Evaluation of pinyon sapwood to phytomass relationships over different site conditions

ROBIN J. TAUSCH AND PAUL T. TUELLER

Abstract

Detailed studies of competitive interactions in the pinyon/juniper (*Pinus monophylla* Torr. & Frem., *Juniperus osteosperma* (Torr.) (Little) ecosystem require accurate estimates of biomass from physical measurements of the plant species involved. Relationships between green leaf biomass (phytomass) and trunk sapwood area were evaluated on 6 plots on a western Nevada mountain range. Four of the plots covered a range of environmental conditions from the lower to the upper edge of the woodland belt in 100-m elevation increments. The remaining 2 covered canyon and mountain top environments. The sapwood area to phytomass relationship was first individually analyzed for each of the 6 plots and the results compared. The ratio for grams of phytomass per cm² of sapwood area for the tree in each plot with the highest value ranged from 1.5 to over 2 times the tree with the lowest value. The highest average plot ratio was only 10% greater than the lowest average plot ratio. Individual regression slopes for the 6 plots did not significantly differ and the data were combined for the remaining analyses. The regression relationship for trees with less than 40-cm² sapwood area differed from the overall relationship. The slope values for the sapwood area to foliage biomass relationship for the western Nevada data averaged about 2/3 the slope values for a data set from a mountain range in southwestern Utah. These differences were significant between a subset of young trees from each site with up to 40-cm² sapwood area ($P \leq 0.01$) and for an analysis between all the sampled trees from each site ($P \leq 0.10$).

Key Words: singleleaf pinyon *Pinus monophylla*, sapwood area, leaf biomass, phytomass

Detailed studies of competitive interactions and the associated successional processes of pinyon-juniper (*Pinus monophylla* Torr. & Frem., *Juniperus osteosperma* (Torr.) Little) woodlands require biomass estimates for the plant species present. Particularly important are the competitive effects of the trees on forage production by understory species. Because of the size of the trees and the remoteness of most study sites, direct collection of their biomass is time consuming and expensive (Meeuwig and Budy 1979). The ability to use physical measurements of the trees to estimate green leaf biomass, or phytomass, can simplify field data collection.

Close relationships have been shown to exist between the total phytomass or leaf area of woody plants and their sapwood area. Species evaluated include conifers (Grier and Waring 1974, Kline et al. 1976, Whitehead 1978, Running 1980, Long et al. 1981, Kaufmann and Troendle 1981, Waring 1983, Marshall and Waring 1986, Hungerford 1987, Miller et al. 1987); evergreen and deciduous broad leaf trees (Dixon 1971, Waring et al. 1977, Kaufmann and Troendle 1981); and shrubs (Waring et al. 1977, Ganskopp and Miller 1986). Although the relationship is consistent for a species, the slope of the regression line can vary depending on where the trunk cross section is taken and the length of the crown free bole (Waring et al. 1982, Brix and Mitchel 1983, Marchand 1984, Dean and Long 1986, Bancalari et al. 1987, Hungerford 1987). The phytomass to sapwood area ratio for small trees or saplings can also be less than for mature trees of the same species for pinyon (Tausch 1980) and for other conifers (Snell and Brown 1978, Waring et al. 1982, Pearson et al. 1984, Dean and Long 1986, Hungerford 1987, Keane and Wheetman 1987).

The objectives of this study were twofold. First we wanted to determine the sapwood area to phytomass relationships for pinyon within and between several sites on a western Nevada mountain range and between those sites and a southwestern Utah site. Second we wanted to find out if the variation in the relationship observed was related to site conditions.

Study Area

Tree data were from 6 locations in the pinyon-juniper woodlands of the Sweetwater Mountains in western Nevada. These locations ranged in elevation from just over 2,000 m to 2,300 m (Table 1). All 6 sites were in woodlands that were fully stocked or fully tree occupied as described by Meeuwig and Budy (1979). Tree data for S1, S3, and S4 were sampled adjacent to previously sampled plots (Meeuwig 1979). Plots 1, 2, and 3 were added to extend the range of environmental conditions. Plots 2, 1, S1, and S3 represent a transect up the east side of the Sweetwater Mountains from the lower to the upper edge of the woodland belt at 100-m elevation intervals. Plot S4 is a north facing slope in a large canyon and plot 3 is on a broad mountain top. A few juniper were present in plot S4 but the other plots contained only pinyon.

Table 1. Elevation, slope, aspect, and total tree cover for 6 plots on the Sweetwater Mountains, Nevada and California. The plots S1, S3, and S4 are from Meeuwig (1979).

	Aspect (degrees)	Slope (degrees)	Elevation (meters)	Total tree cover (%)
1.	81	3	2120	47
2.	75	2	2030	39
2.	90	4	2280	72
S1.	80	3	2210	49
S3.	120	8	2300	64
S4.	345	20	2020	36

Methods

Sampling Techniques

Plots S1, S3, and S4 were 30 m by 30 m in size. Every tree on these plots was measured for height, average crown diameter, and for basal diameter. All trees were harvested and their biomass determined (Meeuwig 1979, Meeuwig and Budy 1979). Plots 1, 2, and 3 (Table 1) were 20 m by 50 m (0.1 ha) in size. Every tree in the plots was placed in 1 of 6 age classes based on those described by Blackburn and Tueller (1970) and was measured for average crown diameter, total height, and basal diameter. Basal diameter measurements were above the root crown and approximately 15 cm

Authors are assistant professor and professor, Department of Range, Wildlife and Forestry, University of Nevada Reno, Reno, Nevada 89512. This research was performed with funds provided by the USDA Forest Service Intermountain Forest and Range Experiment Station agreement 22-C-4-INT-26. The authors wish to thank James Gilleard for his help in processing the field data.
Manuscript accepted 19 November 1988.

above the ground surface. Where multiple trunks branched below this point, each trunk was individually measured and an average basal diameter determined as described by Meeuwig and Budy (1979). All data were collected during the first week of August.

A random sample of 12 trees with mature foliage, stratified by age class, was harvested on plots 1, 2, and 3. The sampled trees were those closest to a random point on the center line of the plot. Twelve random trees were collected adjacent to each of the previously sampled plots S1, S3, and S4 from Meeuwig (1979) and Meeuwig and Budy (1979) in an area with the same site and stand conditions. Plot S2 did not have a suitable adjacent area. A base line was located in the adjacent area parallel to and 10 m from the side of the plot and the selected trees were those closest to a random point on that line.

The 12 harvested trees for each plot were sampled by 2 methods depending on tree size. All green foliage was collected on trees with basal diameters outside the bark up to about 15-cm. A trunk cross section was collected at the point of basal diameter measurement. Trees with larger basal diameters were subsampled. The subsampling was based on the assumption of linearity of the phytomass to sapwood area ratio through a tree crown described by Kaufmann and Troendle (1981), Long et al. (1981), Waring et al. (1982), and Waring (1983). Two subsamples were collected, one from the main stem and one from a random major branch in the middle third of the tree. A major branch or secondary trunk was also selected because they support a major portion of the crown. Main stem and branch subsamples were cut at a diameter of about 12-cm to exceed the 40-cm^2 sapwood area (about 10-cm diameter outside the bark) below which the phytomass to sapwood area ratio in individual pinyon trees declines with decreasing tree size (Tausch 1980). A cross section was collected from the base of each stem and branch subsample and a trunk cross section was collected from the base of the tree. All green foliage was collected from each stem and branch subsample.

One randomly selected tree in plot 2 was subsampled with 6 additional cross sections taken at approximately equal intervals over the height of the tree. All phytomass was collected for each subsample. Cross sections on this tree were removed from sections of the trunk that was free of branches for at least 10 cm.

Analysis Techniques

All collected foliage was oven dried and weighed. Trunk and branch cross sections were measured for heartwood and sapwood area with a dot grid. The measured sapwood area and phytomass data of the 2 subsamples from the larger trees were combined and an overall ratio of phytomass to sapwood area determined. This ratio was multiplied times the sapwood area of the trunk cross section to estimate the total tree phytomass.

Potential increased variability resulting from the subsampling procedures was evaluated by comparing the rate of variability between the subsampled trees with the variability of the totally sampled trees of equivalent size from southwest Utah (Tausch 1980). Variation in error related to tree size was checked by a regression analysis between the basal area and the difference between the 2 subsamples for each tree. Data were not available to directly determine the existence of an overall over or under estimate of the phytomass to sapwood area ratio. Two indirect evaluations for this were used. First was an evaluation of the change in the phytomass to sapwood area ratio at different levels in the subsampled tree. Second, the basal area and total tree phytomass for the trees sampled adjacent to plots S1, S3, and S4 from Meeuwig (1979) and Meeuwig and Budy (1979) were used in nonlinear regression analysis to develop prediction equations. These equations were used to predict the total pinyon phytomass in the adjacent plots and the results were compared with their published phytomass values (Tausch and Tueller 1988).

Sapwood area to phytomass regression analyses were computed individually by plot for trees less than or equal to 40-cm^2 sapwood area, greater than 40-cm^2 sapwood area and for all sampled trees. Regression slopes were then statistically compared between plots. The data for all plots were then combined in single analysis for each size range. Results from the combined Sweetwater Mountains data for each size range were statistically compared with results for equivalent data from southwestern Utah from Tausch (1980). All southwestern Utah trees were totally sampled and had mature foliage.

Crown diameter measurements on plots 1, 2, and 3 were used to compute the percent cover of the trees. Percent tree cover data for plots S1, S3 and S4 are from Meeuwig (1979).

Results and Discussion

The sampled trees on the Sweetwater Mountains ranged in height from 2 dm to 10 m. Total tree cover values on the plots ranged from 36% to 72% with the higher cover values generally occurring at the higher elevations (Table 1). The base of the tree crowns was at the ground surface for most of the pinyon trees. The trunks on the remaining trees were usually short with less than a meter from the litter surface to the first live branch.

Phytomass to sapwood area ratios for the trees from southwest Utah (Tausch 1980) ranged from 86 g/cm^2 to 149 g/cm^2 and averaged 118 g/cm^2. The largest value was about 1.7 times the smallest. Highest ratios for the subsampled trees on each plot on the Sweetwater Mountains were from 1.5 to 2.1 times the lowest values and the plot average was 1.7. The phytomass to sapwood area ratio for all the subsampled trees ranged from 53 g/cm^2 to 109 g/cm^2, a range of 2.3 to 1, and averaged 86 g/cm^2. Average plot ratios varied by a maxiumum of 10% with the highest ratios on the upper elevation sites. Individual lodgepole pine trees on a site had about a 2 to 1 range in the leaf area to sapwood area ratio (Keane and Weetman 1987). Overall, tree to tree variability of the subsampled trees were equivalent to the totally sampled trees.

Regression analysis between the basal area of the subsampled trees and the difference between the phytomass to sapwood area ratios of the 2 subsamples was not significant ($r^2 = 0.02$). Variation between the subsamples was not related to tree size.

Analysis of the one subsampled tree starting at the base (the crown base was at the litter surface) had sapwood areas of 205, 87, 71, 56, 48, 16, and 8 cm^2. Associated phytomass to sapwood area ratios were 87, 116, 97, 88, 83, 91, and 54 gm/cm^2 respectively. Branches between the basal cross section and the first subsample supported nearly 60% of the phytomass of the tree. Although one tree is not necessarily representative, the results are consistent with those for western juniper in eastern Oregon (Miller et al. 1987) and other conifers (Brix and Mitchell 1983, Marchland 1984, Bancalari et al. 1987). These results indicate that cross sections within pinyon crowns that are about 12-cm diameter outside the bark and larger will have phytomass to sapwood area ratios that are potentially greater than the value at the base of the crown. At the subsample size used here an over estimate of as much as 10% plus is possible for cross sections on the main trunk. Phytomass to sapwood area ratios for the subsamples for the secondary trunk or major branch averaged 4% less than for the main trunk. This may have provided some compensation for the possible overestimation of the main trunk subsection.

Equations using basal area to predict total tree phytomass were computed for the pinyon collected adjacent to plots S1, S3, and S4. Basal areas computed from these data for each plot were used to predict pinyon phytomass. Results were summed by plot and compared with the total pinyon phytomass values they reported. Prediction equations based on nonlinear regression overestimated the total pinyon phytomass in the 3 plots by an average of 0.5%

(Tausch and Tueller 1988). Overestimation resulting from the sub sampling does not appear to be large.

Linear regression slopes for the sapwood to phytomass relationships did not significantly differ (F-test) between the individual plots for trees less than 40-cm² sapwood area, greater than 40-cm² sapwood area, or for the analyses using all the trees on each site (Fig. 1). The different environmental conditions of the sample

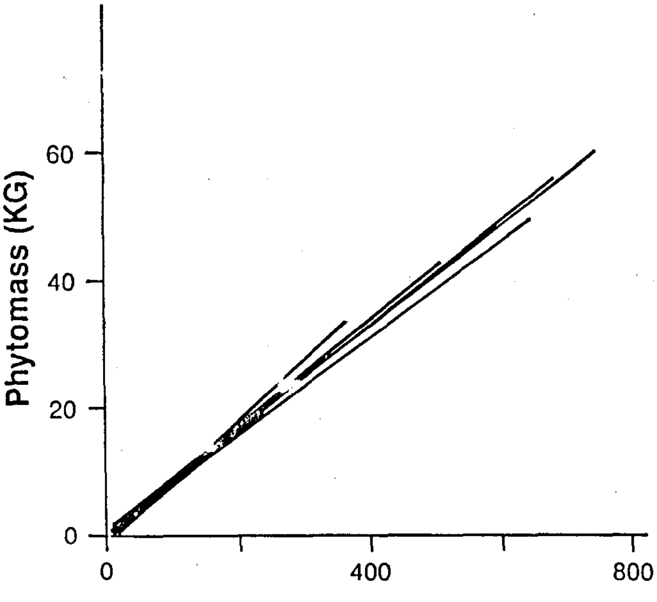

Fig. 1. *Individual regression lines for the sapwood area to phytomass relationships for all sampled pinyon on 6 plots on the Sweetwater Mountains of western Nevada.*

locations on the Sweetwater Mountains did not significantly change the relationship. Results of an analysis combining all the trees for all 6 plots (Fig. 2) gave the same high precision generally observed for other tree species.

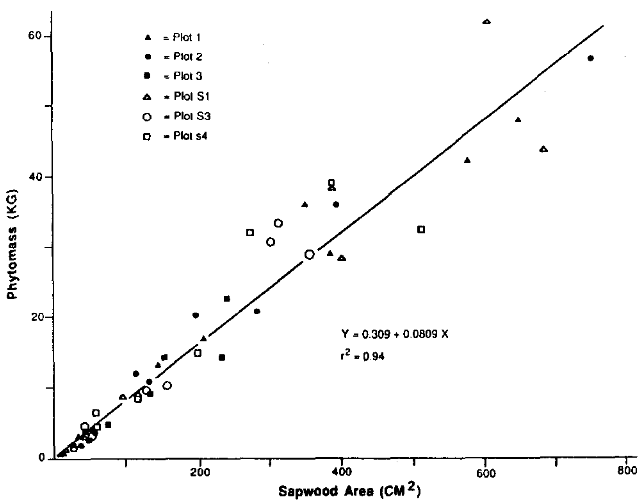

Fig. 2. *Regression analysis for the sapwood area to phytomass relationship for the combined data for 6 plots on the Sweetwater Mountains of western Nevada. Definitions for the individual plots are in Table 1.*

The linear relationship did not hold for the smaller trees as previously observed by Tausch (1980). Below about 40 cm² sapwood area the data points are consistently below the line in Fig. 2. When these data are analyzed separately (Fig. 3) a non-linear trend line can be fit to the data. Trees up to 52 cm² sapwood area were

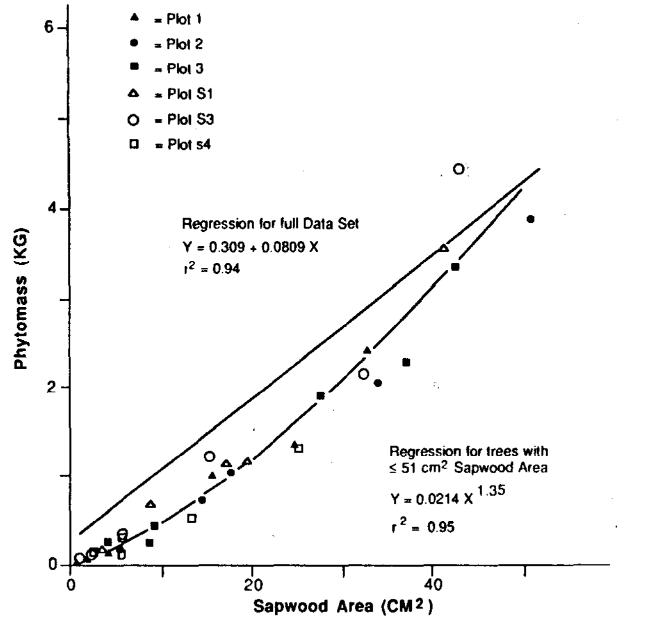

Fig. 3. *Regression analysis for the sapwood area to phytomass relationship for the combined data for 6 plots for trees with up to 52 cm² sapwood area. Trees with from 40 to 52 cm² sapwood area have been included to illustrate the merging of the non-linear regression line for the small trees with the linear regression line for the larger trees. Regression analysis for the full data set is in Fig. 2. Definitions for the individual plots are in Table 1.*

included in the analysis in Figure 3 to show the merging of the nonlinear relationship of the smaller trees with the linear relationship of the larger trees. The smallest trees sampled supported only about a third as much phytomass per cm² of sapwood area as the larger tree. The ratio steadily increased with increasing tree size up to about 40 cm² of sapwood area. At this point the ratio became linear. A tree of this site with 40 cm² of sapwood area has a basal diameter of about 10 cm outside the bark and a height of about 1.8 m.

Possible differences between geographic regions were evaluated by comparison of the Sweetwater Mountains analysis results with the similar data for 17 pinyon trees with mature foliage from Tausch (1980) for the Needle Range of southwestern Utah. Sampling also occurred in mid summer and total tree cover on the tree dominated site was 24%. The trees ranged from 2 dm to 3 m in height.

The linear regression slope for the southwest Utah trees with up to 40 cm² sapwood area (125 g/cm²) was significantly greater ($P \leq 0.01$) than the regression slope for the combined Sweetwater mountain data for the same tree size range (79 g/cm²). For trees greater than 40 cm² sapwood area the southwest Utah regression slope (127 cm/cm²) and the Sweetwater Mountain regression slope (78 g/cm²) were not significantly different. The overall linear regression slope for all the southwestern Utah trees (120 g/cm², $R^2 = 0.97$) was significantly different ($P \leq 0.10$) and half again steeper than the relationship in Figure 2 for all the trees on the Sweetwater Mountains. Phytomass to sapwood area ratios have also been shown to differ between sites for other conifer species (Whitehead 1978, Bancalari 1987).

Phytomass to sapwood area relationships represent an effective way for obtaining accurate phytomass estimates of the overstory for studies of successional patterns in these woodlands. Caution must be exercised when using an equation from one site in new areas because of potential differences in the relationships between geographic areas.

Literature Cited

Bancalari, M.A.E., D.A. Perry, and J.D. Marshall. 1987. Leaf area-sapwood area relationships in adjacent young Douglas-fir stand with different early growth rates. Can. J. Forest. Res. 17:174-180.

Blackburn, W.H., and P.T. Tueller. 1970. Pinyon and juniper invasion in black sagebrush communities in east central Nevada. Ecology 51:841-848.

Brix, H.B., and A.K. Mitchell. 1983. Thinning and nitrogen fertilization effects on sapwood development and relationship of foliage quantity to sapwood area and basal area in Douglas-fir. Can. J. Forest. Res. 13:384-389.

Dean, T.J., and J.N. Long. 1986. Variation in sapwood area—leaf area relations two stands of lodgepole pine. Forest. Sci. 32:749-758.

Dixon, A.F.G. 1971. The role of aphids in wood formation. I. The effect of the sycamore aphid, *Drepanosiphum platanoides* (Schr.) (Aphididae), on the growth of sycamore, *Acer pseduoplatanus* (L.). J. Appl. Ecol. 8:165-179.

Ganskopp, D., and R. Miller. 1986. Estimating leaf area of big sagebrush for measurement of sapwood. J. Range Manage. 39:338-340.

Grier, C.C., and R.H. Waring. 1974. Conifer foliage mass related to sapwood area. Forest. Sci. 20:205-206.

Hungerford, R.D. 1987. Estimation of foliage area in dense Montana lodgepole pine stands. Can. J. Forest. Res. 17:320-324.

Kaufmann, M.R., and C.A. Troendle. 1981. The relationship of leaf area and foliage biomass to sapwood conducting area in four subalpine forest tree species. Forest. Sci. 27:477-482.

Keane, M.G., and G.F. Weetman. 1987. Leaf area-sapwood cross-sectional area relationships in repressed stands of lodgepole pine. Can. J. Forest. Res. 17:205-209.

Kline, J.R., K.L. Reed, R.H. Waring, and M.L. Stewart. 1976. Field measurement of transpiration in douglas-fir. J. Appl. Ecol. 13:273-283.

Long, J.N., F.W. Smith, and D.R.M. Scott. 1981. The role of douglas-fir stem sapwood and heartwood in the mechanical and physiological support of crowns and development of stem form. Can. J. Forest. Res. 11:459-464.

Marchand, P.J. 1984. Sapwood area as an estimator of foliage biomass and projected leaf area for *Abies balsamea* and *Picea rubens*. Can. J. Forest. Res. 14:85-87.

Marshall, J.D., and R.H. Waring. 1986. Comparison of methods of estimating leaf-area index in old growth Douglas fir. Ecology 67:975-979.

Meeuwig, R.O. 1979. Growth characteristics of pinyon-juniper stands in the western Great Basin. USDA Forest Serv. Res. Pap. INT-238.

Meeuwig, R.O. and J.D. Budy. 1979. Pinyon growth characteristics in the Sweetwater Mountains. USDA Forest Serv. Res. Pap. INT-227.

Miller, R.F., L.E. Eddleman, and R.F. Angell. 1987. Relationship of western juniper stem conducting tissue and basal circumference to leaf area and biomass. Great Basin Natur. 47:349-354.

Pearson, J.A., T.J. Fahey, and D.H. Knight. 1984. Biomass and leaf area in contrasting lodgepole pine forests. Can. J. Forest. Res. 14:259-265.

Running, S.W. 1980. Relating plant capacitance to the water relations of *Pinus contorta*. Forest Ecol. Manage. 2:237-252.

Snell, J.A., and J.K. Brown. 1978. Comparison of tree biomass estimators—Dbh and sapwood area. Forest. Sci. 24:455-457.

Tausch, R.J. 1980. Allometric analysis of plant growth in woodland communities. Utah State Univ., Logan, Utah, PhD. Diss.

Tausch, R.J., and P.T. Tueller. 1988. Comparison of regression methods for predicting singleleaf pinyon phytomass. Great Basin Natur. 48:39-45.

Waring, R.H. 1983. Estimating forest growth and efficiency in relation to canopy leaf area. Adv. in Ecol. Res. 13:327-354.

Waring, R.H., H.L. Gholtz, C.C. Grier, and M.L. Plummer. 1977. Evaluating stem conducting tissue as an estimator of leaf area in four woody angiosperms. Can. J. For. Sci. 55:1474-1477.

Waring, R.H., P.E. Schroeder, and R. Oren. 1982. Application of the pipe model theory to predict canopy leaf area. Can. J. Forest. Res. 12:556-560.

Whitehead, D. 1978. The estimation of foliage area from sapwood basal area in scots pine. Forestry 51:137-149.