Yields of Southwestern Pinyon-Juniper Woodlands

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*ABSTRACT. Site quality and growth-growing stock relations were developed for southwestern woodlands of pinyon (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) or Utah juniper (*J. osteosperma*). Anamorphic height-age site index curves for pinyon were developed from a regional sample of 60 woodlands. Site index was unaffected by variation in stocking and was correlated with woodland yield when used in conjunction with density.*

Pinyon and juniper PAI, when taken separately, were highly correlated with stand density and pinyon site index. Pinyon was twice as productive as juniper at similar stand densities. Pinyon and juniper yields in woodlands of average density and site index were estimated at 0.29 and 0.15 $m^3ha^{-1}y^{-1}$. At high densities pinyon and juniper yields increased to 0.61 and 0.31 $m^3ha^{-1}y^{-1}$. Pinyon and juniper yields appeared independent of the density of the other species in an individual woodland. Maximum yield of dense mixed species woodlands on average sites was 0.78 $m^3ha^{-1}y^{-1}$, and occurred when pinyon constituted 65% of woodland density.

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The ability to measure potential productivity and estimate growth rates of southwestern pinyon-juniper woodlands is a critical element for improving their management. Indiscriminate exploitation and conversion to grasslands characterize past practices (Aro 1971). But now, woodlands are being regarded as a manageable, renewable resource providing a unique mix of benefits on 11 million ha in Arizona, New Mexico, and Colorado. Estimates of potential productivity and response to management are required to devise and assess treatment alternatives.

The xeric environment and complex stand structures of woodlands have discouraged the development of quantitative managerial tools like those used in most forested lands. Canopy closure rarely occurs in this xeric woodland, and it is assumed that woodland growth is fundamentally different from that of more mesic forests. Woodlands are also complex mixtures of tree ages and species influenced by natural development, past human use, and fire history (Meeuwig and Cooper 1981). These conditions have often been taken as indications that common site and yield estimation approaches do not apply to woodlands.

As a result, relatively little empirical growth information is available. Nor is there a generally applicable method for estimating site quality and yield in relation to woodland density and

Fig. A. High-site pinyon-juniper woodland Cedar Ranch, Coconino National Forest, Arizona.

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Fig. B. Low-site pinyon-juniper woodland at Deadman Flat, Coconino National Forest, Arizona.

species composition. In this paper, we present a system to characterize site quality of pinyon-juniper woodlands, and to estimate actual yields of mixed species woodlands based on site quality, woodland density, and species composition. Our first objective was to develop a site quality estimation procedure that was consistent with inventory practices, independent of density, and useful in developing yield functions. Our second objective was to develop a species-specific, variable-density yield estimator that is applicable to structurally complex pinyon-juniper woodlands.

METHODS

Our study area was a major portion of southwestern pinyon-juniper woodland type including north central New Mexico north of Santa Fe, southeastern Colorado near the Front Range, southwestern Colorado in the Four Corners area, and Arizona north of the Mogollon Rim. Sampled woodlands were confined to community types supporting pinyon pine (*Pinus edulis* Engelm.), one-seed juniper (*Juniperus monosperma* [Engelm.] Sarg.) and Utah juniper (*J. osteosperma* [Torr.] Little). These woodlands are generally found at 1400–2300 m where annual precipitation is 30–50 cm (Springfield 1976).

Plots were established in 129 woodlands in rough proportion to their occurrence in the study area. Woodlands were stratified by apparent site quality, stocking, size, and species composition and were selected to represent a range of woodland types with respect to these variables (Table 1). Stands with obvious damage from insects or diseases were avoided, as were those known to have been disturbed in the past 20 years.

Our variable-sized plots each included 30 to 40 live and dead pinyon and juniper trees over 2.5 cm in diameter at stump height (*DSH*) where *SH* was taken at 15 cm above the root collar. Understory cover was measured along three line transects evenly spaced within each plot.

Living and dead trees exceeding 2.5 cm *DSH* were measured for species, *DSH*, and total height. If a fork occurred below *DSH*, each of the individual stems was measured at stump height and the equivalent diameter was determined. In the case of multiple stems below stump height, an equivalent quadratic mean diameter was determined as the square root of the sum of squared stem *DSH*. Metric Stand Density Index (*SDI*) (Reineke 1933, Long 1985) was determined for each sampled woodland as:

$$SDI = N \times (DSH_q/25)^{1.6}$$

where

N = number of stems ha^{-1}

DSH_q = quadratic mean *DSH*.

A disk or two increment cores were removed from the primary stem of each tree at stump height. Ten-year radial increment for each core or disk was measured on a Bannister Incremental Measuring Device (Fred C. Henson Co., Mission Viejo, CA) to determine diameter growth. Diameter growth of multiple-stem trees was determined from the ratio of equivalent stem to primary stem basal areas and the diameter growth of the primary stem. Ten-year periodic annual volume increment ($m^3ha^{-1}y^{-1}$) to a 2.5 cm top was determined for each plot from individual tree volume estimates (Clendennon 1979), adjusted to a ha basis from plot size.

Age at the root collar and total height were measured for two or three vigorous codominant or dominant pinyons and junipers on or near each plot. These were well-formed trees free of visible defect, but were not necessarily the largest trees present. Sixty plots were used to develop height age site index for pinyon. One-third of the 60 plots were located in each of 3 visually determined site quality classes—good, medium, and poor. Thirteen of these were "fully stocked" plots where understory cover was 10% or less (Meeuwig and Cooper 1981) paired with nearby "less-than-fully-stocked" plots of similar apparent site quality of lower stocking where understory cover was greater than 10%.

RESULTS AND DISCUSSION

Site Quality Estimation

Our first objective was to develop a procedure to characterize potential productivity of southwestern woodlands. We felt that any index derived

Table 1. Characteristics of 129 sampled southwestern pinyon-juniper woodlands.

Variable	Mean	S.D.	Min.	Max.
Average stand diameter at stump height (cm)	20.1	6.7	9.6	45.3
Stems (1/ha)	910	580	50	3571
Average stand height (m)	3.8	1.0	2.1	8.1
Stand density index[1]	540	240	44	1150
Pinyon stand density index	248	211	0	869
Juniper stand density index	276	242	0	882
Basal area (m^2/ha)	25.0	12.3	2.3	57.5
Volume (m^3/ha)[2]	61.4	43.7	5.6	288.5
Site index base age 200 years (m)	7.3	2.0	3.9	14.0
Percent pinyon (%)	43	35	0	100
Gross volume increment (m^3 ha^{-1} y^{-1})	0.36	0.19	0.07	1.18
Net volume increment (m^3 ha^{-1} y−1)	0.16	0.61	−3.43	1.18

[1] English SDI = metric SDI/2.5
[2] ft^3/ac = 14.30 × m^3/ha

should be independent of density and stand history, must be compatible with commonly measured inventory data, and should be a continuous variable useful in developing growth estimators. We examined the relation between height and total age for pinyon and juniper trees to evaluate the feasibility of height-age site index curves for woodlands.

Graphical analysis indicated that height-age data for the pinyon site index trees were similar in form to those observed for most conifers. A guide curve was developed by fitting the Chapman-Richards function to total height–total age data for the 60 site quality plots (Clutter et al. 1983, Aguirre-Bravo and Smith 1986):

$$H = \theta_1 \, [1 - \exp(-\theta_2 A)]^{[(1-\theta_3)^{-1}]}$$

θ_1 = asymptotic height

θ_2 = rate "θ_1" is approached

θ_3 = inflection parameter

H = Tree height

A = Root collar age

The parameters θ_1, θ_2, and θ_3 of the Chapman-Richards function were estimated using a nonlinear regression procedure (Dixon 1983) and produced the unconstrained final parameter estimates:

θ_1 = 7.63

θ_2 = 0.014

θ_3 = 0.062

Residual sum of squares = 282

Mean square error = 2.91

There was no evidence of bias in the residual plots.

Prediction of individual tree site index from height and age measurements at a base age of 200 years was determined from the following equation:

$$S = H\left[\frac{0.933}{1 - \exp(-0.0135A)}\right]^{1.066}$$

The reference age of 200 years was chosen with regard to the age at which the height age curves approach an asymptotic height. These equations produce a family of anamorphic site index curves which can be used to derive an estimate of site index at base age 200 years for pinyon pine from measures of total age and height (Figure 1).

We feel that this method of estimating site index is better than simply using woodland basal area (Howell 1940) or basal area growth of "fully-stocked" woodlands (Meeuwig and Cooper 1981). Basal area is itself a measure of density and is affected by

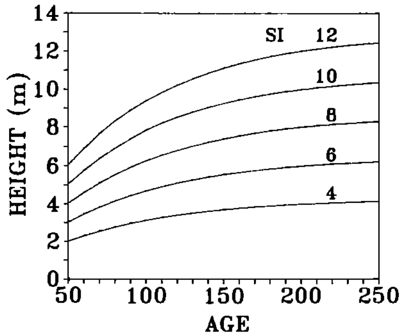

Fig. 1. Total height–root collar age anamorphic site index curves for southwestern pinyon pine at base age 200 years (SI_{200}).

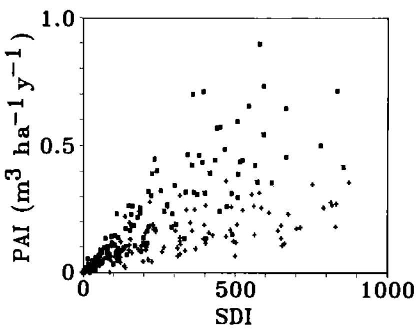

Fig. 2. Gross periodic annual increment (PAI) ($m^3ha^{-1}y^{-1}$) of pinyon (square) and juniper (crosses) components of southwestern pinyon-juniper woodlands in relation to Stand Density Index (SDI).

management practices. And determination of full stocking is based on understory cover that may be affected by grazing (Arnold et al. 1964), or even year-to-year variation in weather (Campbell and Ryan 1982). To verify that pinyon site index was independent of density, we compared site index estimates for fully-stocked woodlands to estimates for adjacent less-than-fully-stocked woodlands. The slope of a linear regression was not significantly different than 1, and the residuals were unbiased.

Attempts to define a similar height-age based site index system for juniper were not successful. Height appeared independent of age for our sample. This limits application of site index to woodlands where pinyon site trees are present and precluded development of a correlation between pinyon and juniper site quality (e.g., Clutter et al. 1983).

Growth–Growing Stock Equations

We examined the relationship between 10-yr periodic annual increment (PAI) ($m^{-3}ha^{-1}y^{-1}$) and SDI of woodlands. There is a general increase in volume increment as SDI increases, but there is considerable variability in the relation. Two factors may explain a large proportion of this variation—differences in species composition, and differences in site quality. Volume increment at a given density would be expected to vary directly in proportion to differences in land productivity, as measured by site index and soil type. Also, it might be expected that there are differences between the growth rates of pinyon and juniper. Gross PAI is higher for pinyon than for juniper at any given density (Figure 2). Therefore, separate relations were developed for pinyon and junipers. No differences were found in the growth relations of *J. osteosperma* or *J. monosperma* and they were treated as a single group.

We described gross PAI as a function of density and site for pinyon and juniper (Table 2). All growth equations were fit with a monomolecular growth function, which is a modified Chapman-Richards function with no inflection parameter, using a nonlinear parameter estimation procedure (Caceci and Cacheris 1984). The coefficients of determination (R^2) for the nonlinear regressions were approximated by calculating the total sum of squares of the dependent variable and dividing this figure by the sum of squares of the differences (residuals) between actual data and data predicted by the fitted equation. Stand density index and pinyon SI were significantly correlated with PAI for pinyon and juniper woodland components. The coefficients of determination of the relations for pinyon and juniper were 0.70 and 0.63 and mean square errors were 0.00989 and 0.00525. We feel these equations are adequate descriptors of pinyon-juniper woodland yield relations. The

Table 2. Growth–growing stock equations for southwestern pinyon-juniper woodlands by species and soil parent material. All data were fit with the equation: $PAI = SI(\theta_1 - \theta_2 \exp^{-\theta_3 SDI})$. *PAI* is 10-year gross periodic annual increment ($m^3\ ha^{-1}\ y^{-1}$), *SI* is pinyon site index at base age 200 (m), *SDI* is stand density index, and θ_1, θ_2, and θ_3 are parameter estimates.

Species	Soil parent material	θ_1	θ_2	θ_3	n	R^2	Mean square error
Pinyon	all	9.52×10^{-2}	9.51×10^{-2}	1.88×10^{-3}	118	0.70	0.001
Juniper	all	4.64×10^{-2}	4.54×10^{-2}	2.00×10^{-3}	115	0.63	0.005
Juniper	sandstone	5.15×10^{-2}	5.00×10^{-2}	1.20×10^{-3}	51	0.67	0.006
Juniper	volcanic	4.83×10^{-2}	4.84×10^{-2}	2.61×10^{-3}	33	0.71	0.007
Juniper	other	4.83×10^{-2}	4.60×10^{-2}	2.29×10^{-3}	32	0.29	0.015

correlations between SDI and SI_{200}, and PAI were relatively high considering the inherent variability in size, age and species composition of woodlands.

Growth–growing stock curves developed from the individual species growth equations can be used to analyze potential volume production of woodlands with respect to stocking and site (Figures 3 and 4). There are substantial differences between yields of pinyon and juniper components of woodlands when densities are similar. At SI_{200} 8 m, PAI of pinyon and juniper are estimated as 0.29 $m^3ha^{-1}y^{-1}$ and 0.15 $m^3ha^{-1}y^{-1}$, when SDIs of both are 250, near the average for sampled woodlands. At densities near the observed individual species maximums (SDI = 850), PAI was estimated at 0.61 $m^3ha^{-1}y^{-1}$ for pinyon and 0.31 $m^3ha^{-1}y^{-1}$ for juniper. Across a wide range of density, pinyon is about twice as productive as the two juniper species studied.

Species composition and relative stocking of woodlands would influence the expected growth rate because of the large differences in PAI between species. Gross PAI of one species must be independent of the density of the other, if one is to use separate equations for pinyon and juniper to describe growth of mixed species stands. We examined residuals of each species' growth equation relative to the SDI of the other species present. Residuals were unbiased, indicating that growth of each species is indeed independent of the density of the other. Therefore, the effect of species mix was examined by varying species densities near the limits of the observed maximum density for woodlands (SDI = 1150) and for separate species components (SDI = 850) (Figure 5). Maximum woodland PAI at SI_{200} 8 m of 0.78 $m^3ha^{-1}y^{-1}$ occurs when pinyon represents 65% of woodland SDI. Increment declines rapidly when the percentage of pinyon falls below about 60% of the total woodland density. At SI_{200} 14 m, the highest observed site index, PAI at a woodland SDI of 1150 was estimated at 1.37 $m^3ha^{-1}y^{-1}$.

Besides species differences in yield, there are also differences in volume increment across soil types. For juniper, PAI was higher on soils derived from a volcanic parent material than on soils of sandstone origin. Volume growth equations were derived for junipers on three soil parent material classifications—sandstone, volcanic and other (Table 2). Pinyon SI was a significant variable for each soil parent material, but growth on volcanic derived soils exceeded that on sandstone derived soils when density and pinyon SI were the same (Figure 6). For example, at an SDI of 850 for juniper and a SI of 8 m, growth on volcanic derived soils is 0.34 $m^3ha^{-1}y^{-1}$, 22% greater than for the same stand conditions on a sandstone derived soil, where growth is 0.27$m^3ha^{-1}y^{-1}$.

CONCLUSIONS

Height-age based site index curves proved valid on a regional scale suggesting that, at least for pinyon, height growth is related to site productivity. Differences between soil types in growth of juniper at a given site index indicate that soil-site relations are important factors in site productivity. Soil-site indices should prove to be especially appropriate in woodlands since they are not dependent on the presence, age, or vigor of existing vegetation.

Development of growth-growing stock relations for woodlands is therefore feasible. When woodlands are broken into components by species, much of the variability in the relation between yield and density can be explained. Growth-growing stock curves represent an important initial tool for designing density management prescriptions in the woodland community types studied. Densities can be chosen to realize desired levels of gross yield and to determine appropriate species mixes. Further work should describe the development of tree size in relation to site, density and time. □

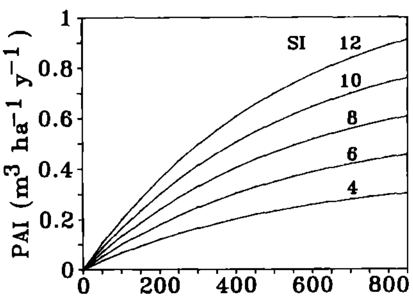

Fig. 3. Estimated gross periodic annual increment (PAI) ($m^3ha^{-1}y^{-1}$) for the pinyon component of southwestern pinyon-juniper woodlands in relation to Stand Density Index (SDI) and pinyon site index (SI_{200}).

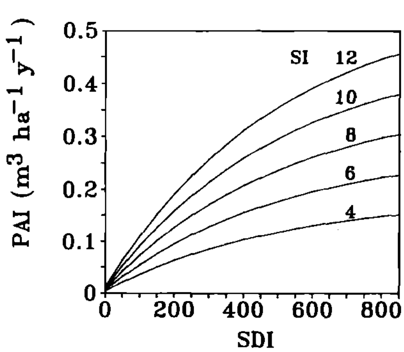

Fig. 4. Estimated gross periodic annual increment (PAI) ($m^3ha^{-1}y^{-1}$) for the juniper component of southwestern pinyon-juniper woodlands in relation to Stand Density Index (SDI) and pinyon site index (SI_{200}).

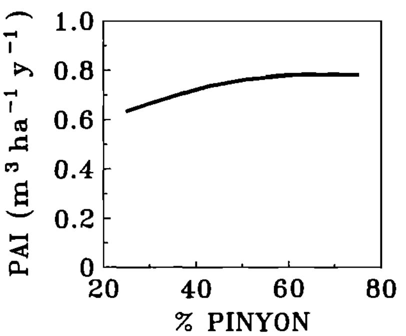

Fig. 5. Estimated gross periodic annual increment (PAI) ($m^3ha^{-1}y^{-1}$) of mixed species woodlands at pinyon site index (SI_{200}) 8 m where maximum woodland Stand Density Index (SDI) is 1150 and maximum pinyon or juniper SDI is 850.

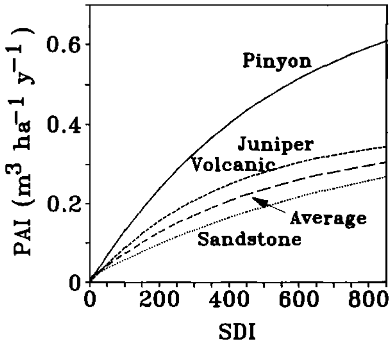

Fig. 6. Differences in estimated juniper gross periodic annual increment (PAI) on solid derived from volcanic and sandstone parent materials relative to estimated average juniper and average pinyon gross PAI.

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Consulting Foresters in the Pacific Northwest

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ABSTRACT. In 1986, 83% of an estimated total of 218 consulting foresters in Washington, Oregon, Idaho, and Montana were surveyed; 56% consulted full-time and 44% consulted part-time. In total, consultants provided 155 person-years of service to all owners. Most respondents believed the number of consultants in the areas they served was about right. Consultants averaged 24 years of forestry experience, including 10 years in consulting. Consultants belongs to a variety of professional and other organizations and most had completed at least a four-year degree. Consultants' primary clients were nonindustrial private forest (NIPF) owners, industry, and federal government. In the last year, consultants provided 57 person-years of assistance to over 2,130 NIPF owners holding over 2 million acres. Most of these NIPF clients were assisted with services related to timber management or harvest.

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A consulting forester is "a professional forester whose services are available to the general public on a contract of fee basis—with the fee paid by the client" (Society of American Foresters 1984). Consulting foresters work as professional representatives of landowners and offer a wide variety of services.

A recent national study of consulting foresters (Field and Holt 1984) had a relatively low response rate for the Pacific Northwest (22% of the consultants in Washington, Oregon, Idaho, and Montana). Hodges and Cubbage (1986) noted that consultants are more likely to respond to a regional or state survey than a national one. Therefore, a survey was undertaken to develop a current profile of Pacific Northwest consulting foresters.

THE STUDY

Survey methodology was in accordance with Dillman's (1978) *Total Design Method*. Names and addresses of foresters from Washington, Oregon, Idaho, and Montana were collected from consulting forester directories published by the Society of American Foresters, the Association of Consulting Foresters, and state and regional agencies. Names and addresses were also collected from telephone directories and advertisements. A questionnaire requesting information on consultants' characteristics and activities in the previous 12 months was mailed to 427 individuals in late September 1986. Two follow-ups were sent to encourage response.

Responses were received from October through November, 1986; 84 questionnaires were undeliverable. Sixty-three percent of the remaining 343 individuals returned questionnaires (at least 60% responded from each of the four states covered in the survey). In most cases, questions were skipped by less than 5% of the respondents. Forty randomly chosen nonrespondents were interviewed over the telephone in early December 1986.

RESULTS

Consultant Numbers

There were an estimated 218 active consulting foresters (56% full-time and 44% part-time) in the combined mail and telephone surveys (Table 1) The majority of the consultants were self-employed (74%). Seventeen percent were partners in a consulting firm, and 5% were employees of a consulting firm.

The majority of consultants (64%)

Table 1. Estimated total numbers of consulting foresters in the Pacific Northwest in 1986, by state of residence.

State	Full-time consultants	Part-time consultants
Washington	50	32
Oregon	46	35
Idaho	12	15
Montana	15	13
Totals	123	95

Table 2. Why Forestry Consulting?

Most important reason	Full-time consultants	Part-time consultants	All consultants
		%	
Left previous forestry employment of own choice to consult	55	31	44
Career goal	23	18	21
Laid off from forest industry	10	10	10
Supplement income	1	18	9
Laid off from public forestry agency	4	4	4
Poor employment opportunities elsewhere	0	0	0
Other	7	19	12

Table 3. Average percent time Pacific Northwest consulting foresters worked for various clients over 12 months.

Type of client	Average percent time spent by consultants: Full-time	Part-time
NIPF owners	45	35
Industry	26	28
Federal government	9	17
State or other government	7	5
Indian tribes	3	5
Other	10	10