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Research paper

Biomass from young hardwood stands on marginal lands: Allometric equations and sampling methods

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ABSTRACT

We developed allometric equations for small-diameter woody species growing on mixed forest marginal lands, which are potential sources of biomass for bioenergy. Eleven species of trees and shrubs were sampled from a site located in eastern Canada. Equations derived in this study generally performed better than equations from the literature. Also, fixed-area plots (FAP) and line-intersect sampling (LIS) methods using both random or systematic selection of sampling units were compared to determine which method required the lowest number of measurements to estimate stand biomass for the same precision.

The fixed-area plots method was successfully used to estimate relatively accurately oven-dry biomass per hectare. Results indicated that potentially harvestable woody biomass (oven dry basis) varied between 33-41 and 12–13 t ha^{-1} for the most and least productive marginal sites respectively. On the most productive site, LIS estimates (between 20 and 42 t ha^{-1}) were usually lower than those obtained using different FAP sampling methods (i.e. systematic or random, small (50 m^2) or large (100 m^2) plots), but similar on the more open sites (between 10 and 14 t ha^{-1}). Small FAP resulted in a plot without measurements in one case. Moreover, estimates based on small FAP were generally higher, even if not significantly different from larger plot estimates. We therefore suggest using FAP with 100 m^2 plots to estimate small-diameter woody biomass on marginal lands with dense vegetation, while LIS, even if promising for open stands, needs further evaluation before recommendation.

1. Introduction

Due to urban migration and increasing intensification of agricultural practices, previously cultivated marginal lands are being abandoned at an increasing rate, particularly in eastern North America and Europe; thereby leaving hundreds of thousands of hectares to natural recolonization by vegetation, such as shrubs and trees [1–3]. Given the long-term inevitable decrease in availability of crude oil [4,5], plus concerns associated with climate change, there is a growing interest in renewable "greener" energy sources and diversification of the energy sector [6–8]. Bioenergy, which includes both biofuel production and biomass burning for heat or electricity production, may be an interesting avenue to diversify local and national economies, favouring land occupation and rural development [9]. In Quebec, an eastern Canadian province,

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Vouligny and Gariépy [10] estimated that there are nearly 109,000 ha of abandoned marginal lands. An unknown proportion of this area could be exploited for bioenergy feedstock production, depending on site fertility and accessibility. Young irregular natural stands composed of pioneer species with little commercial importance that grow on marginal and abandoned lands may be perceived negatively by farmers [11,12]. However, if farmers can be shown a return on investment or a reduction in heating costs for farm buildings, they may support the use of marginal lands for biomass production while maintaining other ecological functions, such as wildlife habitat and windbreaks [8,9,11,12]. The potential for harvesting biomass on these marginal lands may be significant [9,13,14], but the available biomass stocks need to be estimated accurately for the decision-making process before encouraging their utilization.

Sampling methodologies used to efficiently estimate the amount of biomass that can be harvested from young irregular forested sources have not been thoroughly evaluated [15]. Also, there is a lack of adequate allometric equations to accurately estimate standing biomass of small-diameter woody species growing on marginal lands [16–18]. Equations currently available for saplings and understory trees developed using data from mature forests do not apply well to young trees growing on marginal lands [16,19,20] or may simply be lacking entirely for non-commercial species. Equations that include both diameter and height are needed, since they will be more flexible and precise when applied to different sites and account for differences in stand density [16,17,21].

The challenge in choosing the best sampling method to obtain stand estimates, i.e. the one which, for a desired accuracy, requires the minimum number of measurements while minimizing bias, needs to be addressed for estimating biomass on young hardwood stands on marginal land. The use of fixed area plots (FAP sampling) with detailed tree measurements for biomass estimates is a commonly applied procedure. Its application may provide relatively accurate estimates, but may be time consuming and expensive when plot establishment in terms of size and number is considered. Plot size, which depends on the characteristics of the stands under study (age, stand density, number of species, variability in terms of diameter and height, etc.) [22–27], must be carefully chosen as it may affect the precision and cost of the estimates. . Other methods, such as horizontal point sampling or line-intersect sampling (LIS) [28,29], may be more efficient (i.e. less time consuming) in estimating standing biomass, but need further evaluation [28,30,31]. However, horizontal point sampling is a method requiring equipment and expertise that farmers and some landowners may lack. Moreover it may be difficult to apply in very dense stands with many small stems. LIS, which is generally used for the inventory of coarse woody debris [32,33], has recently been used to determine standing biomass of natural forests in Delaware, eastern USA. This field sampling method was coupled with LIDAR remote sensing technology and used to extrapolate estimates of standing biomass at a state-wide level [31], thus raising new interest in this sampling technique.

In this paper, our objectives were to (1) develop allometric equations for small-diameter woody species growing on marginal lands recolonized by natural vegetation after land abandonment; (2) compare our allometric equations with those from the literature to evaluate expected gains in accuracy; (3) test FAP and LIS to estimate the amount of oven-dry biomass per hectare and find the most reliable method requiring the lowest number of samples and (4) make recommendations on the sampling methods to be used when dealing with small-diameter woody species growing on marginal lands.

2. Materials and methods

2.1. Study area

The study site is located in a forested area adjoining the Rivière-du-Loup airport (47°46′23.9″ N, 69°34′26.4″ W, elevation 113 m), in Quebec, eastern Canada. The nearest weather station with climate data for the 1981–2010 period is located in Saint-Arsène (47°57′00.0″ N, 69°23′00.0″ W, elevation 76 m, 25.2 km from the study site). This location receives on average 963.5 mm of precipitation annually, 72% of which falls as rain, including 462 mm during the May–September period (Saint-Arsène Climate Normals 1981–2010 [34]). Annual average daily temperature is 3.5 ± 2.9 °C (mean ± std. dev.), with spring and summer monthly average temperatures ranging from 9.3 ± 1.5 (May) to 17.6 ± 1.2 °C (July). On average, the frost free period lasts 135 days, with the first frost occurring on October 1 and the last on May 18. From 1981 to 2010, the snow cover reached on average 43 cm in March, with snow disappearing by the end of April and starting to accumulate again in November. The area is characterized by a flat to gently rolling terrain.

The study area can be described as a young hardwood stand of variable density, species composition and canopy cover growing on marginal lands within the balsam fir-yellow birch bioclimatic domain [35]. This site was chosen to represent abandoned lands recolonized by natural vegetation in southern Quebec. No information was available on the history of the site. This site had variable vegetation structure; it was occupied by tall shrubs and young trees of commercial and non-commercial timber species. It included open areas with more abundant tall shrubs and herbaceous vegetation. Shrubs included serviceberry (*Amelanchier* spp.), elderberry (*Sambucus Canadensis* L. var *Canadensis*), red-osier dogwood (*Cornus stolonifera* Michx.) and beaked hazel (*Corylus cornuta* Marsh.). Small and medium trees included grey alder (*Alnus rugosa* (DuRoi) Spreng.), paper birch (*Betula papyrifera* Marsh.), cherries (*Prunus* spp., specifically *Prunus pensylvanica* L.f. and *Prunus virginiana* L.), willows (*Salix* spp.), balsam poplar (*Populus balsamifera* L.), trembling aspen (*P. tremuloides* Michx.) and American Mountain-ash (*Sorbus americana* Marsch.).

2.2. Development of allometric equations

To develop allometric equations for small diameter species (DBH < 100 mm), trees and tall shrubs were sampled by selecting small, medium and tall plants to cover the range of diameter and height observed in the field. In August 2014, between 8 and 12 plants from each of the aforementioned species were cut as close as possible to the ground. A mark was made at 15 and 130 cm (breast height) from the ground before felling the plant. Diameter at ground level (DGL), at 15 cm from the ground (D15) and at breast height (DBH, if the plants reached 1.3 m), and height were recorded after felling.

Leaves were manually removed to obtain woody biomass. Larger plants (DBH > 20 mm) were generally separated into three approximately equal parts (the base, middle and top), plus the stump, which was defined for this study as the part between the D15 mark and the ground. Each plant or plant part was weighed in the field with an electronic scale (±1 g) to obtain its fresh weight, without leaves. If the part or plant was too heavy or too big to be easily carried to the laboratory, a subsample from each part (base, middle, top and stump) was taken, weighed in the field to obtain the fresh weight, and carried to the laboratory for drying. Otherwise, the entire plant was cut into small pieces using a small hand saw, weighed in the field, put into paper bags, and carried to the laboratory for drying at 70 °C for 72 h. Plant dry weight was