Tree Invasion of Montane Meadows in Oregon

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ABSTRACT: Mesic montane meadows in the Cascade Mountains of central and southern Oregon have been invaded recently by trees from the adjacent forests. Cessation of sheep grazing coincides with the initiation of the tree invasions, but the absence of frequent fires and cool moist weather both may have contributed to the conditions which favored the unstable ecotones.

INTRODUCTION

The dense coniferous forests on the western slopes of the Cascade Mountains of central and southern Oregon are occasionally broken by mesic meadows on, or near, ridge tops. Throughout most of the last century, and perhaps longer, the ecotones between the forests and the meadows have been stable, judging from the abrupt edges of the mature forests. Yet the presence of young trees within the meadows today, usually growing most densely as a band bordering the forest edge, suggests a recent invasion of these formerly treeless areas (Fig. 1). The purpose of this paper is to evaluate several possible causes of these recent tree invasions.

SITES

Six meadows were selected for investigation after review of appropriate published works (Franklin *et al.*, 1972; Franklin and Dyrness, 1973), field reconnaissance and consultation with personnel at local offices of the U.S. Forest Service. These particular meadows were chosen because they had invasive trees, they were close to one another, and they had varied land-use histories. The meadows represented two of

Fig. 1.—Invasive trees on Big Bunchgrass meadow

the nonforested types (*Rubus parviflorus/Pteridium aquilinum* meadow associes, and *Bromus carinatus/Rudbeckia occidentalis* meadow associes) identified by Hickman (1976). They were located within four of the forested zones recognized by Franklin and Dyrness (1973); the invasive trees represented several species, reflecting the composition of these surrounding forests (Table 1).

METHODS

At each meadow, at least one rectangular belt transect was laid out perpendicular from the edge of the mature forest and extending across the stand of invasive trees bordering the meadow. All transects ended in open vegetation beyond the belt of young trees. The transects were 50 m long and 2, 5 or 10 m in width, with narrower transects in areas of denser trees. Eight transects were sampled. All trees rooted within the transects and exceeding 1.4 m in height were identified to species, measured for circumference at breast height, and cored with an increment borer ca. 8 cm above their bases. Age was estimated as the number of annual rings plus 3, to allow for growth to the level of the core. Trees were stratified into 5-year age classes for comparison with data on climatic trends and land-use histories. A total of 202 trees were cored and aged. Trees 1.4 m and shorter were identified to species and recorded by height. General conditions of the meadows and the adjacent forests were also noted. All field data were collected during the summer of 1976.

The records of four Weather Bureau stations from ca. 1910 were used to characterize the recent weather history of the region. The names of the stations, their elevations and their horizontal distances from the closest meadow sampled were as follows: Prospect, 756 m, 22 km; Crater Lake, 1973 m, 32 km; Oakridge, 399 m, 23 km, and McKenzie Bridge, 418 m, 17 km. Three aspects of the records were evaluated: annual precipitation (based on precipitation from 1 July to 30 June), spring temperatures (the average of the monthly means for March, April and May), and summer temperatures (the average of the monthly means for June, July and August). Means for the periods of record for each of the three variables at each station were computed, and the annual deviations were calculated. These deviations were then averaged for the four stations for each year, and then the composite

TABLE 1.—Environments and invasive trees in meadows sampled

Meadows	Elevation (m) and aspect	Invasive trees	Forest zone
Abbott Butte	1737 SW	*Libocedrus decurrens*	Mixed conifer zone
Yellow Jacket Camp	1448 NNW	*L. decurrens* *Abies concolor**	*Abies magnifica* zone
Hershberger Mountain	1722 SSE	*A. magnifica* *Pinus monticola** *Tsuga mertensiana**	*Abies magnifica* zone
Grasshopper Mountain	1463 SSW	*L. decurrens* *A. grandes* *Pseudotsuga menziesii** *T. heterophylla**	*Tsuga heterophylla* zone
Wildcat Mountain	1365 SW	*A. procera* *T. mertensiana* *A. amabilis**	*Abies amabilis* zone
Big Bunchgrass	1664 S	*Pinus monticola** *P. contorta* *Abies* sp. *Tsuga* sp.*	*Abies amabilis* zone

*Indicates species represented by only one or two individuals among trees cored with increment borer

means were averaged again for 5-year periods. The pentads were then ranked from lowest to highest for each of the three variables, and they were then grouped into three clumps of equal size; the groups represent below normal, normal and above normal pentads. Adjustments in placement of individual pentads were then made so that periods with identical values were not placed in different groups. This procedure resulted in the following arrangement of pentads: for annual precipitation, five dry, four normal and four wet; for spring temperatures, four cold, five normal and three warm; and for summer temperatures, three cold, four normal and five warm. Considering each meadow individually, chi-square tests were used to determine whether or not pentads during which tree invasions occurred were characterized by weather conditions distinct from those when tree invasion did not occur.

To extend the weather record beyond 1910, two additional Oregon stations (Portland, elevation 23 m, closest meadow 145 km, first records 1872; and Roseburg, elevation 146 m, closest meadow 71 km, first records 1878) were evaluated in a manner identical to that used for the four stations closer to the meadows. Linear regression and Spearman's rank correlation analyses indicated that the records of Roseburg and Portland were strongly correlated ($P<0.01$) with those of the four stations closer to the meadows (precipitation Roseburg $R^2 = 0.79$, $r_s = 0.87$, Portland $R^2 = 0.59$, $r_s = 0.74$; spring temperatures Roseburg $R^2 = 0.82$, $r_s = 0.86$, Portland $R^2 = 0.68$, $r_s = 0.82$). The weather conditions for pentads prior to 1910 were then compared with the mean values for the years after 1910.

Fire histories of the meadows were determined from fire records of the U.S. Forest Service. (Fire scars on trees were not common, and it was felt that even where present such data would likely underestimate the frequency of burns within the meadows.) The total number of acres burned during each 5-year period was compiled for the two national forests in which the meadows are located. The acreage burned in each pentad was expressed as a percent of the acreage burned in the pentad with the highest value. The percentages were graphed, and the timing of successful fire suppression was visually estimated by observing when decreases in burned acreage occurred. The results were compared with descriptions of early fires and fire regimes as reported in government reports, newspaper accounts and scholarly works.

The history of livestock grazing in the meadows studied was also reconstructed from the records of the U.S. Forest Service. The meadows were located within named grazing allotments, and the numbers of livestock per allotment and per year were determined from grazing permit cards, on which are recorded by name of permittee, the type and number of livestock by grazing allotment. These cards were sometimes incomplete, and occasionally ambiguous or contradictory, but they did allow a reasonable reconstruction of the relative intensity of livestock use.

The resulting numbers were used to determine stocking rates per meadow per year. Data were aggregated into 5-year periods and classified by type of livestock use. Chi-square analysis was used to test the proposition that pentads with tree invasion were characterized by grazing use distinct from those without tree invasion.

RESULTS AND DISCUSSION

Only an occasional tree became established in the meadows prior to 1935 (Table 2). The rate of invasion increased over the next 10 years, although trees were not invading all six meadows until after 1945. The decade 1950-1959 was characterized by the largest number of invasive trees.

Based on the weather histories of the four stations closest to the meadows studied, the pentads with tree invasion were characterized by above normal precipitation and near normal spring temperatures (Table 3). Summer temperatures during years

of tree invasion were not significantly different from those of years without tree invasion.

The extension of the weather history based on Roseburg and Portland revealed that the 30-year period 1875 - 1904 featured those conditions which were correlated with tree invasion, *i.e.*, precipitation above normal and spring temperatures close to, but slightly below, the means for the period 1909-1974 (Fig. 2). This 30-year period, however, was one during which the forest-meadow ecotone was stable. Therefore, the cool and wet weather after 1950 could not have acted as a "trigger" for the tree invasion.

The sequence of dry conditions followed by a wet period may have been more important as a cause of the tree invasion than the above normal precipitation alone. The warm dry years between 1925 and 1945 were, in fact, extreme, constituting the longest and most pronounced warm dry period in western Oregon in at least 475 years (Fritts, 1965). It might be argued that the meadows were sufficiently desiccated during this unique period to reduce the vigor of the herbaceous plants and thereby allow the establishment of trees when precipitation increased. Other than this possibility, weather fluctuations seem unable to account for the tree invasions, and some other environmental factor must be invoked to explain the unstable ecotones.

TABLE 2.—Numbers of invasive trees, by date of germination and pentad

Date of germination	Number of invasive trees	Number of meadows with invasive trees
Before 1920	0	0
1920-1924	1	1
1925-1929	0	0
1930-1934	2	2
1935-1939	9	4
1940-1944	8	3
1945-1949	25	6
1950-1954	76	6
1955-1959	66	6
1960-1964	15	5
1965-1974	(599)*	5

*Indicates trees too small to core; some of these trees probably belong to the next older age class

TABLE 3.—Climatic and grazing characteristics of pentads with and without tree invasion

	Climate			
	Above normal	Normal	Below normal	
	Annual precipitation			
With invasive trees	22	8	12	
Without invasive trees	8	4	24	$x^2 = 11.47$, $P < 0.01$
	Spring temperatures			
With invasive trees	10	23	9	
Without invasive trees	14	7	9	$x^2 = 7.41$, $P < 0.05$
	Summer temperatures			
With invasive trees	13	11	18	
Without invasive trees	5	13	12	$x^2 = 3.01$, $P > 0.05$, n.s.
	Grazing			
	Sheep grazing	Cattle grazing	No grazing	
With invasive trees	6	16	20	
Without invasive trees	28	4	5	$x^2 = 30.24$, $P < 0.01$

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7.41, $P < 0.05$

.01, $P > 0.05$, n.s.

0.24, $P < 0.01$

Wild fires are often responsible for the maintenance of grasslands or mixtures of grass and brush free of trees; decreases in these burns may trigger tree invasions (*e.g.*, Humphrey, 1963; Bragg and Hulbert, 1976; Burkhardt and Tisdale, 1976). Such a cause of ecotone instability depends on a preinvasion fire regime of frequent surface fires, but forest fires in Oregon W of the Cascade crest were typically infrequent crown burns in presettlement times (Martin *et al.*, 1976). The even-aged structure of the forests surrounding at least two of the meadows studied in the central Cascades supports this characterization of the fire regime (Franklin *et al.*, 1972). Surface fires, however, apparently also occurred occasionally in the forests of this region (Weaver, 1974). The forests of the Cascades of southern Oregon, particularly those of mixed conifers, were typified by more frequent, less intense ground fires, as evidenced by the relatively rapid change in the species composition of forest reproduction since the initiation of fire suppression (Cole, 1977). Some early descriptions of these forests as open and parklike support this view (Langille *et al.*, 1903; Briem, 1937; Sundam, 1937). At least in the more southerly meadows studied, then, the forest fire regime was conducive to the maintenance of the meadows.

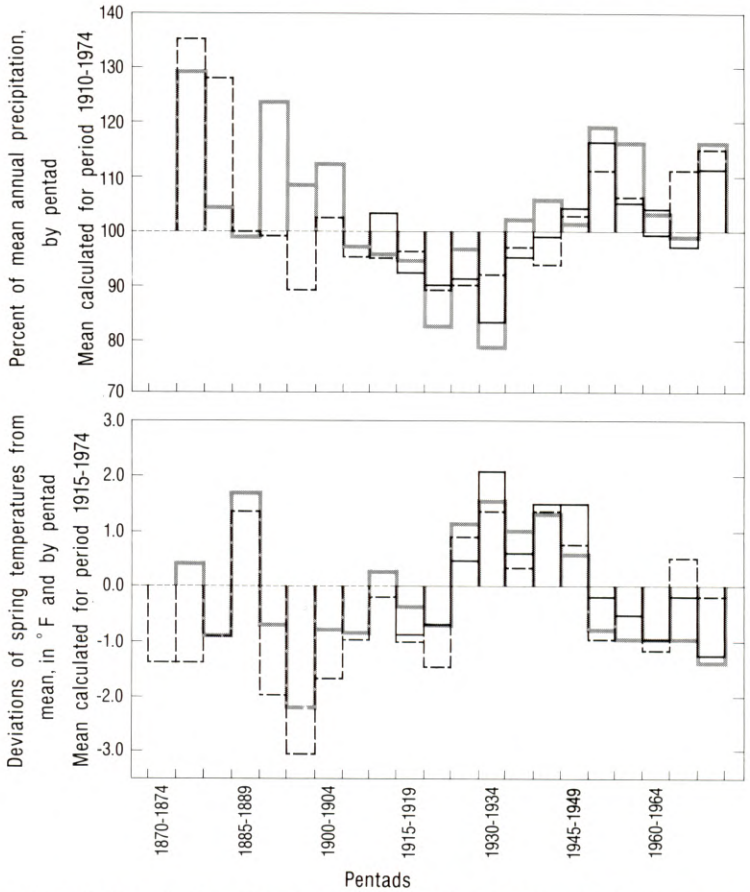

Fig. 2.—Climatic histories for selected Oregon locations. Dark solid line is average of Crater Lake, Prospect, Oakridge and McKenzie Bridge. Light shaded line is Roseburg. Dashed line is Portland. Calculation procedure explained in text

Regardless of the fire regimes in the forests, the frequency of burns in the meadows may have been much greater than that in the surrounding timber. The evidence for this suggestion is the occasional mention in historical sources of Indian-set fires in the meadows (Briem, 1937; Sundam, 1937). A regime of frequent, human-initiated fires was responsible for the maintenance of grass vegetation in the relatively dry Willamette Valley (Minto, 1896; Johannessen, 1971), presumably a climatic environment less conducive to tree growth than the mesic mountain meadows. Early sheepherders also may have burned the grasslands in order to increase forage (Brown, 1960), thereby replacing native Americans when they were eliminated as an ecological factor. It seems possible, then, that fires were critical to the prevention of forest expansion into the meadows.

If a decrease in frequent fires was responsible for the establishment of trees in the meadows, the ages of the oldest trees should coincide with the timing of successful fire suppression. Cole (1977) states that fire frequencies were greatly reduced in western Oregon by the middle of the 19th century, but Morgan (1964) indicates that forest fires were common and typically burned unchecked until the U.S. Forest Service assumed administrative responsibility for the forest reserves in the 1st decade of the 20th century. In support of Morgan, Morris (1934) suggests that large forest fires occurred in many years through the early part of this century.

Records of the acreage burned in the two national forests that encompass the six meadows studied begin ca. 1910 (Fig. 3). The high values recorded for the period 1910-1920 probably represent the lack of fire suppression, or at least only partial success. By 1930, the area burned was greatly reduced, although large fires in individual years produced high values for certain subsequent pentads in the Willamette National Forest.

This timing for a successful fire suppression policy far predates the establishment of the invasive trees. It is possible, however, that fires prevented tree invasion prior to 1920, and warm, dry weather discouraged the germination and survival of trees between 1920 and 1945. According to this view, the absence of fires and the abundance of moisture after 1945 allowed the tree invasion to accelerate.

It is also possible that still another factor, grazing by domestic livestock, helped keep the meadows free of trees after the frequency of fires was greatly reduced. Chi-square analysis indicates that pentads with tree invasion were characterized by either no grazing or grazing by cattle only; pentads without establishment of trees were characterized by sheep grazing (Table 3). The negative association between sheep grazing and tree invasion is even more strongly expressed when numbers of invasive trees are compared with grazing use (Fig. 4). Although nearly one half of the total time of the grazing record was characterized by sheep grazing, less than 4% of the total number of trees germinated with that livestock use. Conversely, grazing by cattle and an absence of all grazing each account for about one fourth of the total time, but both categories are associated with disproportionately large numbers of invasive trees.

Hidden within these aggregated data is the important fact that each period lacking livestock use followed a period of use by sheep. In addition, tree invasion began on one meadow when grazing use was changed from sheep to cattle. It is possible that sheep grazing reduced the herbaceous vegetation in the affected meadows, and that the more meager herbaceous plant cover subsequently allowed the tree invasion once the sheep were removed. Historical accounts describing meadows damaged by overgrazing support this interpretation (Coville, 1898; Langille *et al.*, 1903; Elliot, 1946; Chriswell, 1952). Even if the sheep grazing did not act as the "trigger" which subsequently allowed tree invasion, it probably precluded establishment of trees in the meadows during the time of such livestock use.

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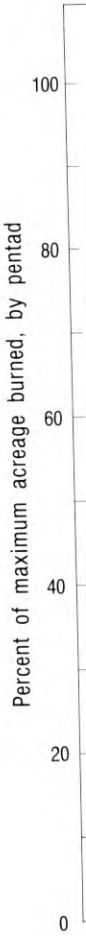

Fig. 3.—Re

The identification to the environmental change which "triggered" the invasion of the meadows by trees is made difficult by the coincident or near-coincident timing of the environmental changes investigated, and by the gradual but accelerating rate of invasion which prevents the identification of the "beginning" of the invasion (Fig. 5). Cessation of grazing by sheep provides the best single-factor explanation, and precedent for this explanation exists in the literature (Vankat and Major, 1978). Interactions among the three factors, however, are perhaps more likely in this instance. For example, frequent burning by Indians may have maintained the meadows prior to European contact; burning by herders and heavy grazing by sheep may have prevented tree invasion during the late 1800s and early 1900s; and warm, dry weather and sheep grazing may have kept the meadows nearly free of trees from 1920 - 1945. Tree invasion was thus possible at accelerated rates only after 1945

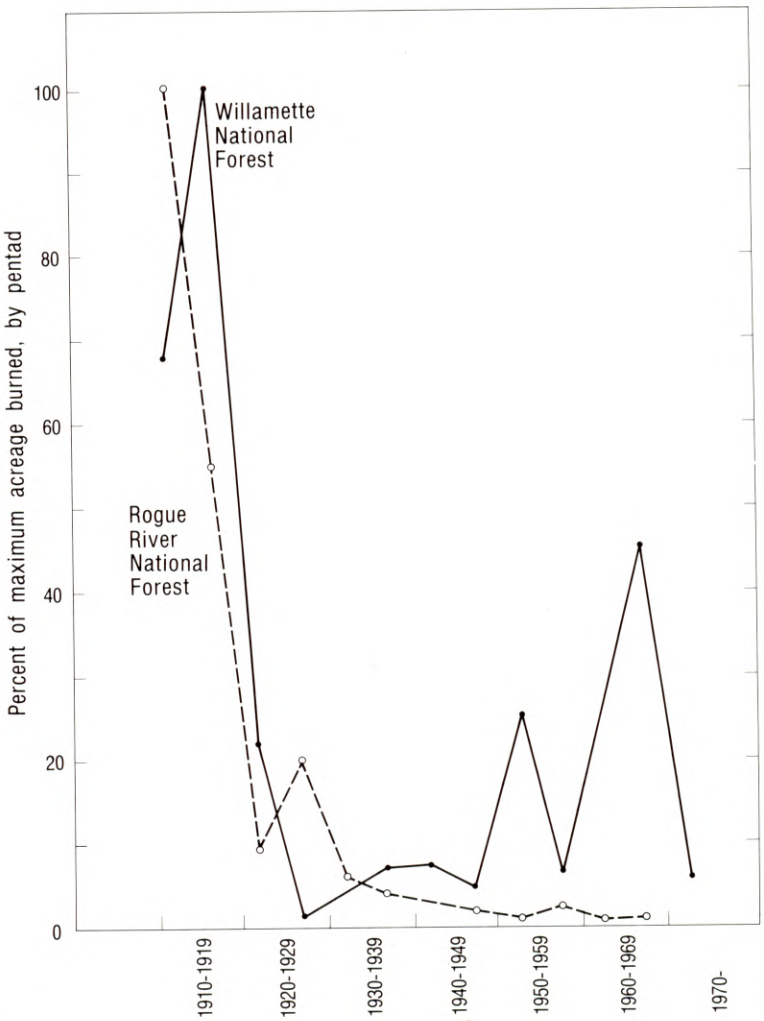

Fig. 3.—Recent fire histories of national forests in which study meadows are located. Calculation procedure explained in text

when all three factors were conducive to ecotone instability: absence of frequent fires, cessation of grazing by sheep, and a period of cool, wet weather.

These tree invasions may or may not represent a change which is transforming the meadows into forest. The meadows may be maintained indefinitely by disturbance phenomena which kill invasive trees but which occur too infrequently to be evaluated properly in this study (*e.g.*, occasional fires); the presence of trees in the meadows at any one time may merely represent episodes between disturbance events. On the other hand, the meadows may be so singularly changed from presettlement conditions by processes associated with modern humans (*e.g.*, introduction of domestic sheep) that these formerly treeless areas will gradually become forested.

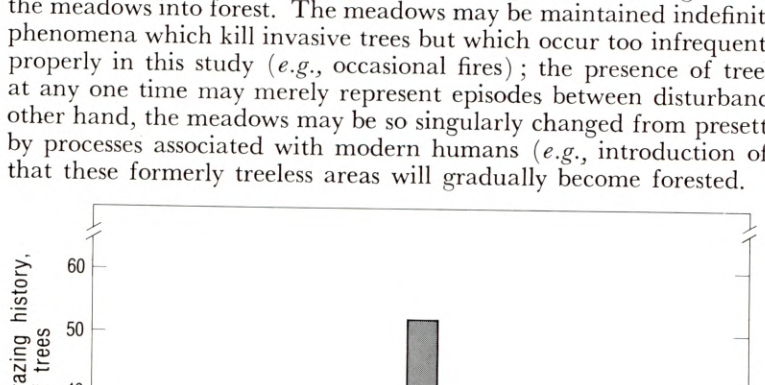

Fig. 4.—Comparison between numbers of invasive trees and type and intensity of grazing use. Dark heavy line indicates percent of time associated with differing livestock uses. Shaded areas indicate percent of invasive trees associated with differing livestock uses

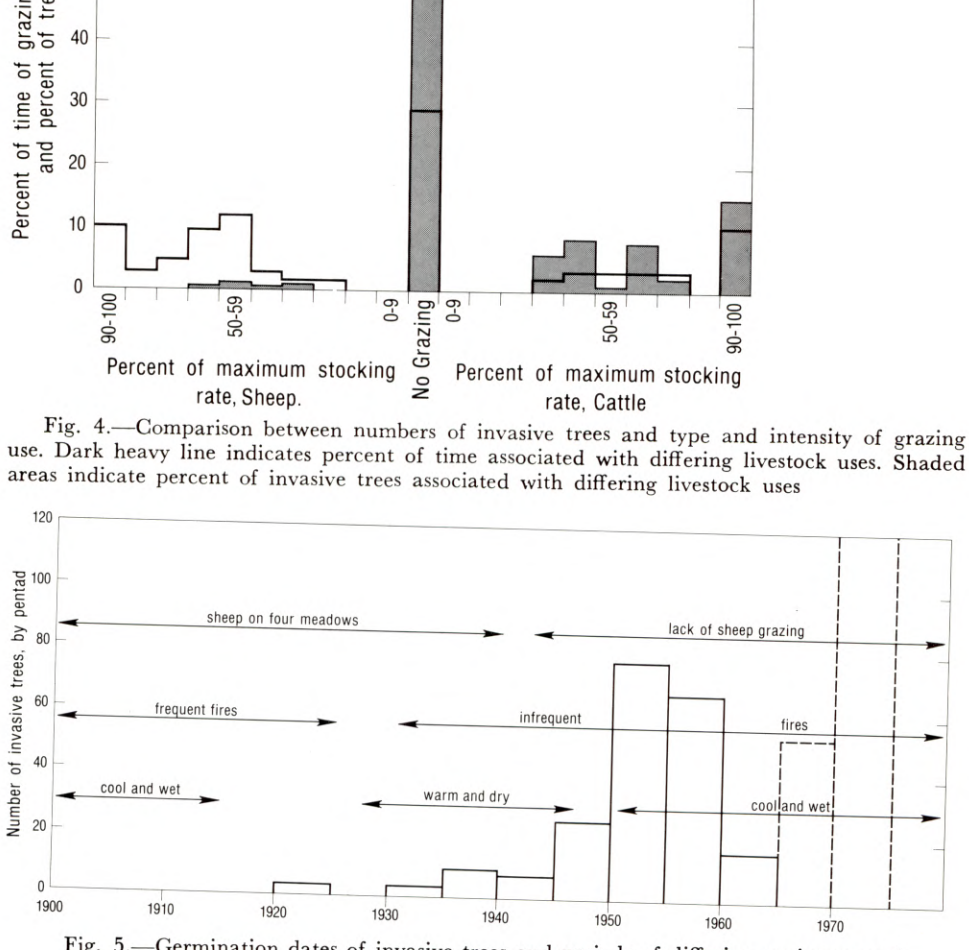

Fig. 5.—Germination dates of invasive trees and periods of differing environmental conditions. Dashed lines indicate two classes of trees recorded only by height

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SUBMITTED 20 NOVEMBER 1979 ACCEPTED 7 FEBRUARY 1980