TABLE 1. Site characteristics for the 15 quadrats (redundant data are not repeated within a geographic region).

Quadrat number	Geographic region	Latitude (decimal)	Longitude (decimal)	Elevation (meters)	Slope	Aspect	Soil WHC[1]	Canopy species[2]
1	Humphrey Peak	35.27	111.6	2226	17°	S 80° E	32-88/45-60	PIPO/QUGA
2					25°	N 70° E		PIPO/QUGA
3					25°	N 75° E		PIPO/QUGA
4,5,6	Flagstaff	35.03	111.73	2165	0°		40-90/50-77	PIPO/QUGA
7,8,9		35.00	111.67		8°	N 65° E	40-90/50-77	PIPO/QUGA
10	Pinedale	34.3	110.25	1982	4°	N 45° W	unknown	PIPO/QUGA
11				2012	0°			PIPO/QUGA/JUXX
12				1982	20°	S 10° E		PIPO/QUGA/JUXX
13	Sandia Mountains	35.13	106.53	2226	15°	S 80° E	46-122/58-65	PIPO/PIED/JUXX/QUGA
14					10°	S 60° E	40-85/42-46	PIPO/PIED/JUXX/QUGA
15		35.15	106.53	2165	23°	S 30° W	54-66/60-62	PIPO/PIED/JUXX/QUGA

[1]WHC = Water Holding Capacity (%). A range of water holding capacities is reported for the soil surface layer and at a depth of 30 cm (Neilson and Wullstein 1983).
[2]PIPO = *Pinus ponderosa*, QUGA = *Quercus gambelii*, PIED = *Pinus edulis*, JUXX = *Juniperus* sp.

flat lowland area (No. 10), and a flat plateau area. All three areas possessed a high density of seedlings, with the plateau exhibiting the greatest number (1,080/ha). All three areas had been artificially thinned, but still possessed a fairly dense canopy. Quadrats 10 and 12 were primarily mature ponderosa pine with ca 500 stems/ha and an average dbh of 18 and 27 cm, respectively. Quadrat 11 was mixed conifer/oak woodland.

Quadrats 13–15 in the Sandia Mountains, New Mexico, were characterized by mixed conifer forest with a Gambel oak component. Quadrat 15, on a south-facing slope, was similar in seedling density to most other quadrats, with 513 seedlings/ha. Quadrats 13 and 14 were on east-facing ridges. These quadrats were of the same elevation and aspect and were within 1 km of each other. Quadrat 14 was located on a primary ridge separating major drainage basins. It was at a lower angle than No. 13 and contained more bare ground. Quadrat 13, by contrast, was located on a ridge within a major drainage basin, was at a steeper angle, and contained less bare ground than No. 14. By virtue of their close proximity, the two quadrats would be expected to receive similar amounts of rainfall. Because of its position as a drainage divide, the primary input of moisture to Quadrat 14 was likely limited to incident rainfall. Quadrat 13, however, received moisture from both rainfall and runoff from the surrounding basin within which it occurred. This was particularly evident from extensive rill development, which was absent on Quadrat 14. Quadrat 13 possessed 1,320 seedlings/ha in contrast to 120 seedlings/ha in Quadrat 14.

Table 2 indicates the number of seedlings in sheltered and unsheltered positions for each of the quadrats. Quadrats 11, 13, and 15 were too dense to allow judgements of sheltering. Sixty percent (341/571) of the seedlings in 12 quadrats (i.e., excluding quadrats 11, 13, and 15) were scored for their orientation with regard to a sheltering object (Table 2, Fig. 1). The distribution is significantly skewed ($X^2 = 33.74$, $P \ll .01$) to the NE quadrant.

Age estimates of 14 randomly collected seedlings (<30 cm crown height) ranged from 6 to 17 years. Regressions of root length against root diameter indicated root taper ranging from $-.06$ to $-.19$ mm/cm (r^2 ranged from .81 to .99). Since these measurements were obtained from broken taproots, total root length was extrapolated from the regression equations and found to range from 40 to 114 cm. Root growth rates were estimated to range from 2.7 to 11.4 cm/yr.

Discussion

Several points are apparent from these data. First, Gambel oak seedlings are abundant and widely distributed in the southern part of the range of this species and are rare in

TABLE 2. Total seedlings (sheltered and unsheltered) per quadrat.

Quadrat no.	Sheltered	Unsheltered	Seedlings/ hectare
1	40	19	590
2	16	20	360
3	32	16	480
4	24	20	440
5	29	6	350
6	14	10	240
7	19	20	390
8	12	13	250
9	58	28	860
10	50	37	870
11	unknown	unknown	1080
12	35	41	760
13	unknown	unknown	1320
14	12	0	120
15	unknown	unknown	513

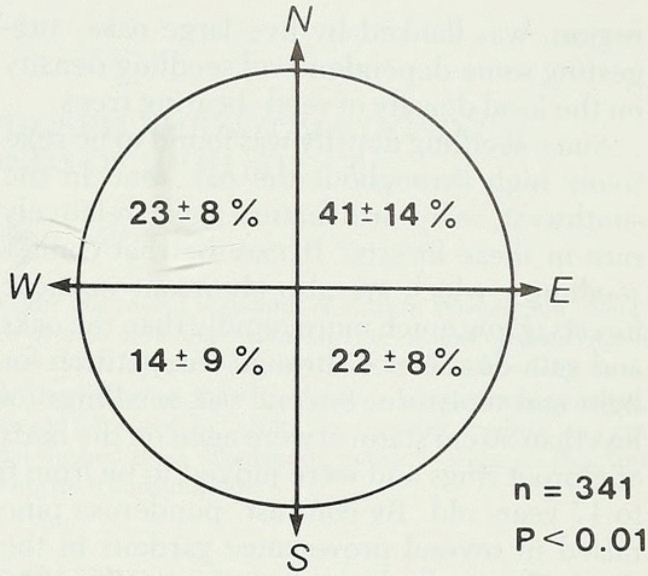

Fig. 1. Compass orientation of seedlings (% per quadrant) associated with a sheltering object in all quadrats, excluding quadrats 11, 13, and 15 (see text for explanation).

the northern part of the range. Second, mature Gambel oak is a relatively minor component of the ponderosa pine–mixed conifer forest. Third, although Gambel oak does clone in Arizona and New Mexico, the apparent number of ramets per clone is relatively few (1–7 in the quadrats sampled, although larger numbers can be found) compared to the hundreds to thousands of ramets per clone that are common in the northern parts of the range (Brown 1958, Ream 1963). A corollary to this point is that mature ramets are much larger in the south than in the north, where dbh is typically in the range of 5–8 cm (Brown 1958, Ream 1963) compared to 16–17 cm in the south. Fourth, although seedlings are widespread across a range of microhabitats, their distribution and abundance does appear to reflect some dependence on soil moisture.

This last point is most interesting. We previously reported (Neilson and Wullstein 1983) that seedling survival in the southern parts of the range was largely independent of microhabitat, being high in all situations from sheltered to unsheltered. The three contiguous quadrats on Humphrey Peak are in support of this contention. Whereas the shrub distribution indicated considerable edaphic and/or hydrologic differences between the swale and ridge habitats, the seedling density across this gradient indicated no trend. Nevertheless, 60% of the seedlings in these and the other quadrats did exhibit a strong pattern of sheltering, apparently favoring mesic microhabitats. This is further supported by the two ridge quadrats in the Sandia Mountains. One ridge was apparently swept frequently by surface flow, as indicated by the extensive rill development and the location of the ridge within a major drainage basin. Intense summer thunder showers are common in this region (Bryson and Lowry 1955). This ridge contained the highest density of seedlings observed in any of the quadrats, notwithstanding the apparently high surface wash. A neighboring ridge, a major drainage divide, apparently received little to no runoff from the surrounding landscape, as indicated by the absence of rills. This ridge contained the lowest density of oak seedlings observed (all of which were sheltered) in any of the quadrats. In almost every respect but hydrology, the two ridges appear to be similar. This suggests that even in a region where summer rain is relatively high, a consistently mesic microhabitat may be required to provide adequate soil moisture for seedling survival.

The six quadrats on the relatively flat Mogollon Rim south of Flagstaff present some evidence that the density of seedlings is not entirely independent of the density of adults. Five of these quadrats possessed seedling densities ranging from 250 to 440 per hectare (quadrats 4–8), whereas one (quadrat 9) possessed a seedling density of 860 per hectare (Table 2). All these quadrats contained a similar density of mature oaks. However, quadrat 9 with the highest seedling density in this