ESTIMATING ROOT COLLAR DIAMETER GROWTH FOR MULTI-STEM WESTERN WOODLAND TREE SPECIES ON REMEASURED FOREST INVENTORY AND ANALYSIS PLOTS

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Abstract.—Tree diameter growth models are widely used in many forestry applications, often to predict tree size at a future point in time. Also, there are instances where projections of past diameters are needed. An individual tree model has been developed to estimate diameter growth of multi-stem woodland tree species where the diameter is measured at root collar. The model was built from radial growth data on trees sampled from plots measured in Utah, Arizona, and Nevada. Individual tree growth can be predicted from the ratio of live woodland stems to all stems and from mean past 10-year radial growth of trees by ecological subsection, section, or province. Coefficients were estimated for four woodland tree species groups that cover most tree species in the Southern Interior West region.

INTRODUCTION

Estimating diameter growth is an important aspect of forest management and inventory. Determining diameter growth is problematic for many western woodland tree species because they are measured at the root collar, are very slow growing, often contain multiple stems, and are poorly suited to measurement methods used for other temperate tree species. Site quality and stand competition in dry arid regions comprised of woodland trees species are not well understood.

Forest Inventory and Analysis (FIA) data on diameter growth are often obtained from repeatedly measuring the same trees over time or by measuring increment cores. Historically, the Interior West FIA (IWFIA) region has had to rely on increment core measurements for estimates of diameter growth because of inconsistent inventories over time or gaps in previous inventories where there were insufficient numbers of previously established permanent plots. When the annual inventory system was implemented in the IWFIA region in 2000, FIA plots were established on a systematic grid (Reams et al. 2005) across the landscape regardless of land use and ownership. Now, those initially established plots are beginning to be remeasured and there will be a need for procedures that reliably and efficiently estimate tree growth from paired plots measured at two points in time.

FIA requires measurements or models of tree diameter growth to estimate individual tree growth. Diameter growth, along with other volume attributes such as total height, is used to calculate growth for every qualifying tree measured on a plot. Individual tree growth is used for compiling inventories made up of tree data because growth can be calculated for each tree and then summarized in many different ways. Therefore, an individual tree modeling approach is used in this analysis.

Multi-stem woodland trees are the most problematic when comparing measurements between two points in time, referred to as time 1 (previous measurement) and time 2 (current measurement). Measurement error can

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be very significant because of extremely high numbers of stems, presence of obstacles that hinder accurate measurements such as thorns and rock outcrops, swelling and irregular form, or extremely degraded stems. The measurement point can change because of a field crew at time 2 disagreeing with where the field crew at time 1 took diameter at root collar (d.r.c.) measurements. Diameters can also change between time 1 and 2 because of stems breaking off due to cutting or mortality resulting in a d.r.c. reduction between time 1 and time 2.

It is because of these inherent difficulties in measuring d.r.c. at time 1 and time 2 that using a change in d.r.c. on multi-stem woodland trees will often yield artificial estimates of diameter growth. Chojnacky (1997) used radial growth data to estimate diameter growth of pinyon and juniper (*Juniperus* spp.) trees in New Mexico. Therefore, for multi-stem woodland trees, a measure of radial growth may be a superior metric for estimating diameter growth than a change in d.r.c. between time 1 and time 2.

STUDY AREAS

The data for this study came from inventory plot data collected by the IWFIA crew in Arizona, Nevada, and Utah. These three states were selected because of the preponderance of multi-stem woodland species and because they are located in the largely arid southern portion of the Interior West region. All data were collected under the annual inventory system that began in 2000 in Utah and covered the following years: Arizona (2001-2009); Nevada (2004-2005); Utah (2000-2009).

DATA

Tree data came from a total of 4,376 inventory plots measured across the three states. The plot design used during the annual inventory is described in Bechtold and Scott 2005. Only multi-stem woodland trees were used in the study because they are measured differently than single-stem woodland trees and are considered to be the most problematic growth form for determining growth. All multi-stem woodland trees used to develop the models had increment cores extracted and 10 years of radial growth measured. The minimum d.r.c. of the study trees was 5.0 inches. There were a total of 7,996 trees used in the analysis.

The woodland trees were grouped into four species groups: (1) common pinyon (*Pinus edulis* Engelm.); (2) Utah juniper (*Juniperus osteosperma* (Torr.) Little); (3) other junipers including redberry juniper (*Juniperus coahuilensis*), California juniper (*Juniperus californica* Carr.), alligator juniper (*Juniperus deppeana* Steud.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), and oneseed juniper (*Juniperus monosperma* (Engelm.) Sarg.); and (4) other woodland trees including singleleaf pinyon (*Pinus monophylla* Torr. & Frem.), Mexican pinyon pine (*Pinus cembroides* Zucc.), Arizona pinyon pine (*Pinus arizonica* Engelm), bigtooth maple (*Acer grandidentatum* Nutt.), curlleaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.), western honey mesquite (*Prosopis glandulosa* Torr.), velvet mesquite (*Prosopis velutina* Woot.), gray oak (*Quercus grisea* Liebm.), Emory oak (*Quercus emoryi* Torr.), Gambel oak (*Quercus gambelii* Nutt.), Mexican blue oak (*Quercus oblongifolia* Torr.), silverleaf oak (*Quercus hypoleucoides* A. Camus), and evergreen oaks.

METHODS

Radial growth measurements were converted into an annual change in d.r.c. using the following formula:

$$madc = \frac{2r}{10},$$

where *madc* is mean annual change in d.r.c. in inches of a live stem, and *r* is the length in inches of a radial-growth core representing 10 years of growth. Dividing by 10 converts the periodic estimate of 10 years of diameter growth into an annual estimate, standardizing the time frame so the modeled estimate can be applied to any number of years. This is common practice in many FIA diameter growth models (Westfall 2006). Differing remeasurement intervals, estimating diameter growth on trees that either died or were cut at various points in time during a measurement interval, and proper assignment of trees to the appropriate growth component are common applications of an annualized change in diameter.

Numerous attributes have been correlated with diameter growth rates. Often, stand and tree-level measurements that are observed or computed are used as predictor variables in diameter growth models. Examples of stand-level predictors often include age, site productivity, and stand density. Several predictor variables were identified for possible inclusion. Least angle regression was used to identify variables thought to be significant for model development and to create model parameters.

Two variables were deemed significant for predicting *madc*: (1) the number of live woodland tree stems divided by the number of live and dead woodland tree stems for an individual tree (lpct), and (2) the mean *madc* for a species group for an ecological subsection assigned to the plot the tree is sampled on ($ecog_{index}$). Ecological subsection refers to areas of unique geomorphology with distinct boundaries (Cleland et al. 2007). All FIA plots nationally are assigned a code that identifies the ecological subsection (Woudenberg et al. 2010). These two predictor variables yielded the following diameter growth equation:

$$madc = \beta_0 + \beta_1 lpct + \beta_2 \ln(ecog_{index})$$

RESULTS AND DISCUSSION

Parameter estimates for average annual change in d.r.c. are given in Table 1. Resulting parameters should be sufficient for most broad-scale inventory needs and can be used to estimate diameter growth on trees that have been cut or have died during the remeasurement interval or trees that need a previous or past diameter predicted because of field crew measurement error. It may even be desirable to use a model developed from increment core measurements to predict diameter growth for all multiple-stem woodland trees because of the high level of d.r.c. measurement error associated with these growth forms.

A more powerful explanatory growth model was not developed because of poor correlation between diameter growth and available FIA site description variables. There are several reasons why the correlation is poor. First, the FIA site description variables are not refined enough for many western forest conditions. For example, physiographic variables for arid woodland tree conditions are very

Table 1.—Parameters for estimating mean annual change in diameter at root collar (d.r.c.) of multi-stem woodland trees in Utah, Arizona, and Nevada

Species Group	Parameter Estimates β_0	β_1	β_2	Number of Trees	Regression Statistics R^2	C.V.
Common pinyon	.071	.021	.053	826	.17	48.0
Utah juniper	.065	.018	.043	3,934	.12	52.2
Other juniper	.067	.027	.060	1,787	.11	54.8
Other woodland species	.079	.00	.050	1,449	.15	57.0

Diameter growth equation (Eq. 2): $madc = \beta_0 + \beta_1 lpct + \beta_2 \ln(ecog_{index})$ where:
madc = mean annual change in d.r.c (inches) based upon 10 years of past radial growth;
lpct = number of live stems divided the total number of live and dead stems for an individual woodland tree;
$ecog_{index}$ = mean *madc* for a species group for an ecological subsection assigned to the plot the tree is sampled on;
R^2 = coefficient of determination;
C.V. = coefficient of variation.

limited. Second, measures to estimate site quality such as site index and site class are not collected on sites dominated by woodland tree species. Site quality studies are limited for many woodland tree species. Third, uncertainty exists for equating growth rates with ring counts for certain species. False and missing rings are known to occur for juniper (Despain 1989). Certain species, such as curlleaf mountain-mahogany, are never cored because of very hard wood characteristics. The inherent slow growing nature of these growth forms can make ring counting difficult.

CONCLUSIONS

The model described is easily applied and uses a minimum amount of field data. What is needed is the proportion of live woodland tree stems for an individual tree (*lpct*) and the mean 10-year diameter growth by species group for the ecological subsection assigned to the plot the tree is sampled on ($ecog_{index}$). The model could be further refined by improving methods to identify growth ring identification such as sanding and magnification and conducting further analysis to determine optimum number of tree samples per species groups for ecological subsection.

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