MAXIMUM CROWN AREA EQUATION FOR OPEN-GROWN BUR OAK

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Abstract.—Bur oak (*Quercus macrocarpa* Michx.) is a classic savanna species with a range that covers much of the eastern United States. Because savannas are an endangered habitat in North America, significant restoration efforts are in progress across much of the range of bur oak. For open sites being planted with bur oaks as well as fully stocked sites that are being thinned to create savanna conditions, an understanding of potential maximum crown area is of great utility. Between 2013 and 2015, 45 open-grown bur oaks ranging in size from 3.6 to 36.1 inches diameter at breast height (d.b.h.) were measured across central and southern Wisconsin. The equation $Crown\ Area = 3.253DBH^{2.004}$ was used to predict crown area with an r^2 of 0.93 ($p < 0.001$). This strong relationship has substantial utility for modeling crown cover to guide management of savanna restoration sites.

INTRODUCTION

Savanna is one of the most endangered habitats in North America. The majority of oak savannas have either grown into closed canopy conditions (creating two-cohort forests) or been converted into agricultural land. Research from Nuzzo (1986) suggests that current savanna remnants represent only 0.02 percent of former cover. With the loss of open conditions, plant species diversity changes dramatically (Bray 1958). Wilcox et al. (2005) determined that 40 percent crown cover appeared to result in the highest level of species diversity. In addition to crown cover, other factors, most notably fire (Dorney and Dorney 1989, Haney et al. 2008), impact species diversity; however, during savanna restoration, crown cover is one of the easiest factors to manipulate using logging. Nielsen et al. (2003) demonstrated that restoring both the structure and processes for savannas (logging and added fire) resulted in a better response than restoring processes only (solely reintroducing fire). While restoration of fire also tends to reduce crown cover (Bowles et al. 2011), fire alone does not readily regulate canopy cover at levels desired for savanna restoration or maintenance.

Because logging is a valuable tool for managing savanna structure, tools to aid timber marking crews are essential. For this reason, Law et al. (1994) developed a savanna crown cover chart. This crown cover chart follows a similar approach to stocking charts piloted by Gingrich (1967) using crown competition factors based on tree area equations developed by Krajicek et al. (1961). Ek (as cited in Johnson et al. 2002) developed an equation for bur oak (*Quercus macrocarpa* Michx.) in Wisconsin but did not apply it to savanna restoration. However, crown competition factors that use tree diameter to estimate corresponding crown diameter and area of open-grown trees do not consider tree height, only spread of the crowns. Because the majority of savanna restoration will be occurring in either existing closed canopy forest cover (where the crowns have been influenced by competition for years) or in completely open conditions (in the case of conversion of past agricultural land to conservation covers), the impact of tree height may also be important. Additionally, the crown cover chart from Law et al. (1994) is focused at a stand level and does not include bur oak, a common savanna tree in the Upper Midwest; however, a tool which allows a forester to specifically consider individual trees would be of use in both newly

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planted savannas (targeting future stand conditions) as well as overstory reductions (in the case of restorations in existing woodlands and forests).

Inclusion of tree height in the modeling of crown cover can improve the accuracy of the predictions. Many studies have shown that height and crown geometry are quite important when determining the impact of wind on diameter growth (Meng et al. 2008, Sellier and Fourcaud 2009, Sharma and Parton 2007). For this reason, Seymour and Smith (1987) included height in their creation of a new stocking guide for white pine (*Pinus strobus* L.), which reduced the b-line (the minimum level at which full stocking can be achieved).

The objective of this study was to develop an equation for maximum crown area for bur oak that can be used by managers in both marking existing forests for savanna restorations as well as in decisions on planting densities for savanna restorations in former agricultural land.

METHODS

Between 2013 and 2015, 45 open-grown bur oaks ranging in size from 3.6 to 36.1 inches diameter at breast height (d.b.h.) were measured across central and southern Wisconsin. For each tree, d.b.h., crown radius (in the four cardinal directions), and total height were measured. Using the approach of Krajicek et al. (1961), a quadratic regression equation was used to predict measured crown area from tree diameter:

$$MCA = b_0 + b_1D + b_2D^2 \qquad (1)$$

Where

MCA = maximum crown area (square feet), and

D = d.b.h. (inches).

Additionally, to incorporate height (using the approach of Seymour and Smith 1987), the following equation was fitted using Minitab 10.5.1.1.0^{TM} (Minitab, Inc., State College, PA):

$$lnCA = b_0 + b_1 lnD = + b_2HT \qquad (2)$$

Where

CA = crown area (square feet), and

HT = total tree height (feet).

RESULTS

In the quadratic regression (Eq. 1), D was not significant ($p = 0.498$); however, D^2 was significant ($p < 0.001$). The following equation predicted crown area with an r^2 of 0.84 ($p < 0.001$):

$$CA = -54.80 + 3.539(D^2) \qquad (3)$$

When modeled using Eq. 2, no improved prediction was found by incorporating height into the model ($p = 0.415$ for lnHT). With height removed, the following equation with $r^2 = 0.93$ was generated (presented here in its multiplicative form):

$$CA = 3.253D^{2.004} \qquad (4)$$

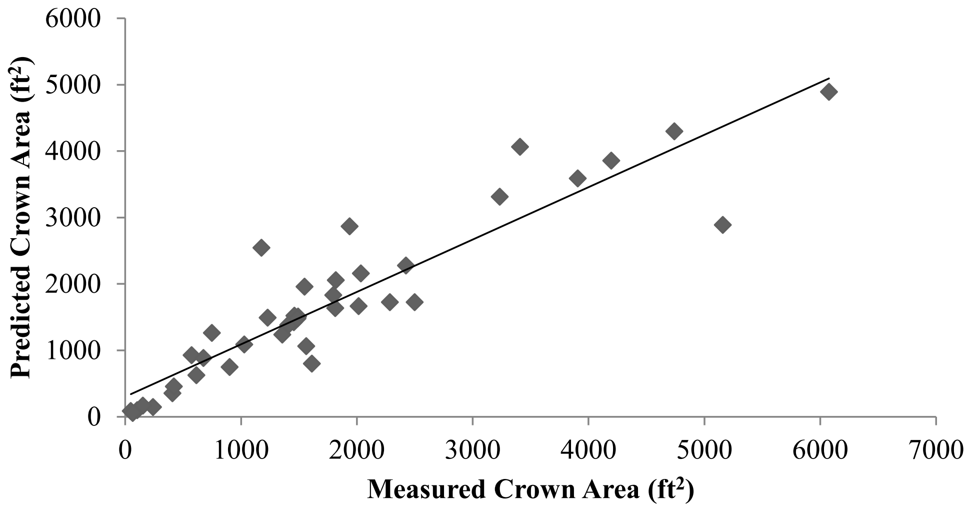

Figure 1.—Predicted crown area versus measured crown area for open-grown bur oaks in Wisconsin.

Table 1.—Number of open-grown bur oak trees of varying diameters needed per acre to meet different crown cover goals

			Crown cover			
D.b.h.	Crown radius	Crown area	100%	50%	25%	10%
inches	*feet*	*square feet*	*trees/acre*			
10	10.2	327	133	66	33	13
14	14.3	642	68	34	17	7
18	18.4	1064	41	20	10	4
22	22.5	1590	27	14	7	3
26	26.6	2223	20	10	5	2
30	30.7	2961	15	7	4	1
34	34.8	3805	11	6	3	1

Because the relationship in Equation 4 was extremely strong, this was the crown area model we accepted (Fig. 1). Using this equation, the number of open-grown bur oak trees needed per acre to reach different crown cover goals was calculated using the predicted radius for different diameter bur oak trees (Table 1).

DISCUSSION

It was surprising that height did not improve the prediction within the model because unpublished results by Demchik et al.[2] using height and crown area predicted crop tree d.b.h. very well for trees in a forest condition. The most likely explanation for this difference is that the selected bur oak trees were all open-grown. For this reason, these trees had probably maximized crown and diameter growth without limitations on height growth. The difference that we found between these open-grown trees and the forest trees suggests that using open-grown trees to model the lowest level of full stocking may not be sufficient for modeling maximum crown area

[2] Demchik, M.C.; Conrad, J.; Vokoun, M. Unpublished oak thinning data. Available from M.C. Demchik at: TNR Building, 800 Reserve Street, University of Wisconsin Stevens Point, Stevens Point, WI 54481.

under forest conditions. The use of height as a factor in the prediction of maximum crown area will require additional research.

For those involved in savanna restoration activities, decisions on what level of crown cover to leave will strongly impact the woody and herbaceous species diversity after restoration. When converting fully stocked stands to savanna conditions using logging, some windthrow and mortality should be expected. In ponderosa pine (*Pinus ponderosa* Dougl. Ex Laws.) restoration, Covington et al. (1997) left three times as many trees as they hoped to retain in an effort to allow sufficient trees for wind damage. However, the number of trees that need to be left to maintain target crown cover in spite of wind damage may vary by species. For example, Mujuri and Demchik (2009) found white oak (*Quercus alba* L.) reserve trees (which were growing in similar conditions to newly released savanna trees) had little mortality for 15 years after release, while northern pin oak (*Quercus ellipsoidalis* E. J. Hill) experienced 5.5 percent mortality after release. Additionally, the ability of trees to respond with increased growth as well as increased crown development may also vary by species. Brudvig et al. (2011) found increased growth of remaining trees (white oaks) with minimal mortality of the released trees after encroaching trees were removed to recreate a savanna. Similarly, Mujuri and Demchik (2009) found white oak increased in tree vigor and volume growth after release; however, northern pin oak tended to decline in vigor, although their predicted volume growth rate did increase. Because bur oak is a similarly long-lived tree when compared to white oak, survival after release will likely be similar to the white oaks in the previous two studies, suggesting that fewer trees need to be left for "redundancy" against mortality.

Values in Table 1 can be used to model the number of trees per acre (by diameter) that are needed to meet specific crown cover goals after the trees have expanded their crowns. This table could also be used to model the release of bur oaks in both oak woodland and forest conditions using the crown radius. With increasing interest in oak savanna restoration, tools similar to Table 1 may be of use in making informed management decisions.

ACKNOWLEDGMENTS

We thank Brian Gorman and Matthew Teachout for help with measurements. We thank Sophie Demchik for review of the paper. We thank various land managers for allowing site access to measure the trees.

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