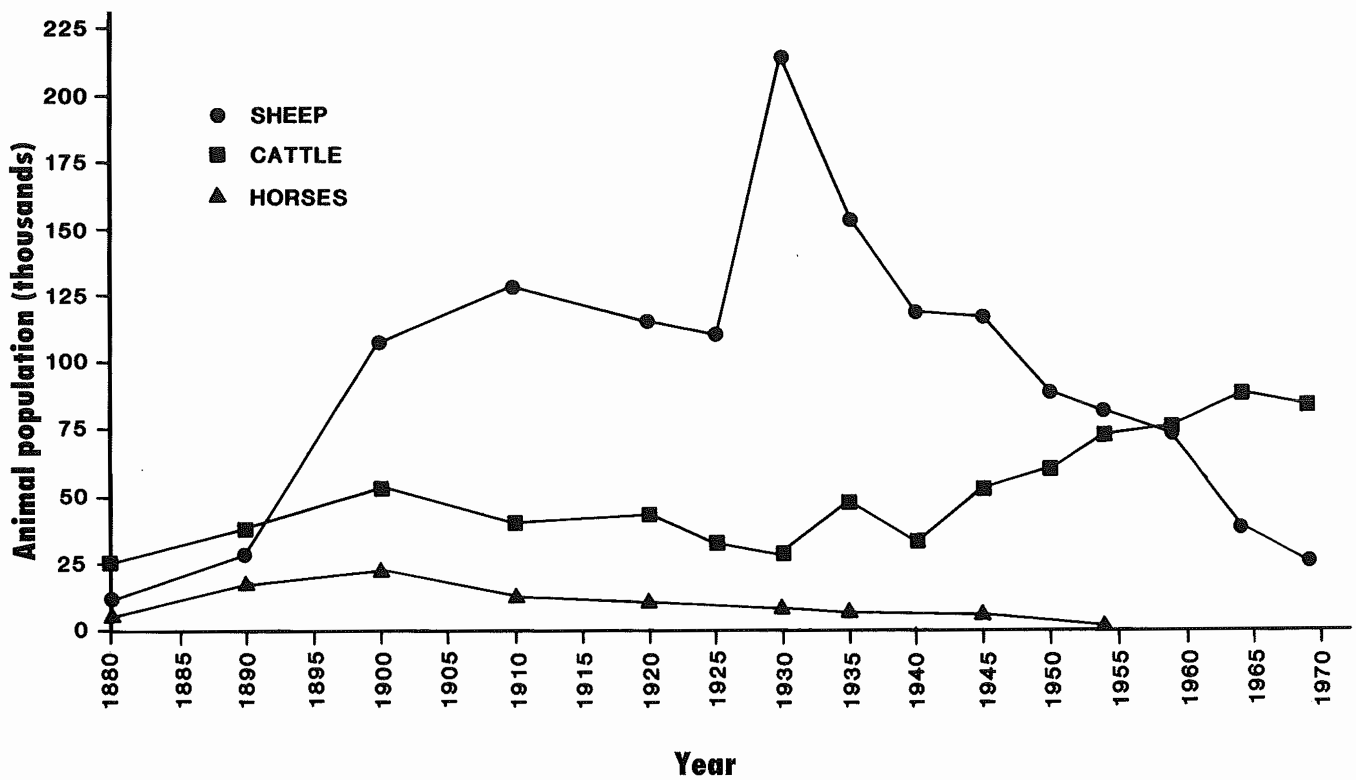


Figure 5 *Domestic grazing-animal population changes in Madison County, Montana, 1880–1970. Source: U.S. Census.*

labor shortages associated with World War II contributed to the lessened emphasis on sheep grazing. At the same time, a higher demand for beef meant that cattle grazing gradually increased across the region, especially on privately controlled parcels and often in conjunction with field rotation schemes. Since the mid-1950s, domestic livestock have more lightly used state- and federally-controlled acreage; instead the government has given increased emphasis to managing forage for area wildlife.[28] Although not specifically studied here, because the emphasis is new, there is a potential competition for grazing resources between wildlife and domestic stock.

Timing of Invasions

The regional history of invasion response indicates that there have been periods or waves of tree invasion (see figure 6). Invasion appears to have started in the late-nineteenth and early-twentieth centuries, increased in the mid-1930s, and reached a period of substantial increase in the 1950s and 1960s. The decline of the

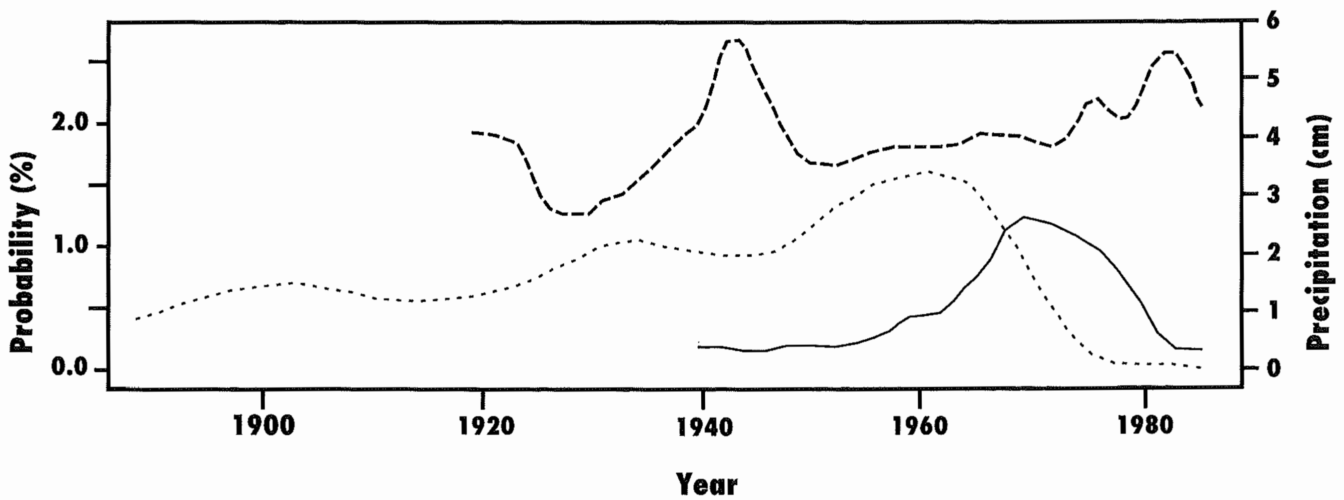


Figure 6 *Smoothed distribution of the tree invasion history for the entire western slope of the Madison Range, Montana.*

Key
——— *invasion timing by age-structure model*
- - - - - - *invasion timing by small, cut trees*
— — — *average total spring and early summer precipitation: April, May, and June*

invasion curve after 1960 is a sampling artifact (many of the 1,980 trees that were too small to core were probably also young), and is probably not a true reading of the current invasion status. In addition, the harvested "training sample" trees could not be combined with the cored trees because of different sampling methodologies. Their age structure, however, indicates that the invasion has continued, as figure 6 shows. The overall pattern is that invasion has occurred during identifiable periods in the past and is continuing.

From the probability curves of invasion, we analyzed site-specific responses. For example, at the Hawk Heaven (HH) site (see figure 4), there were four distinct periods of invasion (around 1880, 1897, 1932, and 1951). Other, less extreme periods of invasion, appearing as shoulders on the peaks of the probability curve, show that the 1897 invasion was followed by invasions around 1901 and 1908. An invasion in the mid-1920s preceded the 1932 invasion, and the 1951 invasion was followed by an invasion around 1960.

Regional and Local Responses to Causal Factors

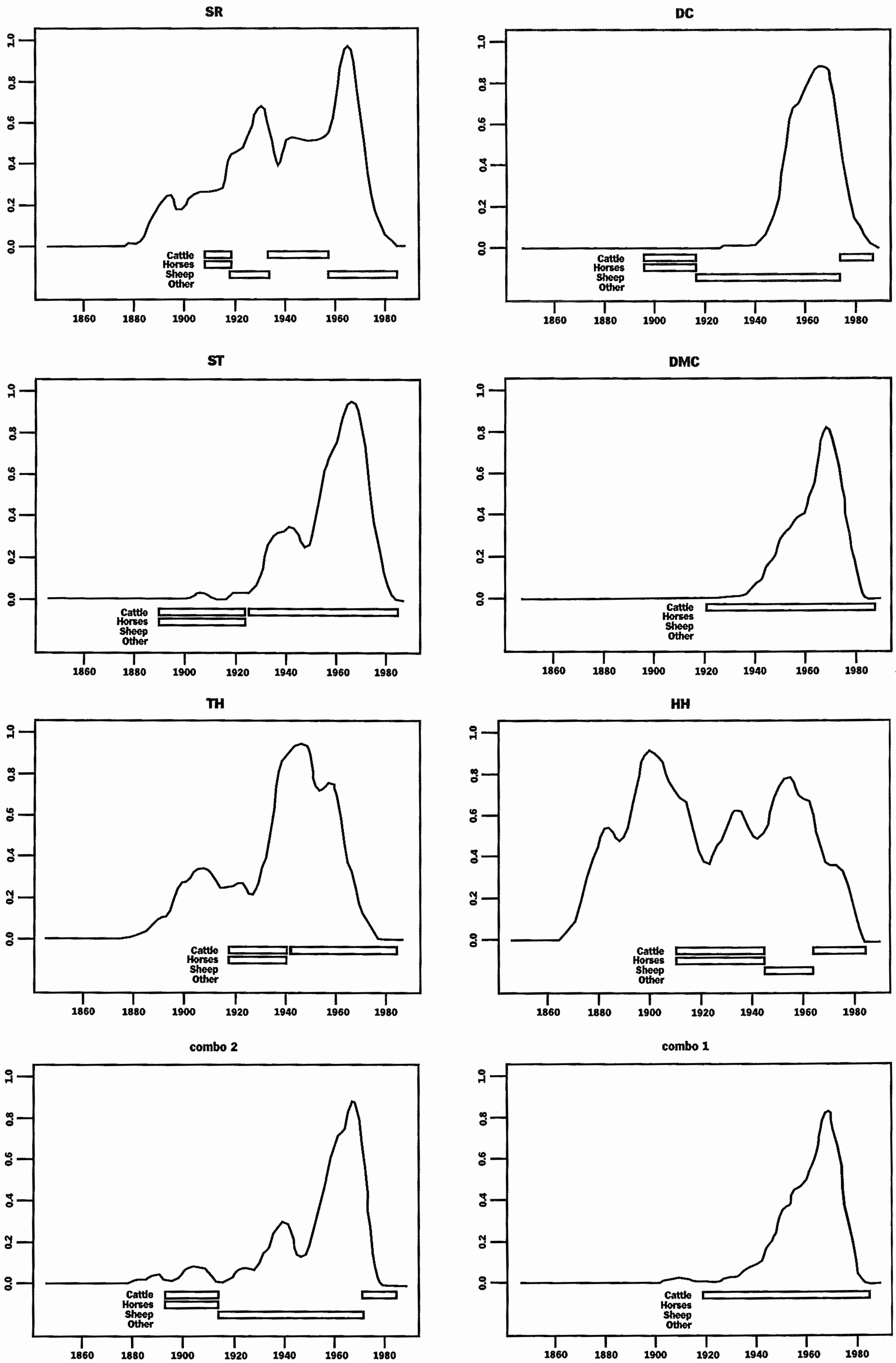
We identified the strongest relationship between invasions and seasonal climate patterns by using spring and early-summer precipitation values (see figure 6). The precipitation data start in 1920 and provide forty years of comparable data.[29] Each invasion event lasted approximately ten to fifteen years. Because of the relatively short time periods, there is insufficient data for a reasonable statistical analysis. However, the strongest invasions occurred following a large increase in precipitation after substantial droughts or decreases in precipitation over a number of years. For example, invasion occurred at a low but slightly increasing level in the late-1920s while precipitation declined. As the precipitation increased in the early-1930s, invasion reached a period maximum and stayed at or near that level until the late-1940s. Accelerated invasion rates occurred again with increasing precipitation after 1950 and continued to increase until the mid-1960s. Most other studies report similar seasonal precipitation relationships that argue for wetter rather than drier climates correlating with forest invasion.[30] A pattern emerges between invasion and relatively stable amounts of precipitation from the late-1940s to the late-1960s. This pattern suggests that adequate moisture provides a form of maintenance for the newly established trees.

Seasonality of grazing did not appear to influence strongly whether invasion occurred. Instead the type of animal or the numbers of animals grazing probably controlled the influence to a greater extent. Increasing and declining invasion trends were associated with spring and fall grazing, just as they were with summer grazing.

Figure 7 shows site-specific invasion and grazing histories for all fourteen sites. The graphs lead to several conjectures about relationships between grazing and invasion. Because other factors than those for which we collected data (such as local microclimates) can have a significant influence on invasions, it is difficult to come to firm conclusions. For example, in sites SR, LSR, and HH a strong invasion follows the switch from horses and cattle to sheep; this leads to the hypothesis that the interaction between removing horses and cattle and starting sheep may cause invasions. But in sites LLL and DC the switch from cattle and horses to sheep did not lead to a noticeable change in invasions. In example combo 2 (a combination of invasion data from two sites with similar grazing histories) and in site SBC the same switch in grazing animals led to only minor increases; in site IBS a minor decrease followed the grazing switch.

The nature of the data precludes most formal statistical tests, but using a statistical permutation test and computer simulation we quantified the strength of relationships between grazing and invasion. We integrated the invasion curve over a specific type of grazing (for instance cattle) for each site and then combined the information from each site to get a measure of the invasion intensity during cattle grazing. We repeated this for each of the grazing types, although not for periods of non-grazing because during the periods for which we had historical data there were no periods of non-grazing. We calculated a number indicating the invasion intensity for each grazing type and then determined whether the number was unusually large (indicating a positive association between invasion and grazing type) or unusually small (indicating a negative association or suppression). If we assume there was no association between grazing and invasion (that is, that they were independent) then the invasion histories are fixed; they would have occurred just as they did, no matter the timing or type of grazing. We randomly shifted the grazing periods around and within each site and integrated the invasion curves over the randomly distributed grazing periods. The resulting invasion intensities represented the typical values we would expect if there were no association between grazing and invasion. These values formed the null distribution under the assumption of independence between grazing and invasion, and we compared our original values to these values to see whether our original values were unusually large or small.

We found invasion intensity during periods of cattle grazing and sheep grazing to be much larger than would be expected if grazing and invasion were independent.[31] The values for horse grazing and cattle and horse grazing were in the middle of the expected values. This indicated that there is a significant positive association between invasions and periods of cattle or sheep grazing but no apparent association between invasions and periods of horse grazing. Invasions occurred more strongly during cattle and sheep grazing than can be accounted for by random chance. We also looked at the five- and ten-year periods immediately following the start of grazing and the end of grazing for each animal type, but did not find significant results.


SR
DC
ST
DMC
TH
HH
combo 2
combo 1
Cattle
Horses
Sheep
Other
0.0
0.2
0.4
0.6
0.8
1.0
1860
1880
1900
1920
1940
1960
1980

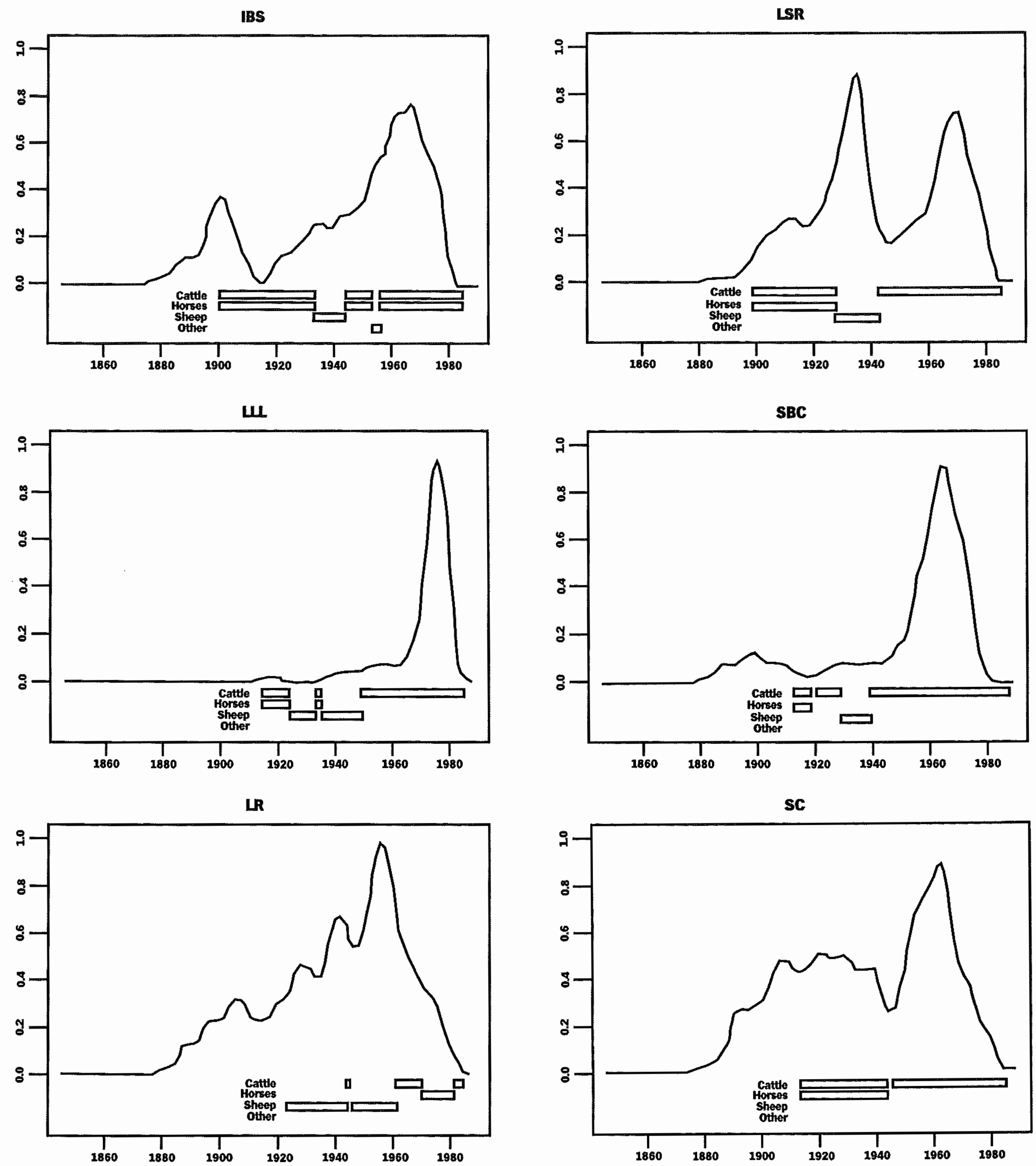


Figure 7 *The probability that a tree would have become established in any given year at the fourteen sites (from 0.0 to 1.0) is shown along the x-axes. The type of domestic livestock grazed (cattle, horses, sheep, or other livestock) and the time period of grazing (from 1860 to 1980) is shown along the y-axes.*

Areal Extent

Of the approximately sixty-eight hundred invadable hectares within the forest-grass/shrubland ecotone, more than fifteen hundred hectares (22 percent) have been invaded by trees at densities greater than 50 percent. This increase in area occupied by trees, almost one-quarter of the invadable area, is substantial because of its great edge effect, spread out along the entire north to south ecotone of the Madison Range. The edge effect is occurring where a higher diversity of species and habitats exists. There are large differences in the amount of invasion between neighboring sections with similar physical attributes, suggesting that different grazing types within these sections have played a substantial role in the amount of invasion.

Our study developed:

1. a method to reconstruct detailed local grazing histories

2. a model to determine more accurately the timing of tree invasions

3. a method to measure areal extent of change over time

4. a graphical method to display relationships between the histories of land use and landscape response

5. an application of these methods to a study area where tree invasion had not previously been studied but the land is under close scrutiny of landowners and managers, and land use activities have changed over time.

The tree invasion of grass communities has affected over fifteen hundred hectares (22 percent) of the forest-grass/shrubland ecotonal belt and has occurred in identifiable periods or waves. The invasions show some response to changes in historical grazing and climate variations. The most dramatic effect of grazing was a statistically significant period of invasion during sheep and cattle grazing. Although the data from some sites suggest that the type of animal being grazed influences invasion, not all sites showed the same relationships, reducing the statistical significance of cause and effect.

The strongest climatic relationship is between invasion and increased spring and early-summer precipitation. This is particularly true when following a drought. In some situations, increased invasion was associated with a decrease in drought conditions. Once the invasion was initiated, the lack of fire probably contributed to the survival of the seedlings and persistence of the trees. Continued adequate moisture conditions are also necessary for tree survival and growth.

The conclusions described here for individual sites as well as for the region as a whole are general and are not definitive. Environmental responses to disturbances are complex, and inability to measure the numerous historical factors that may influence the landscape obscures a precise understanding of the cause and effect relationship.[32] Still, an invasion history can be better understood by representing the most probable causal factors with the best data available.

Management Implications

The change within these grass/shrublands from dominance by grass and shrub to dominance by trees may have initially created optimum habitats for deer similar to that which caused mule deer population eruptions in the Intermountain West between the early-1930s and the mid-1960s.[33] As the invasion continues, however, an inverse relationship between overstory canopy or basal area and the density of the shrub and herbaceous understory may develop, increasing competition for forage among some animals within the forest-grass/shrubland ecotone.[34] As tree density becomes greater, livestock and wildlife movement will become more difficult and often concentrated in some open areas, potentially creating sites of heavy trampling and grazing. In conjunction with a higher amount of woody fuels, the incidence of fire and/or its intensity is likely to increase. Duff accumulations, especially thick layers of needles, may initially hinder the rapid spread of fire; once ignited, however, such material may smolder and be difficult to extinguish.[35] Also, a higher number of trees and more size classes of trees create bridges between the ground layers and tree canopies, which are conducive to the vertical spread of fire.[36] The potential for destructive, crown-carrying, high-intensity fires therefore increases.

Prescribed burning has been advocated as a means of initiating vegetation change back to a stage resource managers and researchers considered more natural.[37] Some observers argue for purposeful disturbance rather than protection from perturbations.[38] Trees that have invaded grasslands and sagelands could either be cut (perhaps first to reduce fuel load) and/or burned to return the habitats to a more productive condition.[39] Purposeful disturbance is controversial in portions of the ecotone that have been designated as wilderness.[40] Minimal change induced by human activities is a critical component to wilderness management strategy, and prescribed burning would produce a deliberate change. Without fire—as a result of human actions—over a long period of time, however, these parts of the wilderness exist today not in a natural state but in a human-altered state. The determination of vegetation as natural or artificial is critical when managing for presettlement conditions and processes.[41] These areas could potentially revert to a more natural condition with the purposeful disturbance of prescribed burning. Grazing by horses and sheep that appeared to be a factor in reducing seedling survival might also be reintroduced for specific situations.

Conclusion

We studied historical grazing and forest invasion in southwestern Montana to determine whether the present landscape in the area is the result of a cause and effect relationship between the two. Using a variety of sources including detailed local histories, county land records, oral interviews, annual grazing reports, historical grazing allotment maps, grazing permits, long-term management plans, and photographs, we reconstructed the type of domestic grazing animal as well as the intensity and seasonality of the animals' grazing impacts. Following an extensive data collection of tree cores to determine the age structure of the forest, we developed a model to date forest changes more accurately. This model is based on growth rates for individual species and probabilities that invasions occurred during a particular year. We suggested associations among grazing, climate, and invasion based on visual examination of the data. We used a statistical permutation test to determine the significance of relationships.

Forest invasion in the study area, not previously documented, is widespread. Major invasion periods occurred from 1935–45 and after 1950, and affected nearly fifteen hundred hectares between 1947 and 1981 along the western slope of the Madison Range. Invasion was strongly linked with periods of cattle grazing and with sheep grazing. Changes in the type of grazing animal resulted in different site-specific responses, but these were not statistically consistent. Invasions were strong during periods of increased spring and early-summer precipitation. Individual sites responded with increased invasion following a drought and then an increase in precipitation. Among the possible management strategies that might be used to control future invasion are prescribed burning.

Notes

Acknowledgments. The National Science Foundation (grant no. SES-8711514), the Association of American Geographers, and Montana State University supported this study. Special thanks to the many Forest Service scientists for consultation, to Sarah Lee for graphic design, and to the field, lab, and office assistants who worked with competence and enthusiasm to collect, process, and synthesize the study's data.

1. Aldo Leopold, "Grass, Brush, Timber, and Fire in Southern Arizona," *Journal of Forestry* 22, no. 6 (October 1924): 1-10; F. W. Emerson, "The Tension Zone between the Grass and Pinyon Juniper Associations in Northeastern New Mexico," *Ecology* 13 (1932): 347-58; and W. P. Cottam and George Stewart, "Plant Succession As a Result of Grazing and of Meadow Desiccation by Erosion Since Settlement in 1862," *Journal of Forestry* 38, no. 8 (August 1940): 613-26.

2. Thomas R. Vale, "Forest Changes in the Warner Mountains, California," *Annals of the Association of American Geographers* 67 (1977): 28-45; and D. J. Parsons and Steve H. De Benedetti, "Impact of Fire Suppression on a Mixed Conifer Forest," *Forest Ecology and Man* 2 (1979): 21-33.

3. U.S. Forest Service, *Beaverhead National Forest, Range Management Plan* (Dillon, Montana: Beaverhead National Forest, 1975).

4. G. T. Zimmerman and L. F. Neuenschwander, "Livestock Grazing Influences on Community Structure, Fire Intensity, and Fire Frequency within the Douglas-Fir/Pinebark Habitat Type," *Journal of Range Management* 37 (1984): 104-10; Cottam and Stewart, "Plant Succession"; Vale, "Forest Changes"; R. S. Rummel, "Some Effects of Livestock Grazing on Ponderosa Pine Forest and Range in Central Washington," *Ecology* 32 (1951): 594-607; Walter F. Mueggler, "Effects of Spring and Fall Grazing by Sheep on Vegetation of the Upper Snake River Plains," *Journal of Range Management* 3 (1950): 308-15; and M. Madany and N. E. West, "Livestock Grazing-Fire Regime Interactions within Montane Forests of Zion National Park, Utah," *Ecology* 64 (1983): 661-67.

5. Ernest M. Steinauer and Thomas B. Bragg, "Ponderosa Pine *(Pinus ponderosa)* Invasion of Nebraska Sandhills Prairie," *The American Midland Naturalist* 118, no. 2 (1987): 358-65.

6. Brian W. Sindelar, "Douglas-Fir Invasion of Western Montana Grasslands" (Ph.D. diss., University of Montana, 1971), pp. 101-102, 113.

7. Sindelar, "Douglas-Fir Invasion"; Lara Dando and Kathy Hansen, "Tree Invasion into a Range Environment Near Butte, Montana," *Great Plains-Rocky Mountain Geographical Journal* 18, no. 1 (1990): 65-76; Philip V. Wells, "Post-glacial Vegetation History of the Great Plains," *Science* 167 (March 1970): 1574-82; Melissa Savage, "Structural Dynamics of a Pine Forest in the American Southwest under Chronic Human Disturbance" (Ph.D. diss., University of Colorado, 1989); and D. F. Arnold, *The Pinyon-Juniper Type of Arizona: Effect of Grazing, Fire and Tree Control,* U.S. Department of Agriculture Production Research Report no. 84 (1964).

8. Vale, "Forest Changes"; Steinauer and Bragg, "Ponderosa Pine"; Michael H. Winter, "Attitudinal Fluctuations of Upper Treeline at Two Sites in the Lemhi Range, Idaho" (master's thesis, University of Kansas, 1984); and David R. Butler, "Conifer Invasion of Subalpine Meadows, Central Lemhi Mountains, Idaho," *Northwest Science* 60, no. 3 (1986): 166-73.

9. George E. Gruell, *Post-1900 Mule Deer Irruptions In The Intermountain West: Principle* [sic] *Cause and Influences,* U.S. Forest Service General Technical Report INT-206 (Ogden, Utah: USDA, Forest Service, Intermountain Research Station, 1986).

10. Gruell, *Post-1900 Mule Deer Irruptions,* p. 16; Zimmerman and Neuenschwander, "Livestock Grazing Influences"; Cottam and Stewart, "Plant Succession," p. 626; Odell Julander, "Range Management in Relation to Mule Deer Habitat and Herd Productivity," *Journal of Range Management* 15, no. 5 (1962): 278-81; M. Hironaka, E. W. Tisdale, and M. A. Fosberg, *The Sagebrush Region in Idaho,* University of Idaho Agricultural Experiment Station Bulletin, no. 512 (Moscow, Idaho, 1969), pp. 1-15; and Stephen F. Arno and George E. Gruell, "Douglas-Fir Encroachment into Mountain Grasslands in Southwestern Montana," *Journal of Range Management* 39, no. 3 (1986): 275.

11. Stephen F. Arno and George E. Gruell, "Fire History at the Forest-Grassland Ecotone in Southwestern Montana," *Journal of Range Management* 36 (1983): 332-36; George E. Gruell, *Fire and Vegetative Trends in the Northern Rockies: Interpretations from 1871-1982 Photographs,* U.S. Forest Service General Technical Report, INT-158 (Ogden, Utah: USDA, Forest Service, Intermountain Forest and Range Experiment Station, 1983); and U.S. Forest Service, *Beaverhead National Forest, Range Management Plan,* pp. 74-75.

12. Sindelar, "Douglas-Fir Invasion"; and M. E. Bakeman and T. J. Nimlos, "The Genesis of Mollisols under Douglas-Fir," *Soil Science* 140, no. 6 (December 1985): 449-52.

13. Duncan T. Patten, "Vegetational Patterns in Relation to Environments in the Madison Range, Montana," *Ecological Monographs* 33 (Autumn 1963): 375-406.

14. Douglas-fir (*Pseudotsuga menziesii* va. *glauca* [Beissn.] Francos), limber pine (*Pinus flexilis* James), and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.)

15. In order to deal with the great variability within climatic data, researchers "smooth" data by averaging a series of observations collected during a particular time period (e.g., a month), and assigning that average value to that time period.

16. Trees that fit the criterion of adequate trunk size included 1,016 individuals.

17. Thomas R. Vale, "Tree Invasion of Montane Meadows in Oregon," *The American Midland Naturalist* 105 (1981): 61-69.

18. The base is considered to be at 0 centimeters.

19. Thus, we estimated the probability that a tree takes "i" years to grow from 0 to 20 centimeters as $(P[A_1 = i])$.

20. For a specified value of (k - i), $P(A_2 = k - i)$ is the percent of trees in the sample from the invasion site that have 20 centimeter core ages of (k - i). The following equation combines the information contained in the training sample with that contained in the trees cored within the sample plots:

$$P[A_1 + A_2 = k] = \sum_{i=0}^{k} P[A_1 = i]P[A_2 = k - i]$$

where A_1 is the number of years for a tree to grow to 20 centimeters and A_2 is the number of years since the tree was 20 centimeters tall.

21. John M. Chambers, William S. Cleveland, Beat Kleiner, and Paul A. Tukey, *Graphical Methods for Data Analysis* (Boston, Massachusetts: Duxbury Press, 1983); Stephen H. C. du Toit, A. Gert W. Steyn, and Rolf H. Stumpf, *Graphical Exploratory Data Analysis* (New York: Springer-Verlag, 1986); and William S. Cleveland, *The Elements of Graphing Data* (Monterey, California: Wadsworth, 1985).

22. Michael P. Malone and Richard B. Roeder, *Montana: A History of Two Centuries* (Seattle: University of Washington Press, 1976), pp. 14-15.

23. James Handly, *The Resources of Madison County, Montana* (San Francisco, California: Francis and Valentine, 1872).

24. U.S. Forest Service, *Madison National Forest Records,* unpublished manuscript, 1920, Supervisor's office, Beaverhead National Forest, Dillon, Montana.

25. Livestock numbers for Madison County are taken from U.S. Bureau of Census, *Census of Agriculture,* 1870-1969 (Washington, D.C.: Government Printing Office, 1870-1969).

26. U.S. Forest Service, *Madison National Forest Records,* unpublished manuscripts, 1923 and 1925, Supervisor's office, Beaverhead National Forest, Dillon, Montana; Cooperative Extension Service, *Annual Reports, Madison County,* 1934 and 1936, Montana State University Archives, Renne Library, Montana State University, Bozeman, Montana; Rancher P. Hacker, interview by Wyckoff, tape recording in author's possession, Madison County, 8 August 1988; Rancher G. Oliffe, interview by Wyckoff, tape recording in author's possession, Madison County, 28 July 1988; Landowner M. Paugh, interview by Wyckoff, tape recording in author's possession, Madison County, 26 July 1988; and Rancher L. Wortman, interview by Wyckoff, tape recording in author's possession, Madison County, 18 July 1988.

27. Native grasses are those that evolve naturally in the region, with no human influence upon their initial distribution; in contrast to domestic grasses, which are introduced and often cultivated by humans. Charles E. Brooks, *The Living River* (Garden City, New York: Doubleday and Company, 1979), p. 122.

28. U.S. Forest Service, *Beaverhead National Forest Grazing Records, 1950-1985,* unpublished manuscript, 1985, Supervisor's office, Beaverhead National Forest, Dillon, Montana.

29. Invasion data beyond 1960 are an artifact of the sampling procedure.

30. See Sindelar, "Douglas-Fir Invasion," pp. 87-94, 104-107, 114, for western Montana, as well as Vale, "Forest Changes," p. 39; Wells, "Postglacial Vegetation," pp. 1576, 1581; Savage, "Structural Dynamics," p. 150; Arnold, Jameson, and Reid, *The Pinyon-Juniper Type*; J. D. Curtis and D. W. Lynch, *Silvics of Ponderosa Pine,* U.S. Forest Service Miscellaneous Publication no. 12-Intermountain Research Station (1957): 1-37; and Arno and Gruell, "Douglas-Fir Encroachment," p. 275.

31. We found p-values less than .01.

32. The complexity of environmental responses to disturbances is emphasized by E. C. Pielou, *Biogeography* (New York: John Wiley and Sons, 1979); Thomas R. Vale, *Plants and People: Vegetation Change in North America* (Washington, D.C.: Association of American Geographers, 1982); Chadwick D. Oliver, "Forest Development in North America Following Major Disturbances," *Forest Ecology and Management* 3 (1980): 153-68; James H. Brown and Arthur C. Gibson, *Biogeography* (St. Louis: The C. V. Mosby Company, 1983); and S. B. Idso, *Carbon Dioxide and Global Change: Earth in Transition* (Tempe, Arizona: Institute for Biospheric Research Press, 1989), p. 292.

33. Gruell, *Post-1900 Mule Deer Irruptions.*

34. Zimmerman and Neuenschwander, "Livestock Grazing Influences," p. 109; Charles F. Cooper, "The Ecology of Fire," *Scientific American* 204 (1961): 151; and D. W. Hedrick and R. F. Keniston, "Grazing and Douglas-Fir Growth in the Oregon White-Oak Type," *Journal of Forestry* 64, no. 11 (November 1966): 738.

35. Regional ecologist W. Hann, Region 1, U.S. Forest Service, interview by Hansen, author's notes, Missoula, Montana, June 1988.

36. Zimmerman and Neuenschwander, "Livestock Grazing Influences," p. 109.

37. Gruell, *Post-1900 Mule Deer Irruptions,* p. 17; Zimmerman and Neuenschwander, "Livestock Grazing Influences," p. 109; and Arno and Gruell, "Douglas-Fir Encroachment," p. 275.

38. See for example Gruell, *Post-1900 Mule Deer Irruptions.*

39. Gruell, *Post-1900 Mule Deer Irruptions,* p. 17.

40. The portion designated as wilderness is part of the Lee Metcalf Wilderness of the Gallatin National Forest.

41. See Thomas R. Vale, "Vegetation Change and Park Purposes in the High Elevations of Yosemite National Park, California," *Annals of the Association of American Geographers* 77, no. 1 (1987): 1-18.