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BOLE VOLUME GROWTH IN STEMS OF *QUERCUS GAMBELII*

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ABSTRACT.—Shrub-form and tree-form Gambel oak (*Quercus gambelii*) stands contain a potentially significant fuelwo
resource. Information on their growth characteristics can form a basis for future stand management. Stem analyses show
that height growth of shrub-form stems essentially ceased after age 50, while tree-form stems continued to increase
height until approximately age 100. Both stem forms continued to increase in basal area and volume at a relatively const
rate as the stems increased in age and size. Increases in all size measures were substantially greater in tree-form stems tl
in shrub-form stems. Mean bole volume for tree-form stems at age 100 was over 16 times that of shrub-form stems. Spro
from tree-form stands would reach minimum size for fuelwood marketing in approximately 45 years.

Key words: Gambel oak, Quercus gambelii, *shrub-form, tree-form, height growth, volume growth.*

Gambel oak (*Quercus gambelii*) is a species important for wildlife habitat, watershed protection, and fuelwood. It is found in many areas of Arizona, Colorado, New Mexico, and Utah. In Utah the optimum elevations are 1700–2300 m where Gambel oak is a dominant in the Mountain Brush or mountain mahogany–oak shrub potential natural vegetation zone (Kuchler 1964, Harper et al. 1985, West 1989).

Gambel oak has a variable growth form. Normally a tall shrub or small tree, it can be found as dense, shrubby patches 1 m tall, or as widely spaced trees up to 23 m tall (Clary and Tiedemann 1986). This morphological variation prompted early taxonomists to recognize as many as eight additional species within populations now considered Gambel oak (Harper et al. 1985). The variability may have an environmental source (Neilson and Wullstein 1983), a genetic source (Pendleton et al. 1985), or both.

Sexual reproduction is sporadic, generally with limited success (Cottam et al. 1959, Neilson and Wullstein 1983, Wullstein and Neilson 1985). However, the species has a high regenerative capacity from adventitious buds situated on the lignotubers and rhizomes of existing clones (Muller 1951, Tiedemann et al. 1987). These buds give rise to numerous sprouts, particularly if fire, herbicides, woodcutting, or chaining has killed the aboveground stem (Engle et al. 1983).

Gambel oak is particularly desirable as fu
wood because of its heat-yielding qualities—a
proximately 1.4 times greater than pondero
pine (Barger and Ffolliott 1972). The superi
heat-producing qualities of this species and
proximity to several major population cent
have generated considerable interest in ma
agement and use of Gambel oak for fuelwo
(Harper et al. 1985, Betters 1986). Retail pric
reflect the heat-producing value of Gambel o
It is typically sold for $10 more per ton than a
other species (Johnson and Grosjean 1980).

Some information is available on project
growth characteristics of Gambel oak based p
marily on diameter increments (Wagstaff 198
However, no information is known to be ava
able on the incremental growth of Gambel o
bole volumes. Because of this, we conduct
this study to determine the volume growth cha
acteristics of Gambel oak stems to assist in f
ture management of this often ignored, b
locally important, species.

METHODS

FIELD METHODS.—The plant materials f
this study were collected as part of earlier stu
ies of standing crop biomass (Clary and Tied
mann 1986, 1987). Eight small tree- a
shrub-form plots were sampled within typic
stands on Bald Mountain near Ephraim, Uta

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TABLE 1. Growth curve[1] coefficients and R^2s.

Stem form	Variables		Coefficient term				R^2
	Y	X	A	B	C	D	
Shrub	Basal area	Age	814.992	.439716	.001586	355.110	0.56
Tree	Basal area	Age	330.944	.762575	.022552	56.1056	0.58
Shrub	Volume	Age	574601.	.846456	.002810	542.712	0.68
Tree	Volume	Age	169008.	.546096	.011471	76.9049	0.55
Combined	Volume	Basal area	223504.	.386965	.002732	173.616	0.94
Shrub	Height	Age	4.11932	−1.09578	.026754	−27.2519	0.78
Tree	Height	Age	9.71913	.819354	.037815	19.0701	0.85
Shrub	Annual incr.	Volume	1363.82	−.053418	.000016	−3426.15	0.75
Tree	Annual incr.	Volume	2409.61	−.242472	.000009	−24327.8	0.80

[1]Model: Y = A*(1 + (B − 1)*EXP(−C*(X − D)))^(1/(1 − B))

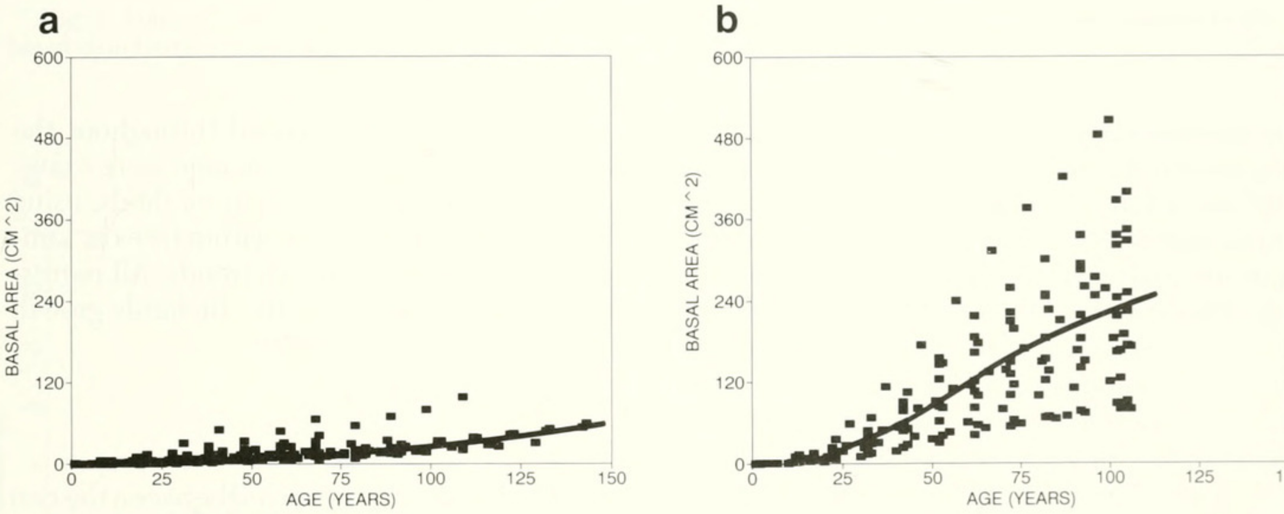


Fig. 1. Basal area (cm^2) versus age (years): a, shrub-form stems; b, tree-form stems.

These are hereafter referred to as *shrub-form*. The sample stands were on slopes of up to 40%. The plots sampled varied in size from 3 × 3 m for high densities of small stems to 9 × 9 m for plots of less dense stems. Large Gambel oak trees were represented by five stands in the Cascade Springs area of the Uinta National Forest, Utah. These are referred to as *tree-form*. Tree-form stands were visibly distinct from surrounding vegetation and occupied concave slope positions where soil depth and moisture favored tree growth. Stands had to be of sufficient size to accommodate a 100-m^2 plot. Plots were square when possible, otherwise rectangular.

Stems greater than 1 m high were counted, numbered, and measured for diameter at a height of 4 cm. Three (in tree-form plots) or five (in shrub-form plots) trees were selected at random for sampling. Stem boles were cut 4 cm above ground line and separated from branches and foliage. Where the tree bole forked, the largest fork was selected as the main bole. These boles were partitioned into 60-cm sections continuing upward until stem diameter outside-bark had decreased to approximately 1 cm. The last sections were therefore of variable length. A 10-cm length was removed from the base of each section for tree-ring analysis by the late Dr. C. Wes Ferguson and associates, Laboratory of Tree-Ring Research, University of Arizona, Tucson.

LABORATORY METHODS.—The basic approach of ring-count dating was augmented in this study by the use of dendrochronological techniques. In instances where the ring pattern was obscured or distorted, two types of controls were used to reconstruct the radial tree-ring sequence. First, a comparison was made with other areas of the cross section, with other sections from the same tree, or with other trees. The second, using

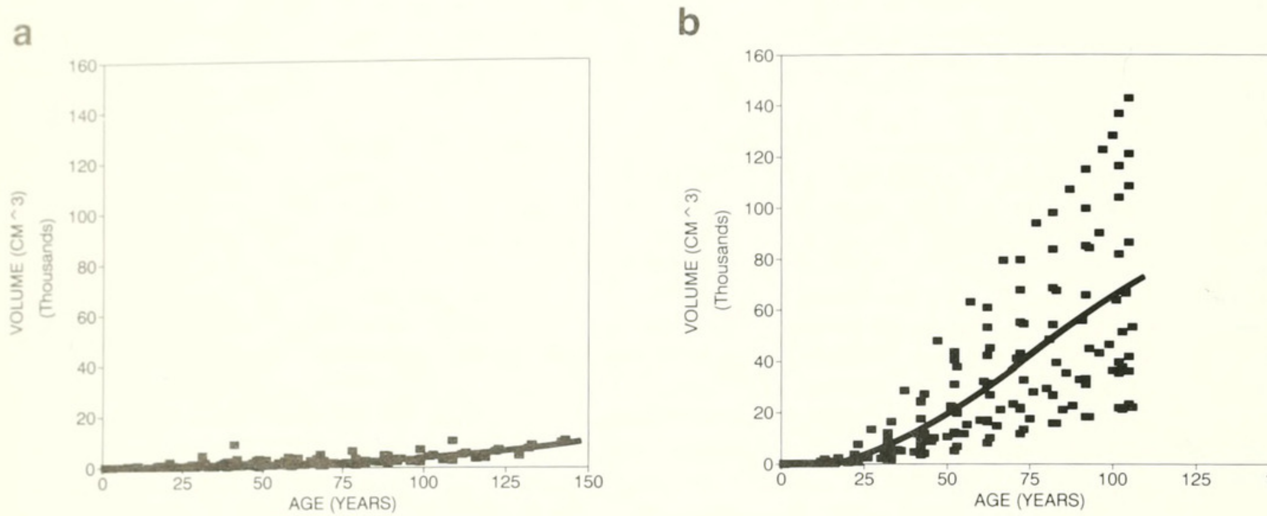


Fig. 2. Volume (cm^3) versus age (years): a, shrub-form stems; b, tree-form stems.

dendrochronological principles, was to date all, or a portion thereof, of the radius in comparison with two relatively nearby established tree-ring chronologies—Nine Mile Canyon and Emory-Link. Several notable reference points were a pair of large rings at 1957 and 1958, and in some instances a wide band of vessels occurred in the 1919 ring. Some data had to be reconstructed for individual bole sections because of tree damage from fire or other injury, distortion due to whorls, etc. The diameter increments were determined to the nearest millimeter by decades, e.g., 1980–1971, progressing from the outer ring of the stem toward the pith. Partial decade growth was recorded when the beginning or ending of the section growth record fell within a decade. As the stems tended to be asymmetrical, the longest and shortest inside bark radii were recorded.

Cross-sectional area and volume calculations were made by using spreadsheet software on a personal computer. Diameter and volume values were calculated on an air-dry, inside-bark basis. The cross-sectional area for a given period was determined for both ends of each section using the longest and shortest radii and assuming an elliptical shape. Section volume for each period (usually decadal) was calculated from the top and bottom cross-sectional areas for the period and the section length using the paraboloid method. Period (usually decadal) volumes were summed across sections to give stem volume totals per period. Bole heights were determined by summing the section lengths. Heights at a given age were estimated in the manner of Lenhart (1972), wherein annual growth tips are assumed to be equally spaced throughout t section. Patterns of volume change were exa ined by graphic and regression methods, usi periods or height segments within trees as sa ple units to illustrate growth trends. All regre sion fits were made using the Richards grow curve model (Richards 1959).

RESULTS

Little data overlap occurred between the tw populations above age 30 in the basal area vers age relationships (Figs. 1a, 1b, Table 1). At a 30 tree-form stems had mean basal area valu nearly 10-fold those of shrub-form stems. Sim lar relationships occurred with volume vers age (Figs. 2a, 2b, Table 1). At age 100 mean ste volumes were 4049 cm^3 and 65,808 cm^3 f shrub-form and tree-form, respectively, or a di ference exceeding 16-fold.

The relationship of volume to basal area w more consistent between stem forms than in t previously described relationships. A sing function fit the full range of data for both pop lations combined (Fig. 3, Table 1).

Relationships of height to age varied b tween the two populations. Rates of heig growth were not greatly different among pop lations for the first 20 years. After 50 yea however, little additional height increment o curred on shrub-form stems (Fig. 4a, Table 1 Maximum height averaged 4.1 m. Tree-for stems continued growth after age 50 at substa tial, although slowly decreasing, rates until a proximately 9.3 m in height was attained at a 100 (Fig. 4b, Table 1).

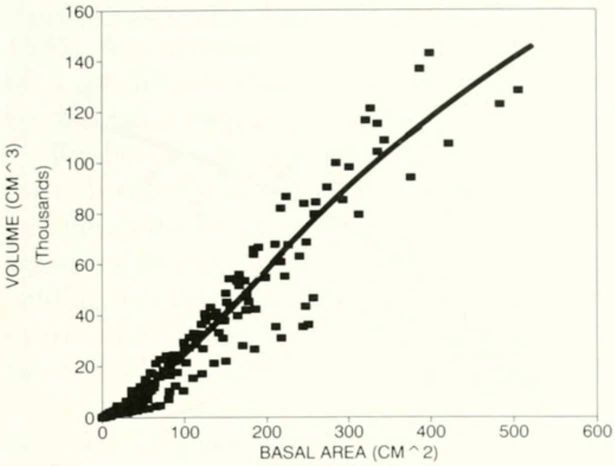
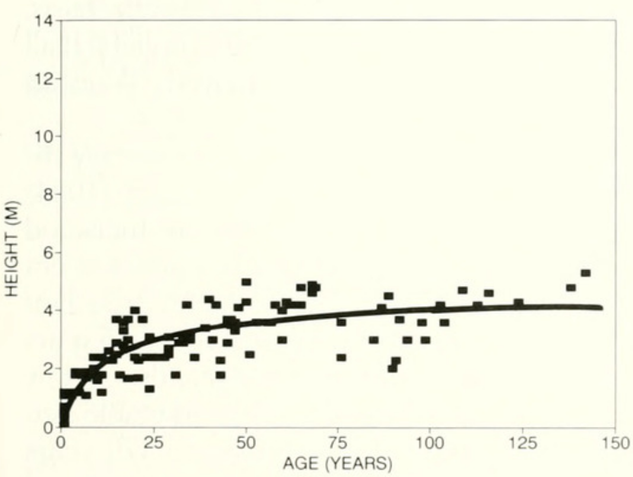


Fig. 3. Volume (cm^3) versus basal area (cm^2) for combined stem forms.

a



b

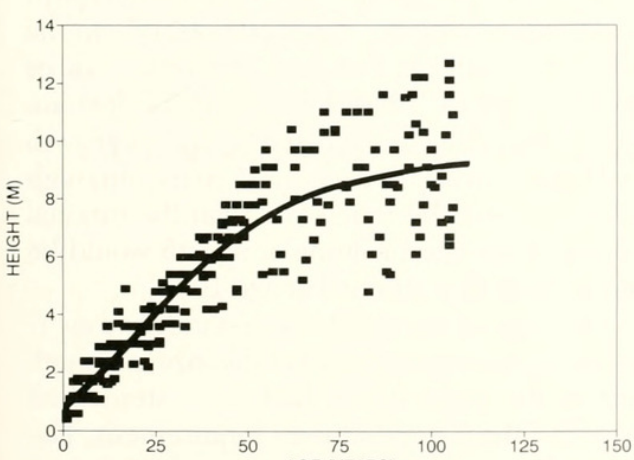


Fig. 4. Height (m) versus age (years): a, shrub-form stems; b, tree-form stems.

The relationship between annual volume increment and age was not strong for either population; R^2 values were .29–.38. A better fit was obtained between annual volume increment and total volume (R^2 = .75–.80). Annual volume increment as a function of existing volume was greater at all volumes in tree-form stems than in shrub-form stems, illustrating more vigorous growth (Figs. 5a, 5b, Table 1).

Discussion

Sampling in this study was limited to central Utah, but stem sizes encountered were representative of sizes across the distribution of Gambel oak. Mean basal diameters of the stands in this study varied from 3.6–11.7 cm in shrub-form stems to 15.1–24.6 cm in tree-form stems (Clary and Tiedemann 1986, 1987). Our shrub-form stems, therefore, corresponded to the average 7.6-cm stump height diameters in western Colorado (Brown 1958). Our tree-form stems were similar in diameter to the larger stems in north central Arizona (Barger and Ffolliott 1972).

Limited information has been available concerning direct volume measures or growth characteristics of Gambel oak. A volume table based on a technique of visually estimated volume is available for Colorado (Chojnacky 1985), and one has been used in Arizona that was developed by modifying a composite volume table for trees in the Great Lakes vicinity (Barger and Ffolliott 1972). Barger and Ffolliott (1972) found that annual stand volume growth in Arizona averaged 0.24 m^3/ha, or about a 2% increment. A similar percentage increment was found in Utah for individual older trees (Wagstaff 1984). Wagstaff's (1984) data showed that diameter growth in tree-form stems slowed little in older trees; thus, the rate of basal area accumulation increased with age. In this study our estimates of annual growth in older tree-form stems were similar to those of Wagstaff, although differences in magnitude between shrub-form and tree-form stems were striking in nearly all data collected. Basal area versus age, volume versus age, height versus age, and annual volume increments in relation to total volume were different between stem forms. Volume versus basal area was the only relationship examined that appeared similar between stem forms.

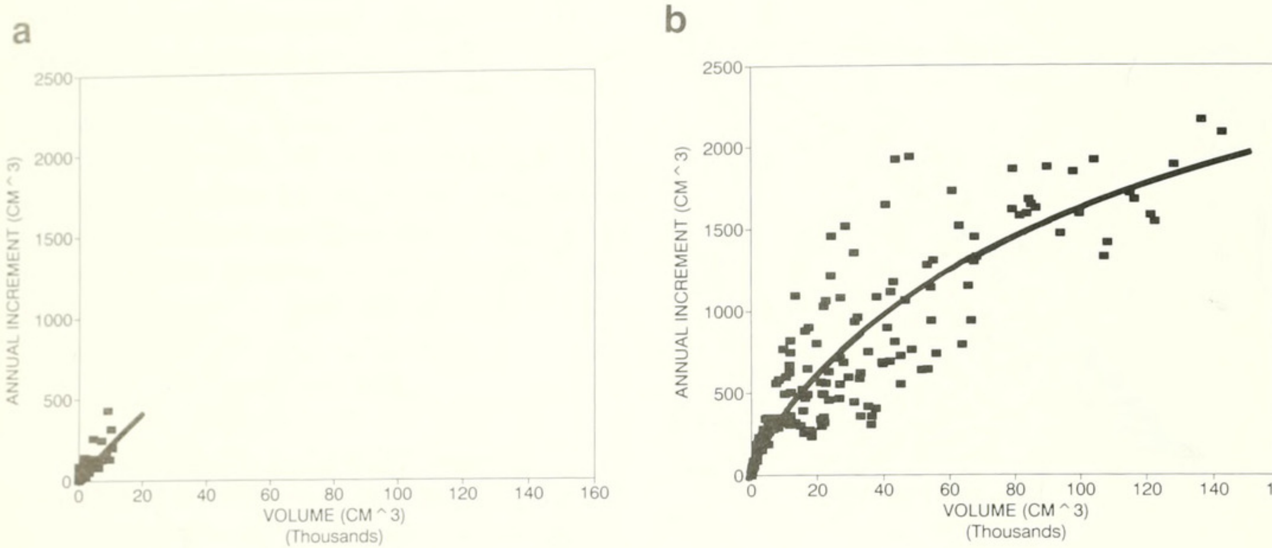


Fig. 5. Annual volume increment (cm^3) versus volume (cm^3): a, shrub-form stems; b, tree-form stems.

A massive underground structure, which supports rapid and normally voluminous sprouting following top removal, provides a reliable reproduction strategy that should fit well into a coppice fuelwood management cycle of harvest and regrowth (Clary and Tiedemann 1986, Tiedemann et al. 1987). This would be especially true on the more productive sites where clones of tree-form stems or larger shrub-form stems are available. While we can offer no direct evidence that tree-form stands will coppice to new tree-form stands rather than to shrub-form stands, circumstantial evidence suggests this is so. Tree-form stands in this study were separated by a distance of several kilometers; yet most of the stems of these stands were established within a 3-year period. The most likely cause would be sprouting following a widespread, hot wildfire. Sprouting following such events typically results in high stem densities. As the new stand ages, a natural thinning occurs. This is reflected in old stem scars on lignotubers and rhizomes (Tiedemann et al. 1987). Scars of previous stems and the underground interconnectedness of Gambel oak clones suggest that generations of stems arise repeatedly from the underground structures. These stems would reflect the same genetic makeup as the previous stems and would be growing on the same site.

Revenue potential of mature stands near cities and towns is substantial. Maximum retail values can approach $55,000/ha of oak clone if individual very high volume Utah sites are completely harvested (Wagstaff 1984). Arizona forests have marketable Gambel oak volumes of 16 m^3/ha averaged across broad clone-occupie and non-clonal areas (Barger and Ffollic 1972). The retail value on a landscape basi therefore, would be $740/ha (1983 dollars) if a harvestable volume were removed (Wagsta 1984).

Gambel oak is marketable when average d ameters are relatively small. Wagstaff (198 reported that stems are salable as fuelwoo when the basal diameter reaches about 9 c (basal area of 64 cm^2). This diameter, based c our stem analyses, would be attained in 45 yea in our unmanaged tree-form stands. A fe shrub-form stems would reach marketable siz in 90 to 100 years, but a projected 170 yea would be required in our average unmanage shrub-form stands.

Our current (mature) tree-form stands wit marketable volumes of 150.6–604.6 m^3/h would be worth $11,144–$44,740 per hectare c clone (Wagstaff 1984, Clary and Tiedeman 1987). Marketing of the resulting sprout growt could occur in approximately 45 years, althoug volumes would be much less than the origin harvest. Estimated volume at age 45 would b only 25% of that attained at age 100.

Only one of our shrub-form stands had ave age stem diameters of marketable size, althoug four of the eight stands had some stems th exceeded the 9-cm-diameter requirement. T stands had mean bole volumes of 46.6–94. m^3/ha and no apparent correlation between vo ume and stand density, although lower densit stands tended to have larger stems. Thus, value for those stands that have attained marketabl