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A method for estimating above-ground biomass in Phragmites stands

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A stratified sampling method is presented for estimating the above-ground biomass of reedbeds. The method involves measuring the shoot height distribution of the population. Shoot height is transformed to shoot dryweight by means of an empirical model. Summing the converted dry weight of all the shoots gives an approximation of the yield.

The method appeared to give more accurate results than did an earlier method in which the average shoot dry weight given by a random sample is multiplied by stand density. The greater accuracy of the present method was particularly evident when small samples were used, consisting of 3–20 shoots.

Key words: biomass, sampling method, *Phragmites*

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INTRODUCTION

Estimates of biomass made by the harvesting method are affected by spatial variation in two phases of the work. Firstly, the plots seldom cover the whole study area and a risk is involved in generalizing from the plots to the whole area. If the plots have been properly sited, however, the variation within the area can be quantified by studying the variation of the yield estimates between the plots.

Secondly, variation can occur within a plot and this affects the estimate when the dry-matter biomass is not measured directly but approximated from a regression. Regression models are not only species-specific, but also specific for each stand. In addition, alternative regressions can be used within a stand, which all have their own special advantages and drawbacks.

In studies on the common reed (*Phragmites australis* (Cav.) Trin. ex Steudel), the parameter generally estimated is the dry weight of the standing crop. This has sometimes been calculated directly by determining the dry weight of all the shoots on the plot (Björk 1967, Kárpáti & Kárpáti 1971, Dykyjova et al. 1973, Ho 1979). Unlike methods using sampling within the plot, this approach excludes errors due to within-plot variation. Some authors, however, have used a sample to calculate the average shoot dry weight and multiplied this value by the reedbed density (Mochnacka-Lawacz 1974, Mason & Bryant 1975, Toivonen & Lappalainen 1980). The resulting estimate may be impaired by sample-dependent variation, and this is also the case when "wet weight" is measured *in situ* and a sample is taken to determine the dry matter content.

Here we present a method which also includes sampling within the plot, but is intended to diminish the effect of sample-dependent variation by using a technique which is not sensitive to anomalies in the shoot size distribution of the sample.

MATERIAL, METHODS AND RESULTS

The method was applied to a pure stand of *Phragmites australis* growing in southern Finland (61°23′, 24°24′). Four permanent 2 x 2 m sample plots were set out at random in the stand on 24 April 1978, when ice still covered the lake. The stand was situated in the central part of a large reedbed. The remnants of the previous year's shoots were removed from the sample plots at the same time.

The annual yield of above-ground biomass was measured on 2 and 3 August 1978. Shoots growing in the plots were cut off individually at the point where they protruded from the lake bottom, which at that time was lying above the water level. The height of each shoot was measured with an accuracy of five centimetres. The total number of shoots was 1 066, and their average density 66 shoots · m^{-2}. The distribution of the shoots in height classes is shown in Fig. 1a.

In the present method the weight determinations are facilitated by converting shoot height to shoot dry weight. Shoot height can be measured *in situ*, but determination of the shoot dry matter requires additional laboratory work.

The relationship between shoot dry weight, w, and shoot height, h, was formulated as follows:

$$w = a \cdot h^{b} \qquad (1)$$

where a and b are empirical parameters.

The model (1) enables the height of every shoot in the sample (shown in Fig. 1a) to be transformed into shoot dry weight. The final goal — a value for the standing crop in a given area — is achieved by summing the dry weights of all the shoots.

A subsample of 49 shoots (Fig. 1b) was taken in order to estimate parameters a and b of Eq. (1). The shoots were dried to constant weight at 105°C. When height was expressed in metres and dry weight in grams, the parameters were estimated to be: $a = 0.949$ and $b = 3.27$ (Fig. 2). These values were obtained by computer iteration without linearizing the height to weight relationship, which would lead to biased values (Baskerville 1972, Wiant & Harner 1979).

Approximation of the biomass, T (g · m^{-2}), over the four sample plots was performed as follows:

$$T = \frac{1}{A} \sum_{i=1}^{1066} 0.949 \cdot h_i^{3.27} \qquad (2)$$

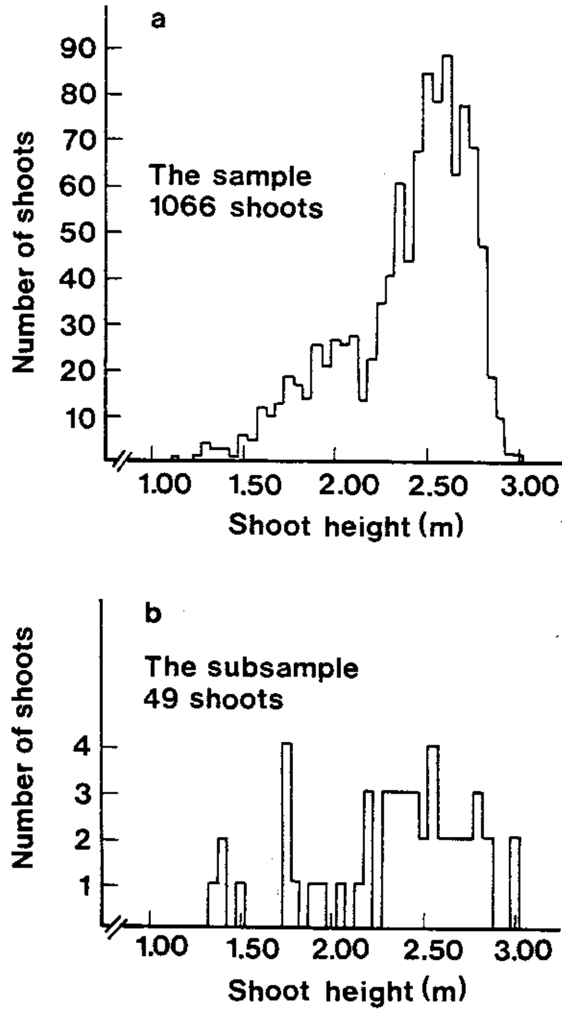

Fig. 1. Shoot height distribution of sample (a) and subsample (b).

where A is the area in square metres, i.e., 16 m^2. The average yield appeared to be 1 170 g · m^{-2}, the figures for the individual sample plots being 1 030, 1 110, 1 290 and 1 250 g · m^{-2}.

AN EVALUATION OF THE METHOD

Equation (2) was considered to be a suitable method for estimating the standing crop from the present data. The value yielded by the equation was used as a criterion in comparisons with some alternative methods.

Since measuring the dry weight of reed shoots

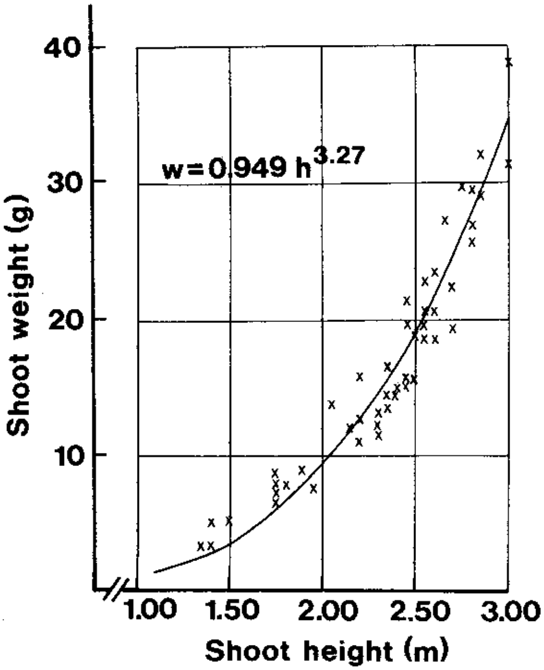

Fig. 2. Relationship between shoot height and shoot dry weight in the subsample.

is laborious, we examined whether a subsample of only 10 shoots was large enough for estimation of the parameters in Eq. (1). A random sample of 10 shoots was taken for this purpose from the original subsample of 49 shoots. Parameters a and b of Eq. (1) were estimated and then inserted in Eq. (2) to approximate the biomass, T_{10}. The new estimate was then compared with the criterion (T_{49}) in order to determine the error percentage, e_{10}:

$$e_{10} = 100 \cdot \frac{T_{10} - T_{49}}{T_{49}} \quad (3)$$

The biomass approximation, T_{10}, and consequently the error percentage, e_{10}, vary with the sample. Therefore the procedure of Eq. (3) was repeated four times with independent random samples. The average figure for these four computations, $\bar{e}_{10}$, was obtained to estimate the mean deviation of the yield approximation when 10 sample shoots are used instead of 49. The value of $\bar{e}_{10}$ in our material was 4 %.

The average-weight-*x*-density method was tested in a similar way. A random sample of 10 shoots was taken from the original subsample of 49 shoots. The mean weight of these shoots was calculated and then multiplied by the reedbed density, 66 shoots · m^{-2}. The biomass estimate, τ_{10}, was again compared with T_{49} in order to obtain a value for the error percentage, ϵ_{10}:

$$\epsilon_{10} = 100 \cdot \frac{\tau_{10} - T_{49}}{T_{49}} \quad (4)$$

The mean deviation $\bar{\epsilon}_{10}$, of the value τ_{10} when compared with T_{49} was calculated from the values obtained with four independent samples. $\bar{\epsilon}_{10}$ was 12 %.

The effect of subsample size on the accuracy of the yield estimate was studied in more detail for both of the methods. In addition to the above calculation with samples of 10 shoots, the estimates for the error percentages $\bar{e}$ and $\bar{\epsilon}$ were computed using random samples of 3, 5, 15, 20, 25, 30 and 35 shoots. The values for $\bar{e}$ and $\bar{\epsilon}$ were calculated using identical sets of random samples. The results are shown in Fig. 3.

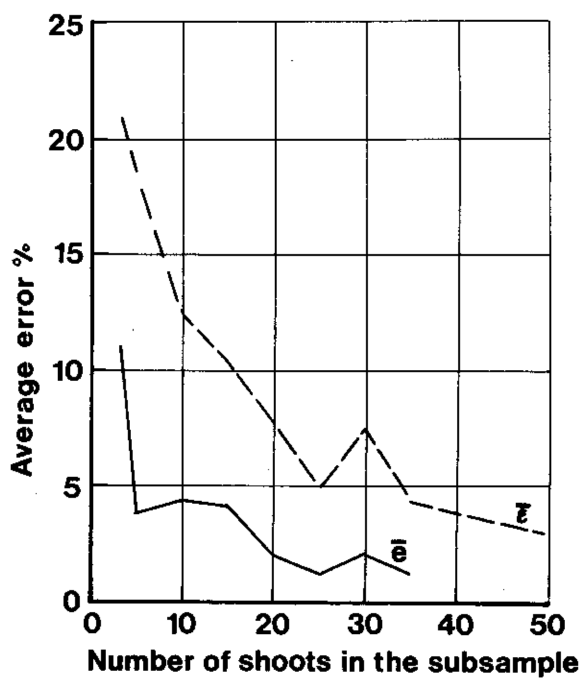

Fig. 3. Error percentages when two different methods are used to estimate biomass, shown as a function of the size of the sample. The percentages for the new method are shown by the solid line ($\bar{e}$) and those for the average-weight-*x*-density method by the broken line ($\bar{\epsilon}$).

Multiplying the average dry weight of the whole subsample shown in Fig. 1b (17.05 g) by the reedbed density (66.05 shoots · m^{-2}) gave a 3 % lower estimate of the biomass than did the new method with the same subsample (Fig. 3). The difference was chiefly due to the difference in shoot size distribution between the sample and the subsample.

DISCUSSION

The present method is based on stratified sampling. It involves description of the shoot height distribution of the population. The measurement work is not too time-consuming, since two persons can easily measure 100–200 shoots an hour.

The description of the shoot height distribution is useful not only for approximation of the yield but also as a basis for more detailed ecological comparisons. Besides varying in density, stands differ in shoot length and in shoot size distribution. The present method makes it possible to quantify these differences.

The problem of sample-dependent variation in the biomass estimate for a plot is, of course, completely avoided by determining the dry weight directly. When this method is used, however, the size of the sample may be restricted by limited space in drying ovens, and related constraints. The idea of using stratified sampling in studies of plant biomass production is not new. It has been applied in forest inventories for decades (cf. Müller 1902), and a method which corresponds to ours has been used by Ross and Ulasova (1966) in studies on maize (quoted in Ondok 1971).

Our results show that the average error was smaller with the present method than with the average-weight-*x*-density method (Fig. 3). The greater reliability of the new method was evident throughout the range of sample sizes studied, but particularly with small samples of 3–20 shoots.

The results shown in Fig. 3 are sensitive to the data sets. In our material the sample (1 066) and subsample (49) differ in their distributions by shoot height (Fig. 1), the curve for the subsample being platykurtic. Such a subsample is more suitable for fitting the regression of Eq. (1) but is unfavourable for the dry–weight–*x*–density method in the comparison shown in Fig. 3. However, another factor acts in the opposite way; i.e., it favours the dry-weight–*x*–density method in the comparison. When the present method is applied, the subsample shoots are never chosen at random. The shoots in a random subsample may be very similar in size, which is unsuitable for fitting the regression curve of Eq. (1). Hence, the estimated mean deviations for the biomass estimates (Fig. 3) depend on the data sets in different ways, but the difference in accuracy between the two methods is most likely to be a general one.

The shape chosen for Eq. (1) appears to be useful in studies of the relationships between shoot height, shoot weight and stand density (Yoda et al. 1963, see also Gorham 1979). The weight of a plant is generally proportional to the cube of a linear dimension of the plant (in our case the height). The exponent obtained (3.27) is somewhat higher than the expected one (3.0), which may indicate light competition. However, the difference is apparently mainly due to the simultaneous estimation of parameters a and b. If the b value was fixed at 3.0 and the a value was allowed to adjust, the fit of the curve would be almost as good as the one in Fig. 2.

In practical applications of this method the selection of the subsample would deserve special attention. A random subsample would make calculation easy, but might not give the optimal compromise between accuracy on the one hand and labour consumption on the other. Instead of looking for a generally valid sampling procedure, selection should be tailored to the study objectives. If the shape of the height-weight curve is of interest, then it would be worthwhile to increase the selection probability of rare size classes. If, in turn, biomass approximation is the only goal, then the largest shoots are the most important and one should increase the probability of their being selected. This could be done with a procedure where selection probability is proportional to, e.g., the cube of the shoot height.

As computed above, the error percentages $\bar{e}$ and $\bar{\varepsilon}$ do not take into account all sources of error in the course of the sampling procedure. For example, the estimate given by the whole subsample, T_{49}, is not a real measurement of the biomass on the plots. However, the fit of the curve in Fig. 2 seems fair and the slope of the function $\bar{e}$ in Fig. 3 suggests that increasing the number of shoots in the subsample would not increase the accuracy by more than 1–2 %.

The sample plots were not sited in the stand so as to study the standing crop outside the plots. To obtain a generalization for the whole reedbed, the location of the plots should follow standard statistical methods. The reedbed border limits should first be defined, and a sufficient number of plots placed according to a predetermined schedule (systematically or at random). This is not too laborious when small plots are used ($\sim 1\,m^2$). With such material the confidence limits for the biomass approximation are easy to determine.

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