Caribbean Journal of Science, Vol. 41, No. 4, 843-848, 2005

Bark Volume Determination of *Bursera simaruba* in Belize

Daniel E. Atha[1]*, Leopoldo Romero[2], and Todd Forrest[3]

[1]*Institute of Systematic Botany,The New York Botanical Garden, 200th St. & Southern Blvd.Bronx, NY 10458*
[2]*The New York Botanical Garden, 200th St. & Southern Blvd. Bronx, NY 10458*
[3]*General Delivery, Santa Elena, Cayo, Belize*
**Corresponding Author: datha@nybg.org*

Abstract.—Bark volume of *Bursera simaruba* (Burseraceae) is reported for 32 trees of 4 size classes (7-19, 20-29, 30-39, 40+ cm dbh) from two plots in western Belize: 20 year-old secondary forest and relatively undisturbed old-growth forest. Volumes are based on bark thickness and diameter measurements of the section between 0.5 and 3.0 m from soil-line of standing stems. To calculate the volume we used the equation for rotational volume (V_b = Int (Pi((f(x))^2 − (g(x)) ^{2}), x = h_1.. h_2)). Values for all size classes ranged between 2,005.74 cm^3 and 84,492.26 cm^3 (X = 28,558 cm^3). We used belt transects to determine stand density and size distribution in the two plots. We estimated 3,150 kg/ha and 43,767 kg/ha of bark in the undisturbed old-growth forest and 20 year-old secondary forest, respectively. The higher secondary forest value is due to its higher stand density. Results of individual tree volumes were compared with volumes obtained from the linear equation assuming a constant regression coefficient $V_b = V_{ob} *(1 - k^2)$. Resource managers with minimal training and equipment can determine bark stock quickly and non-destructively with stand basal area, mean bark-thickness, and employing a simple algebraic equation.

Keywords.—bark volume, Bursera, sustainable harvest, Belize.

Introduction

Plants and animals are harvested from the wild all over the world, yet we may know little or nothing about their actual numbers, ages, size distributions, reproductive capacity and relationships with other organisms. To ensure their long-term viability, biologists, ecologists and relevant stakeholders must cooperate to perform detailed studies before, during, and after harvest. Unfortunately, most are studied only after the populations begin to decline—typically indicated by a declining yield. Examples in the plant kingdom illustrating this problem are the Pacific yew tree (*Taxus brevifolia* Nutt.) whose bark was wild-harvested for the cancer fighting drug Taxol (Minore and Weatherly 1994) and pygeum or African cherry (*Prunus africana* (Hook. f.) Kalkman) whose bark is exclusively wild-harvested for treating benign prostatic hyperplasia (Cunningham and Mbenkum 1993; Stewart 2003). Despite decades of intensive harvest and millions of dollars in revenue, we still lack the biological information needed to effectively manage these wild resources to ensure their long-term survival. Most discussions of the sustainable harvest of biological resources recognize that basic biological studies are necessary for determining sustainable harvest levels and management regimes (Shanley et al. 2002).

Very few reports actually incorporate detailed studies of the number, age, size-distribution, reproductive capacity and regeneration of the exploited organism. One explanation for the lack of such data might be the perceived difficulty in obtaining and analyzing such information, coupled with the necessity of long-term monitoring. Local people often lack the technical experience and financial resources to carry out detailed ecological studies and visiting researchers are often constrained by a limited number of expeditions and the need to publish results within a relatively short period of time.

ms. received June 10, 2004; resubmitted February 22, 2004; accepted June 25, 2005.

Bursera simaruba (L.) Sarg. is a small to medium-sized tree common in lowland dry or moist forests throughout the Caribbean Region, from southern Florida, through the West Indies and Central America to northern South America. It is most common on rich and limestone-derived soils between sea level and 1,000 meters elevation. The tree typically reaches a height of 25 meters and a diameter at breast height of 60 centimeters. The bark is green or greenish-brown when young, becoming tan, copper or gray with age. The outer layers readily peel off in irregular, paper-like sheets. Like other members of the Frankincense family (Burseraceae), the bark has numerous secretory canals, containing a golden, turpentine-scented resin (Roth 1981).

The tree is known in Belize as gumbo limbo (English), indio desnudo (Spanish) and chacah (Mayan) (Balick et al. 2000). Bark resin is used to treat external skin irritations such as rashes, blistering, swelling and itching caused by insect bites, sunburn and the effects of dermatologically irritating plants such as *Metopium brownei* (Jacq.) Urb. and *Sebastiania tuerckheimiana* (Pax & K. Hoffm.) Lundell. In Belize, the fresh resin is applied directly to the affected area or the patient is directed to drink a tea made from whole bark sections (Arvigo and Balick 1998). The tea is also prescribed for internal infections, to purify blood, treat urinary tract infections, fevers, sun stroke, colds, flu, kidney ailments, and anemia and as a tonic to aid the weak and elderly (Arvigo and Balick 1998). Various parts of the plant are used for many of the same purposes throughout the range of the species (Morton 1981).

Such widespread and similar use of a particular species suggests that local people, whether through de-novo trial-and-error or through cultural exchange, have identified some biological activity and consistently applied it to treat the same symptoms. Numerous pharmacological studies have found that the bark resin of *Bursera simaruba* is biologically active (Camporese et al. 2003; Peraza-Sánchez and Peña-Rodríguez 1992; Rahalison et al. 1993; Rico-Gray et al. 1991; Sánchez-Medina et al. 2001; López-Abraham et al. 1979); two studies show potent anti-inflammatory activity (Abad et al. 1996 and Sosa et al. 2002). Proteins from the bark were among several tested aboard the space shuttle for the treatment of Chagas disease (Eng 2000).

In Belize, the whole bark is removed from the tree or the bark is lacerated to induce the seepage of resin. The resin is scraped from the tree and applied directly to the affected area of the skin. We have no knowledge of the resin itself being stored for later use or sale. The whole bark is usually removed by first making a 12 cm horizontal incision 1 m above the soil line (sometimes as low as 0.5 m). The harvester then inserts the machete horizontally into the incision until the cambium is reached and then pushes upward on the back of the machete, sometimes rocking it from side to side, until the knife glides upward smoothly along the cambium. The harvester stops at the extent of their reach above their head (ca. 3 m above soil line). We have no evidence of harvesters using ladders or scaffolding to reach higher than 3 m. Normally the harvester will take one vertical section from any individual tree and will not recollect bark from that individual, even when the wound has healed over. The collector may use the whole bark fresh or dry it for later use or sale. The bark between 0.5 and 3.0 m above the soil line is defined at "merchantable bark" because known harvesting of the bark in Belize is from this section of the tree.

The goals of the present study were to: 1) determine bark volume of *Bursera simaruba* for individual trees over 5 cm DBH in two forest types; 2) determine whether this value is significantly different in the two habitats where the tree is most common in Belize and; 3) determine the most efficient, precise, and non-destructive method for obtaining these values. Ongoing and subsequent studies will investigate growth, yield and regeneration. Ultimately, these data will be the basis for sustainable harvest recommendations for *Bursera simaruba* in Belize based on quantitative criteria.

Materials and Methods

This study was conducted at two locations in the western portion of the Cayo

District, Belize. Both sites are within the subtropical moist forest zone and receive between 1524 mm and 2032 mm of rain annually (Hartshorn 1984).

The 2,429 hectare, Terra Nova Forest Reserve (TN), is located at approximately 17° 21′ N and 88° 55′ W, about 30 kilometers northwest of the capital city, Belmopan. Most of the forest is old-growth (second-growth in late stages of succession). The approximately 20 ha Chaa Creek Nature Reserve is located at 17° 04′ N, 89° 06′ W, about 10 kilometers southwest of San Ignacio. Local people informed us that during the 1960's, the Chaa Creek site was cattle pasture, with scattered individual trees left un-cut. The Terra Nova and Chaa Creek sites were selected to represent mature or primary forest and secondary forest types, respectively. Sixteen trees of varying size from each site were selected for measurement.

Parallel belt transects 10 m wide and spaced 100 m apart were established in both study sites. In each transect, all stems of *Bursera simaruba* (including seedlings) were counted and measured. A total of 1.16 ha were covered by the transects in the Terra Nova forest and a total of 0.92 ha were covered in the Chaa Creek forest.

We used a diameter tape to measure diameter in centimeters at ground level, 0.5, 1.0, 1.3, 2.0, 3.0 meters, and every whole meter along the standing stems up into the canopy. All but the smallest diameter trees were climbed using a rope and harness. At each point where the diameter was measured (except for ground level), two small rectangular sections of bark 180 degrees from each other were sawed out and the thickness was measured with a vernier caliper, resulting in 304 diameter measurements and 608 bark thickness measurements.

Most of the available data on tree volume determination concerns commercially important timber species and treats bark as a throwaway by-product. For commercial timber purposes, total tree volume (with or without bark) is determined by measuring the cross-sectional area and length of sections of felled trees and applying either the Smalian or Huber formulas (Chapman and Demeritt 1936). The procedure is repeated for several trees within each size-class. Total volumes are then tabulated according to diameter and total tree height to produce volume tables. This method requires felling numerous trees within each size class and was deemed too destructive for the present study.

The most widely cited, non-destructive method for bark volume determination is that proposed by Meyer (1946). This method relies on a single equation expressing the relationship between bark thickness and diameter (or diameter under-bark (d) and diameter over-bark (D)). Diameter under-bark is obtained by subtracting the double bark thickness (B) from diameter over-bark (d = D–B). A regression coefficient (k) is then calculated by the equation: k = d/D. Assuming the ratio d/D is constant for the length in question, the constant k can be used to calculate volume by the equation: $V_b = V_{ob} * (1 - k^2)$, where V_{ob} equals volume over-bark. Meyer cautions against applying k values obtained from small diameter trees to larger diameters and suggests grouping by size class. Another potential problem is whether a given ratio is applicable at various heights of the same tree. Meyer, however, found no significant difference in measured and calculated values of k over approximately twenty meters of hemlock stem.

We calculated the volume of each measured stem section using the equation for rotational volume (Equation 1) where f(x) is the line described by the outside radius and g(x) is the inside radius (in slope intercept form: y = m(x) + b). The symbolic computation system, Maple V (Heal et al. 1998) was used to perform the integration.

$$\text{Equation 1: } V_b = \text{Int}\,(\text{Pi}((f(x))^2 - (g(x))^2),\ x = h_1 \ldots h_2)$$

Volumes of individual sections were then summed to obtain total bark volume for the lengths measured. Bark volumes for each tree were tallied and the average calculated for each size class.

RESULTS

Sampled trees ranged between 7.10 cm and 53.2 cm DBH and 10 and 18 meters tall.

First branches emerged at between 21 and 88 percent of total height (mean 50%) at Terra Nova, and 20 and 88 percent (mean 55%) at Chaa Creek. Some trees were straight and tapered uniformly with few swellings or curves. Others curved one or more times with swellings, particularly where branches emerged.

The equation describing the relationship between basal area and merchantable bark using the sums of integration method (y = 34.554x + 1766.3, R2 = 0.9615) is not significantly different from that obtained using the Meyer method (y = 34.835x + 2539.4, R2 = 0.9567) as shown in Figure 1. Average bark volumes determined by both methods are grouped by size class and compared in Table 1.

Based on preliminary measurements of fresh bark density (1.09075 g/cm^3) and observed basal areas in primary and secondary forests (35.15 m^2/ha and 116.12 m^2/ha, respectively) we estimated 13,250 kg/ha of merchantable bark for primary forest and 43,767 kg/ha for secondary forest. The greater volume per hectare in the secondary forest is due to the greater basal area (112.16 m^2/ha at Chaa Creek vs. 35.15 m^2/ha at Terra Nova).

We found no significant difference in raw bark thickness values between the two sites (P = 0.88, two-tailed test) nor did we find significant differences in volume estimates employing the two methods for calculating volume (Fig. 1).

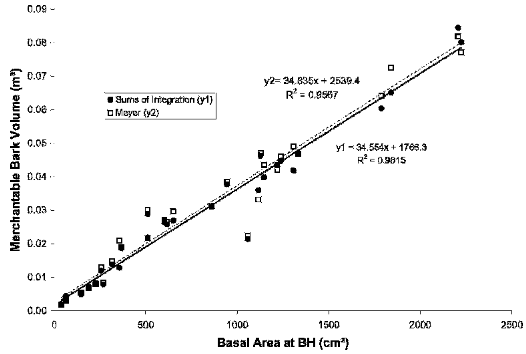

FIG. 1. Linear regression of total merchantable bark volume for individual trees of *Bursera simaruba* in the Cayo District, Belize. N = 32. Values were obtained by the Meyer method (1946) and integration. Bark thickness and diameter measurements used to calculate volume were taken between 0.5 meters and 3.0 m above the ground from standing stems.

DISCUSSION

Bark volume calculations are dependent on accurate determination of bark thickness. Potential error is minimized in smooth-barked species such as *Bursera simaruba* and is greater for species with great variation in bark texture, such as some species of pine and oak which may have fissures and ridges. The method employed for measuring bark thickness is also subject to bias. Use of the Swedish bark gauge takes considerable practice and has been shown to produce errors of ± 1 mm (Loetsch 1973). We initially intended to use the Swedish bark gauge, but could not confidently assess whether the plunger had in fact penetrated the wood and was therefore giving a false value. This problem may be of greater concern in soft-wooded species such as *Bursera simaruba*. The most accurate method is to remove a section of bark and measure the thickness with a caliper rule, which was done in this study. While superior to the Swedish bark gauge, this method is more time consuming and provides a larger opening in the tree's protective bark.

TABLE 1. Bark volumes of *Bursera simaruba* calculated by the Myer (1946) and integration methods from a secondary forest in the Cayo District of Belize (N = 16; 8 for each size class). Bark thickness and diameter measurements were taken between 0.5 meters and 3.0 m above the ground from standing stems.

		Bark Volume (cm^3)	
DBH (cm)	Bark Thickness (cm)	(Meyer)[a]	(Integration)[b]
10-19	0.60 ± 0.13	4841.07 ± 1957.57	4849.98 ± 2113.84
20-29	1.01 ± 0.21	18867.69 ± 6639.04	17469.48 ± 6790.63
30-39	1.42 ± 0.30	34488.51 ± 8059.51	33510.33 ± 7962.30
40-60	1.76 ± 0.31	59989.48 ± 16959.59	58410.95 ± 15833.38

Even assuming accurate bark thickness measurements, precise bark volume calculations are inherently difficult because the shape under consideration is that of a hollow cylinder which not only tapers, but does so at one angle on the inside and another on the outside. This is true when diameter over-bark and diameter under-bark is not constant as in the case of *Bursera simaruba* and other species including oak, pine and spruce (Loetsch 1973). Calculus methods such as the equation for rotational volume (employed in this study) are the most accurate means of measuring the volume of such shapes, with the precision depending on the number of data points taken along the length in question.

Most commercial timber operations rely on volume tables based on relatively few measurements and employ algebraic equations based on average cross-sectional areas and assuming an overall parabaloid shape. Such calculations are approximations of volume and may underestimate or overestimate total volume (Chapman and Demeritt 1936). Constructing these tables requires felling numerous trees and is inappropriate for use on NTFP species of limited quantity or that may be protected by law.

The Meyer method relies on bark thickness and diameter at breast height and assumes a constant ratio of diameter over-bark to diameter under-bark. Our findings indicate that this potential liability does not significantly alter the final volume determination. Trees of a given species should be grouped by size class and bark thickness measurements taken from several individuals within each class to obtain reasonable confidence in an average bark thickness for that size class. This average can then be used to calculate the regression coefficient (k).

CONCLUSIONS

The results of this study provide reliable estimates for current bark stock of *Bursera simaruba* in two forest types in Belize. It is also shown that bark volume may be accurately determined using the non-destructive, Meyer method. We suggest that researchers employing the Meyer method can obtain bark volume data simply and accurately for a number of tropical and temperate trees species.

Acknowledgments.—The Edward and John Noble Foundation is gratefully acknowledged for their generous support. The authors wish to thank the Belize Ministry of Natural Resources and the Forestry Department for their permission and cooperation throughout this study. We especially wish to thank Marcelo Windsor, Earl Codd and Hector Mai of the Forestry Department for their professional and enthusiastic support for this study and botanical research in Belize generally. The dedicated and knowledgeable staff of the Chaa Creek Nature Reserve, managed by Mike Green, provided valuable field assistance and advice, as did Elejio Cocom during field work at the Terra Nova Forest Reserve. The senior author wishes to thank Ulyana Muñoz-Acuña for her patience, support and helpful discussions throughout the research, analysis and writing of the present work.

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