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MEADOW INVASION FROM HIGH-ELEVATION SPRUCE-FIR FOREST IN SOUTH-CENTRAL NEW MEXICO

JAMES M. DYER AND K. EVAN MOFFETT

Department of Geography, Ohio University, Athens, OH 45701
Present address of KEM: United States Census Bureau, Washington, D.C. 20233

ABSTRACT—Stands of corkbark fir–Englemann spruce were sampled on Buck Mountain (elevation 3,282 m) within the White Mountains of south-central New Mexico. A time series of aerial photographs suggests that adjacent meadows have been invaded by these high-elevation stands continuously on the southwestern slope since the 1930s, although the forest-meadow boundary on the northeastern slope has been relatively stable for decades. To obtain baseline information about stands, and to assess patterns of encroachment into meadows, quadrats were established in intact forest on both the southwestern and northeastern slopes, and contiguous quadrats extended into the adjacent meadow. Increment cores were extracted from the two apparently oldest trees of each species within each quadrant (n = 53 trees) to estimate establishment dates. Based on field data and historical records, we conclude that climatic change is a more likely explanation for encroachment of trees into the adjacent meadow, rather than fire suppression or changes in grazing intensities at this site.

RESUMEN—Se muestrearon grupos de árboles de *Abies lasiocarpa* var. *arizonica* y *Picea englemannii* en Buck Mountain (elevación 3,282 m) en la Sierra Blanca del centro-sur de Nuevo México, USA. Una serie de fotos aéreas sugiere que los claros contigüos han sido invadidos por estos grupos de árboles de alta elevación en la cuesta del suroeste continuamente desde 1930, aunque el borde entre el bosque y el claro en la cuesta noreste ha sido relativamente estable durante décadas. Para obtener datos básicos del bosque y para evaluar el patrón de invasión de los claros, se establecieron cuadrantes en bosques intactos en las cuestas suroeste y noreste, y se extendieron cuadrantes contigüos hasta el claro adyacente. Se utilizó un oradador para estimar las fechas de establecimiento de los dos árboles de cada especie aparentemente más antigüos dentro de cada cuadrante (n = 53 árboles). Según datos de campo y documentos históricos, concluimos que el cambio climático es la explicación más probable para la invasión de árboles en el claro contigüo, en vez de supresión del fuego o cambios en la intensidad de pastoréo.

Although much research has been published on spruce-fir communities of the central and northern Rocky Mountains (e.g., Day, 1972; Whipple and Dix, 1979; Knight, 1982; Veblen et al., 1989), the ecology of high elevation spruce-fir communities of the southern Rocky Mountains is not as well known. This study focuses on stands of Englemann spruce (*Picea englemannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*), the only recognized natural geographic variety of subalpine fir, on Buck Mountain, New Mexico. This site, located in the White Mountains (Sierra Blanca), is situated near the southern limit of subalpine forests in North America (Dye and Moir, 1977). Dye and Moir (1977) examined successional stands of spruce-fir on Sierra Blanca, the highest peak in the White Mountains, and found striking compositional differences with more northerly disjunct stands of the Rocky Mountains. Huckaby and Brown (1996) established fire chronologies for sites on Buck Mountain, in the mixed-conifer zone below the spruce-fir zone. In the Sacramento Mountains, Regan and Brown (1996) provided ecological analysis of old-growth montane conifer forests. By and large, however, little research has been published on high-elevation spruce-fir forests in this region.

Encroachment of trees into high elevation meadows adjacent to spruce-fir forests is occurring on Buck Mountain. Meadow invasion is a phenomenon throughout western North America, generally attributable to one or more causal factors: climate change, fire suppression, or change in livestock grazing pressure. Identifying a single cause is problematic, because changes among all three variables were largely synchronous throughout western North America early this century. The spruce-fir boundary with high-elevation meadows has been characterized as dynamic in the vicinity of Buck Mountain (Dye and Moir, 1977), although definitive causes for the invasion have not been identified. Goals of this study were to establish baseline stand composition and structure for these high elevation spruce-fir forests, to assess the pattern and degree of meadow invasion, and to suggest possible explanations for observed encroachment.

METHODS AND MATERIALS—*Study Area*—Buck Mountain (elevation 3,282 m) is situated within the Lincoln National Forest, in south-central New Mexico (33°23′N,105°47′W; T10S, R11E New Mexico Prime Meridian—Fig. 1). Annual precipitation is ca. 75 cm, with a pronounced summer monsoonal character (Alexander et al., 1984). Regional vegetation demonstrates prominent altitudinal patterns, from low elevation desert/grassland to coniferous forests at higher elevations. Vegetation within the study area on Buck Mountain consists of subalpine forest, dominated by corkbark fir and Engelmann spruce, with Thurber fescue (*Festuca thurberi*) meadow surrounding the summit. A time series of aerial photographs supports field observations that trees are encroaching into the meadow. Areas in tree cover were transferred from 1936, 1958, and 1994 aerial photographs onto a common 1:24,000 topographic base map using a zoom transfer scope. Figure 1 shows the extent of forest on the mountain in 1936, 1958, and 1994. A rapid expansion of forest cover is apparent on the northeast slope between 1936 and 1958; thereafter followed a period of relative stability. Continuous encroachment over the past 60 years is witnessed on the southwest slope.

Data Collection and Statistical Analyses—Quadrats were established in continuous forest cover on the northeastern slope (20 m by 20 m) and the southwestern slope (20 m by 50 m). The smaller size of the northeastern quadrat was necessitated by the narrowness of the forest stand, situated between two topographic draws, at least one of which seems to be a snow avalanche chute. From these anchor quadrats, transects of contiguous quadrats were extended across the forest-meadow boundary to the crest of the ridge, perpendicular to slope. For the northeastern transect, slope ranges from ca. 35° in the anchor to 15° near the crest; slope in the southwestern transect ranges from ca. 25° in the anchor to 20° near the crest. Quadrats were of the same dimension as their respective anchors. In addition to the anchor quadrat, the southwestern transect contained nine quadrats and the northeastern transect contained seven quadrats (Fig. 1).

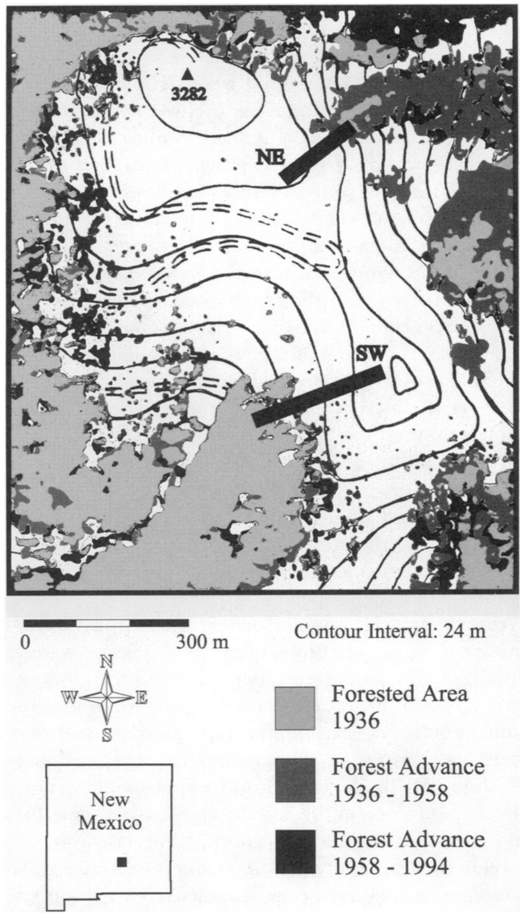

FIG. 1—Location of transects on Buck Mountain. Anchor quadrats of each transect are established in forest; contiguous quadrats (7 in the Northeastern (NE) transect, 9 in the Southwestern (SW) transect) extend upslope. Forested areas were transferred from aerial photographs to a United States Geological Survey 7.5 minute quadrangle using a KARGL reflecting projector.

In each quadrat, the number of trees (≥1 cm DBH; diameter at breast height) and seedlings/saplings (<1.4 m height) were counted by species; DBH was recorded for trees and seedlings/saplings were tallied by height. Percent tree cover, and height of tallest trees were estimated for each quadrat visually. To estimate minimum establishment dates within each quadrat, two increment cores were extracted 30 cm from the base of each of the two oldest trees of each species; these oldest trees were identified by size and overall physiognomy (Schweingruber et al., 1990). A disk taken from a dead southwestern white pine (*Pinus strobiformis*) sapling within the southwestern transect (quadrat SW2) indicated age to coring height at 12 years. Although it would have been preferable to take additional disks from different species and from both transects, we did not wish to use destructive sampling techniques. Therefore, for the purpose of identifying establishment dates, 12 years was the assumed age-to-coring-height for all trees. Cores were extracted from 53 trees. All cores were cross-dated according to standard dendrochronological methods (Stokes and Smiley, 1968).

A composite soil sample was collected from each quadrat. For the southwestern transect, samples were collected from the upper 15 cm of the soil profile. Soils in the northeastern transect were much thinner and rockier, so soil samples usually were collected from the upper 5 to 10 cm of the profile. Textural analysis was performed on samples by hydrometer method (Bouyoucos, 1962). Samples were analyzed for pH, percent organic matter, cation exchange capacity (CEC), total nitrogen, phosphorous, potassium, calcium, and magnesium, and percent base saturation of potassium, calcium, and magnesium (Missouri Agricultural Experiment Station, 1998). Differences in soil properties between the northeastern and southwestern transects, and between each anchor and the average value from its contiguous quadrats were statistically compared using *t*-tests.

Climatic data for Buck Mountain are not available. Annual temperature and precipitation data were obtained for Cloudcroft, New Mexico, the closest high-elevation site with an extended record. Cloudcroft is ca. 55 km from Buck Mountain, and 400 m lower in elevation. Monthly summaries of temperature and snowfall are available since 1948; precipitation records extend back to 1931. However, the only climatic values we could obtain prior to these dates were monthly precipitation averaged for 1902 to 1931, and monthly snowfall averaged for 1903 to 1930 and 1931 to 1949. To examine the relationship of climate and tree establishment for a longer time interval, climatic data were obtained for the New Mexico State Climatic Division (SCD) encompassing Buck Mountain (National Oceanic and Atmospheric Administration, 1997). Monthly temperature and precipitation since 1895 are available, as are Palmer Drought Severity Indices. Monthly temperature and precipitation were used to estimate actual evapotranspiration (Willmott, 1977). The Pearson correlation between annual precipitation at Cloudcroft and the Climatic Division is 0.87 ($P < 0.0001$, $n =$ 56), suggesting that the regional SCD variable adequately describes local conditions near the study site.

RESULTS—Distribution of size classes and age of oldest trees for each anchor quadrat are given in Table 1. Aspect appears to play a key role in composition for these high elevation stands, with mature Douglas–fir (*Pseudotsuga menziesii*) found only on the southwestern slope. The southwestern anchor was dominated by fir, unusual for the central and southern Rockies, but consistent with spruce-fir forests of southern New Mexico (Dye and Moir, 1977). Spruce in the smallest size classes was absent. In the northeastern anchor, spruce was dominant, but both spruce and fir were actively regenerating. Although very old individuals of fire-tolerant Douglas–fir were encountered in the southwestern anchor, both stands would be considered young based on the age of the largest spruce and fir within each quadrat. The young age of the spruce-fir is consistent with recovery from stand-destroying fire. The influence of fire on Buck Mountain is evidenced from a dead and burned quaking aspen in the southwestern anchor, and from fire-scarred trees along the road leading to the summit on the western slope. One fire scar on a spruce near the current forest-meadow boundary was cored and dated to 1940.

Figure 2 presents density and dominance (basal area) values of trees ($\geq$1 cm DBH) for both transects, for each quadrat from the anchor to the top of the slope. It is apparent that the forest-meadow boundary is diffuse along the southwestern transect, with trees occurring in the meadow up the length of the slope. These meadow trees tend to grow in clusters, and take on an increasingly bushy growth form upslope, with much branching low to the ground. Tallest trees in each quadrat were at least 10 m. Along the northeastern transect, however, the forest-meadow boundary was abrupt: tree-size individuals were encountered only within quadrats adjacent to established forest cover. These quadrats occurred on a steep and rocky substrate; the growth form of these young trees, with many adventitious sprouts arising from curved or downed stems, suggests that mass movement is common. Such deformities were not apparent in the anchor, which contained larger trees. Largest trees

TABLE 1—Size class and age data for anchor quadrats. Reported age of oldest Douglas–fir in the southwestern anchor represents a minimum, because the radius of the tree exceeded increment borer length. Aspen was not dated. NE = northeastern, SW = southwestern.

		DBH class (cm)									
		<1 cm									
			Height (m)								
Transect	Species	Density (n/ha)	<1	>1	1–10	10–20	20–30	30–40	40–50	>50	Oldest tree (yr)
NE	Corkbark fir	380	17	5	11	2	1	0	1	0	61
	Englemann spruce	440	16	6	40	10	8	7	7	3	62
SW	Corkbark fir	270	7	20	55	18	5	1	0	1	109
	Englemann spruce	0	0	0	0	4	0	0	0	0	43
	Douglas–Fir	60	0	6	6	3	1	1	0	4	364+
	Southwestern white pine	0	0	0	1	0	0	0	0	0	46
	Quaking aspen	0	0	0	1	0	5	1	2	0	—

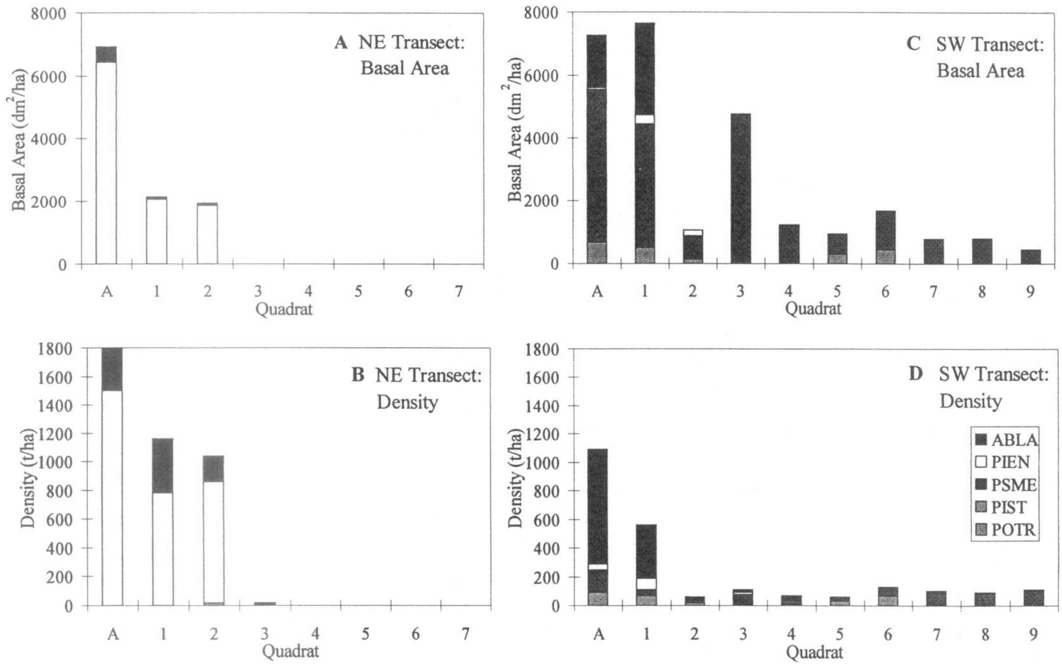

FIG. 2—Basal area and density values for trees (≥1 cm DBH) in the anchor (quadrat A) and contiguous quadrats in the NE transect (A and B) and the SW transect (C and D). Quadrat size is 0.04 ha for the NE transect, 0.1 ha for the SW transect. Species codes: ABLA: corkbark fir, PIEN: Englemann spruce, PSME: Douglas–fir, PIST: southwestern white pine, POTR: quaking aspen.

within the quadrats upslope were found on the edges of the stand.

A distinct compositional difference also is apparent with the different aspects (Fig. 2). Along the southwestern transect, the anchor contained a few very large Douglas-firs and a large number of corkbark fir in smaller size classes. Moving upslope into the meadow of the southwestern transect, Douglas-fir was dominant both in basal area and density within each quadrat, along with southwestern white pine in the midslope quadrats. The anchor of the northeastern transect and the two adjacent quadrats with significant tree cover were dominated by Englemann spruce. Within these quadrats, there was very little herbaceous cover (<50%), unlike quadrats of the southwestern transect with 80 to 90% fescue cover.

Examining patterns of saplings/seedlings (<1 cm DBH) indicated relatively low densities of advance regeneration upslope from the anchor in the southwestern transect (Fig. 3). Corkbark fir was the dominant species regenerating from the anchor to midslope; there was little regeneration along the upper slope with the exception of quadrat SW7, which contained three Douglas-fir, and one southwestern white pine, and corkbark fir, all <1 m tall. Along the northeastern transect, sapling/seedling densities were much higher, with Engelmann spruce dominating advance regeneration near the forest-meadow boundary. Seedlings and saplings that have established in the meadow (quadrats NE4 to NE7; Fig. 3) were all Douglas-fir that have arguably seeded in from the other side of the ridge (i.e., from the southwestern side, Fig. 1); flagging on these individuals indicates dominant winds coming up over the ridge from the southwestern side.

For soil properties, *t*-tests indicated that anchors have a greater CEC than upslope quadrats (23.0 versus 18.8 meq/100 g); compared to the southwestern transect, the more mesic northeastern transect had somewhat finer texture soils and greater amounts of total nitrogen (0.8 versus 0.4%), organic matter (19.9 versus 10.5%), and CEC (21.0 versus 18.0 meq/100 g), and less phosphorous (6.0 versus 31.2 ppm). All differences were significant at $\alpha = 0.05$.

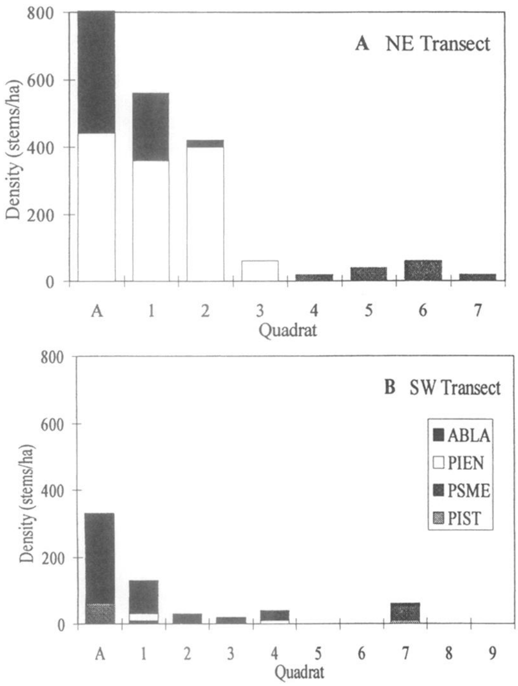

FIG. 3—Density values for seedlings/saplings (<1 cm DBH) in the anchor (quadrat A) and contiguous quadrats in the NE transect (A) and the SW transect (B). Quadrat size is 0.04 ha for the NE transect, 0.1 ha for the SW transect. See Fig. 2 caption for species codes.

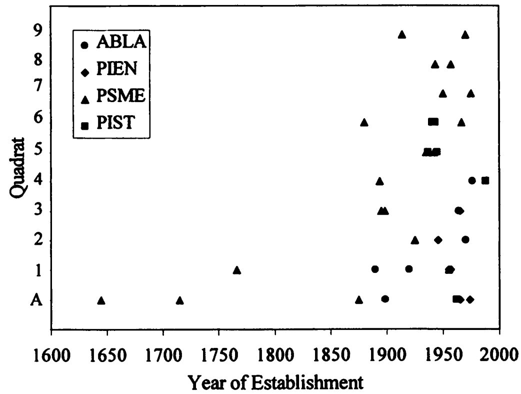

FIG. 4—Estimated establishment dates for the apparent oldest tree of each species in each quadrat of the southwestern transect. Quadrat A is the anchor. See Fig. 2 caption for species codes.

Examination of ages of the two oldest trees of each species suggests that there has not been an incremental upslope movement from anchor quadrats (Fig. 4); trees do not appear to be progressively younger upslope. For example, cores taken at 30 cm indicate that the oldest tree in SW9, the uppermost quadrat on the southwestern transect, was a Douglas-fir established ca. 1902. This individual is older than any other tree cored in quadrats SW8, SW7, or SW5 downslope; Douglas-fir individuals had established prior to 1890 in quadrats SW1, SW3, SW4, and SW6. The oldest tree dated from the northeastern transect occurred in quadrat NE2, not the anchor. This pattern suggests that there is not a temperature-defined treeline that has been advancing upslope because of climatic warming. Indeed, the north-facing slope of Sierra Blanca peak, the highest point in the White Mountains and less than 5 km to the southwest of Buck Mountain, has tree cover to its summit (3,649 m—Dye and Moir, 1977).

Figure 5 presents the number of cored trees established for the southwestern anchor and transect, by 5-year interval (pentad), with corresponding annual climatic variables since 1895. A 5-year interval was used to compensate for uncertainty in the number of years to coring height (Taylor, 1990), which this study assumed to be 12 years. Twelve of the cored trees established before 1895, including two Douglas-firs outside of the transect adjacent to a large block field. Establishment of these apparently oldest trees in this relatively young forested area has been more-or-less continuous since the turn of the century (Fig. 5). Interestingly, no establishment of cored trees is indicated during the 5-year period ending in 1920, which represents a period of enhanced establishment of ponderosa pine (*Pinus ponderosa*) elsewhere in the Southwest (Savage et al., 1996). The period from 1931 to 1965 evidenced greater establishment than the preceding period, 1895 to 1930; this period of enhanced establishment beginning about 1930 corresponds to an increase in annual precipitation (1902 to 1930: 60.5 cm; 1931 to 1960: 65.6 cm) and snowfall (1903 to 1930: 181.4 cm; 1931 to 1960: 188.1 cm) recorded at Cloudcroft. The three periods with highest recruitment (1931 to 1935, 1941 to 1945, 1951 to 1965) experienced years with annual precipitation well above normal. Periods of enhanced tree establishment reveal no unequivocal rela-

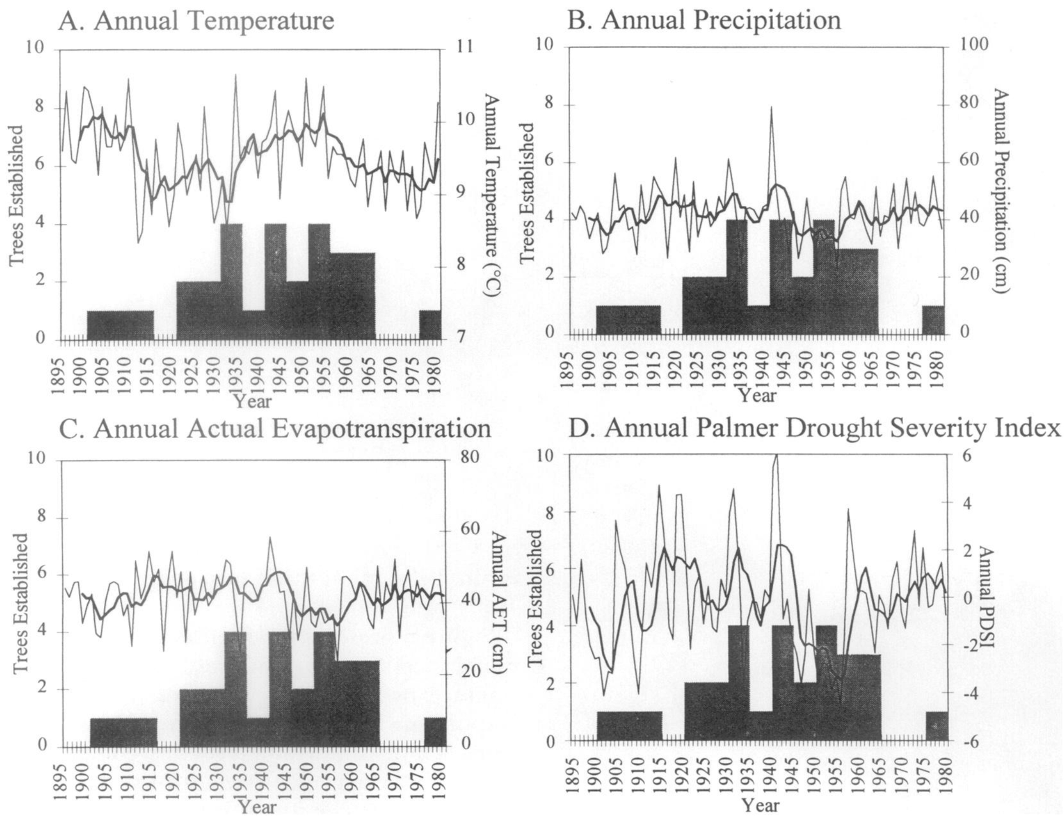

FIG. 5—Number of cored trees established (left axis) for all quadrats of the southwestern transect, with climatic data (right axis) for the Climatic Division encompassing Buck Mountain. Five-year moving averages for each climatic variable are indicated with the heavy line.

tionship with annual values of temperature, precipitation, actual evapotranspiration, and the Palmer Drought Severity Index (Fig. 5). For example, annual precipitation peaks do not always coincide with periods of increased tree establishment. We also examined relationships between tree establishment and seasonal values of temperature, precipitation, snowfall, actual evapotranspiration, and the Palmer Drought Severity Index. A graphical analysis of establishment and these climate measures revealed no strong seasonal relationships.

DISCUSSION—The invasion of subalpine meadows by adjacent forest has occurred extensively throughout western North America during this century. Investigations of the causal factors triggering these invasions have led to the conclusion that three factors generally are responsible, either individually or in combination: fire suppression, grazing cessation, and climate change. Identifying a single causal factor has proved an illusive task, largely due to the synchrony of these events. In much of the western United States, effective fire suppression began in the late 1800s to early 1900s, allowing establishment of tree seedlings and survival of saplings. At about this time, intensive grazing of sheep, and later cattle, was widespread in the western United States. Overgrazing by livestock degrades subalpine meadows, conferring a competitive advantage to tree species upon cessation/reduction of grazing pressure. Finally, changes in precipitation and temperature (including snow accumulation and timing of snowmelt) since the Little Ice Age (ca. 1850) have altered environmental conditions within subalpine meadows, favoring establishment of trees. The nature of climate change appears to be region- and site-specific, such that in some instances meadow invasion has been ascribed to a climatic warming and drying, whereas in other areas a cooler, wetter climate has been credited with initiating meadow invasion. Table 2 provides a summary of subalpine meadow invasion studies from western North America. Studies dealing with encroachment of treeline into tundra are not included (cf. Hessl and Baker, 1997). At many sites it has been impossible to ascribe onset of meadow invasion to a single factor; indeed, separate studies of the same area have evoked different primary factors to explain meadow invasion.

Factors such as accelerated erosion caused by human modification of the site (Dye and Moir, 1977) or the drying influence caused by the establishment of roads within the meadows (Taylor, 1990) do not seem to be important at this site. The access roads to Buck Mountain and adjacent Ski Apache were not constructed until 1960 (R. Parker, pers. comm.).

It has been estimated that as many as 5 million sheep may have grazed in New Mexico in 1890 (Denevan, 1967). By 1900, an open range sheep industry succumbed to a sedentary sheep industry, such that the 1.4 million ha of Forest Reserves within the state at that time were only grazed by residents and land owners within the Reserves (F. Roeder, pers. comm.). When Lincoln Forest Reserve (later National Forest) was established in 1902, the first ranger estimated that there were 66,000 sheep and goats within the Reserve, or approximately 288 animals per km^2 (there are ca. 5,000 animal units within the National Forest now, mostly cattle—F. Roeder, pers. comm.). However, a 1904 report indicates that although there was intensive grazing at the base of Buck Mountain, minimal grazing occurred higher up within the present study area (Plummer and Gowsell, 1904). Although we were unable to locate more recent grazing records for Buck Mountain proper, grazing records obtained from the Smokey Bear Ranger District in Ruidoso for the adjoining allotment indicate minimal grazing pressure by cattle from the 1940s to 1960s, when Wilderness status was conferred on the area and all grazing halted. Finally, grazing by non-livestock does not appear to be excessive within the study area: elk re-established in the management area encompassing Buck Mountain since 1965. Since 1980, an average of 213 elk and 187 deer have been spotted during winter counts within this management unit (New Mexico Game and Fish, in litt.).

Several lines of evidence suggest that fire has been an important disturbance agent affecting subalpine forest dynamics on Buck Mountain. Huckaby and Brown (1996) developed a fire chronology from a high elevation (2,900 m) Buck Mountain site, within the mixed-conifer zone below the spruce-fir zone of the present study area. Through dendrochronological techniques, they documented eight fires since 1775 (1776, 1819, 1841, 1855, 1866, 1882, 1886, 1892) from four fire-scarred trees. A map and accompanying text contained in a 1904 report indicate extensive areas of timber centered on Buck Mountain burned in 1895 (Plummer and Gowsell, 1904). Hanks and Dick-Peddie (1974) report fires in an area including Buck Mountain and the adjacent White Mountain Wilderness occurring in the 1880s, 1939, 1945, 1950, and 1963. In our study, one fire scar was dated to ca. 1940, and the presence of aspen stands on and around Buck Mountain, which aerial photographs suggest established since the 1930s, also imply past fire. Although we observed fire-scarred trees on the western flank of Buck Mountain approaching the summit, in general there were very few fire-scarred trees encountered in the study area. This fact, coupled with the relatively young age of the forest stands, is consistent with the pattern of stand-destroying fire, common to high elevation coniferous forests (Moir, 1993). No burned snags were seen in the meadows, which would have suggested that fires periodically kill trees that routinely advance into the meadow. Fire suppression apparently has not influenced current stand dynamics and composition on Buck Mountain.

It is unlikely that a temperature-limited treeline exists on Buck Mountain and other high elevation peaks of the White Mountains. Sierra Blanca, the highest peak in the White Mountains, is forested to its summit along its north slope. Treeline is at higher elevation on the northeastern slope compared to the southwestern slope of Buck Mountain. Treeline appears to be stable on the northeastern slope of Buck Mountain, whereas continuous encroachment is evident on the southwestern slope. These aspect differences suggest that a microclimatological factor is responsible for control-

TABLE 2—Summary of subalpine meadow encroachment studies that have been conducted in western North America. Factors cited as responsible for encroachment at each study site are indicated with an x.

Study	Location	Fire suppression	Grazing	Climatic change
Strange and Parminter (1980)	Chilcotin Grasslands, B.C., Canada	x	x	
Brink (1959)	Coast Range, B.C., Canada			x
Franklin et al. (1971)	Cascade Range, WA			x
Rochefort and Peterson (1996)	Cascade Range, WA			x
Agee and Smith (1984)	Olympic Mountains, WA			x
Kuramoto and Bliss (1970)	Olympic Mountains, WA			x
Rummel (1951)	Olympic Mountains, WA		x	
Vale (1981)	Cascade Range, OR	x	x	x
Magee and Antos (1992)	Coast Range, OR			x
Taylor (1990)	Lassen Volcanic National Park, CA	x	x	
Taylor (1995)	Lassen Volcanic National Park, CA			x
DeBenedetti and Parsons (1979)	Sierra Nevada, CA			x
Helms (1987)	Sierra Nevada, CA			x
Vale (1987)	Sierra Nevada, CA		x	
Vankat and Major (1978)	Sierra Nevada, CA		x	
Vale (1975)	Warner Mountains, CA		x	x
Vale (1977)	Warner Mountains, CA		x	
Butler (1986)	Lemhi Mountains, ID		x	x
Dunwiddie (1977)	Wind River Mountains, WY		x	
Jakubos and Romme (1993)	Yellowstone National Park, WY			x
Hansen et al. (1995)	Madison Range, MT		x	x
Arno and Gruell (1986)	Rocky Mountains, MT	x	x	
Ostler et al. (1982)	Uinta Mountains, UT			x
Schimpf et al. (1980)	Uinta Mountains, UT			x
Allen (1989)	Jemez Mountains, NM	x	x	

ling treeline. Hanks and Dick-Peddie (1974) suggest that high elevation (>2,900 m) windward ridges are treeless as a result of the desiccating effect of winds in late winter and early spring, when soils are still frozen or partially frozen at these sites. Water uptake therefore would be retarded, resulting in physiological drought. Because this region experiences a short growing season, with a wet summer monsoon season and dry spring and fall months (Alexander et al., 1984), it seems likely that climatic constraints on tree establishment would display a seasonal pattern. A related effect concerning wind effects and tree establishment involves differential snow accumulation. Dominant winds appear to be from the southwest at this site, which should result in higher snow accumulations on the northeastern side. The presence of apparent avalanche chutes on the northeastern side supports the idea of heavy, wind-driven snow accumulation. Greater snow accumulation would result in a shorter growing season on the northeastern slope and reduced chances for tree establishment.

We examined both seasonal and annual climatic relations with tree establishment. Graphically, periods of enhanced establishment on Buck Mountain coincided with peaks in regional precipitation (and similarly, actual evapotranspiration and the Palmer Drought Severity Index); in addition, a potential interactive effect is indicated, with periods of establishment occurring with increased precipitation coupled with warmer temperatures (Fig. 5 A, B). However, no unequivocal relationship between climate and tree establishment can be established based on current data. This could in part be a consequence of sampling methods: only the apparent oldest trees of each species were sampled in each quadrat. If sampling was more comprehensive, and a greater number of cores extracted overall, perhaps a stronger climatic signal might be detected.

CONCLUSIONS—Aspect differences were uncovered between northeastern and southwestern slopes of Buck Mountain, with regard to both stand composition and encroachment. Both stands were relatively young, and suggest recovery from stand-destroying fire near the turn of this century. The forest of the northeastern slope is true subalpine, dominated by Englemann spruce, with corkbark fir as a subordinate species; treeline there appears to have been stable for decades. In contrast, stands of the southwestern slope are dominated by corkbark fir, with Englemann spruce as a subordinate species; the mixed-conifer species Douglas-fir also is a major component of these stands, indicating warmer, drier conditions. Encroachment of the forest into adjoining meadow appears to have been an ongoing process throughout this century on the southwestern slope, with the possibility of periods of enhanced establishment. Douglas-fir may be acting as the pioneer colonizer, its dispersal perhaps facilitated by the numerous rodents encountered within the study area (Hofmann, 1920). Once established, Douglas-fir individuals may then be acting as nurse trees, modifying microclimatic conditions upslope, and perhaps facilitating subsequent colonization by the bird-dispersed southwestern white pine (Lanner, 1996).

Historical records indicate minimal grazing of high elevation meadows of Buck Mountain; therefore, this factor is likely to have had little, if any, impact on meadow encroachment. Fire has played an important role in stand dynamics in the spruce-fir zone. The record of recent past fire at the site, however, suggests that suppression is not a significant factor influencing encroachment at this site. That the forest-meadow boundary is stable on the northeastern slope, but shows roughly continuous encroachment along the southwestern slope, suggests that changes in microclimatological conditions may be responsible for the advancing forest boundary of the southwestern slope. One hypothesis to account for this difference in aspect is that tree establishment may be inhibited along the northeastern transect due to its shallower, finer texture soils, which might reduce water holding capacity and percolation (Doering and Reider, 1992). A second hypothesis also relates to soil moisture. In the Pacific Northwest, it has been suggested that climatic change has an aspect-specific influence related to seasonal snowpack: tree establishment on western aspects (where snow accumulation is greater) is favored by warmer, drier growing seasons, whereas establishment on eastern aspects (where snowpack is less) is favored by cooler, wetter growing seasons (Kuramoto and Bliss, 1970; Rochefort and Peterson, 1996). At our study site in south-central New Mexico, snowpack accumulations are unlikely to be as great as in the Pacific Northwest, but greater accumulations on the northeastern slope is possible. Wetter conditions might facilitate tree establishment along drier exposures (that experience lower snow accumulation). An increase in tree establishment along the southwestern transect coincides with an increase in precipitation since 1930. Enhanced establishment periods of shorter duration (5 years) suggest a relationship with peaks in precipitation and possibly warmer temperatures, but our sample size is not sufficient to establish this relationship unequivocally. The evidence on hand, however, suggests climate change as the dominant factor responsible for meadow encroachment, with fire suppression and grazing pressures playing negligible roles at this site. Further investigations should focus on the link between climate change and establishment, especially focusing on patterns of climate favorable for establishment following successful seed production. Favorable seed years are infrequent at high elevations in the southern Rocky Mountains, especially for corkbark fir (Alexander, 1990).

This study was limited by a small sample size ($n = 53$ trees) by which to establish periods of enhanced establishment. Additionally, because we studied only one meadow, inferences can not be extended beyond our study site. Other uncertainties, independent of sample size, limit conclusions that can be drawn from similar investigations. These include knowledge of 1) precise establishment dates (versus establishment dates estimated from cores taken at 30 cm) to correlate with specific climatic events, 2) physiological limitations of candidate meadow invader species at treeline, 3) microclimatic conditions conducive to the germination of individual species along forest-meadow boundaries, and 4) competitive interactions between forest trees and meadow grasses under various climatic conditions.

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