METLA
FINNISH FOREST RESEARCH INSTITUTE

ELIMINATING THE EFFECT OF OVERLAPPING CROWNS FROM AERIAL INVENTORY ESTIMATES

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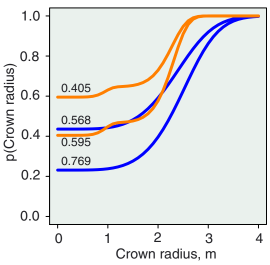

Figure 1. The probability of observing a tree as a function of crown radius in stands where the canopy closure is as shown on the plot and crown radius is distributed according to a unimodal (blue) and a bimodal distribution (orange).

Table 1. Characteristics of the simulated stand. The expected values are based on the underlying distribution used in simulation.

Observed values	
Area, ha	1.0
Number of stems, 1/ha	973
Number of visible trees, 1/ha	481
Min crown area, m²	0.021
Max crown area, m²	44.37
Mean crown area, m²	11.27
Canopy closure	0.677
Expected values	
Number of stems, 1/ha	1000
Number of visible trees, 1/ha	479
Crown area, m²	11.34
Canopy closure	0.678

Introduction

When a forest stand is inventoried by detecting single trees using aerial photographs or laser scanners, a part of the trees remain unobserved. One main reason for this is that trees that are covered by a crown of a larger tree are not visible from the air. This study derived the probability of a tree being observed from the air as a function of crown area and applied it in estimating the distribution of crown areas and the number of stems in two different situations:

A. A known proportion of visible trees of a fixed area have been observed
B. An unknown proportion of visible trees and the canopy closure have been observed.

Assumptions

(i) Trees are randomly located in the stand and tree size is not spatially correlated within a stand,
(ii) tree height is an increasing function of crown diameter,
(iii) tree crown forms a circle around tree tip,
(iv) a tree is visible from the air if the tree tip is not located within a crown of larger tree, and
(v) tree crowns have been observed perpendicularly above the tree.

Relationship between canopy closure, stand density and expected crown area

The total number of stems in a stand can be estimated by

$$\text{number of stems} = -\frac{\ln(1 - \text{canopy closure})}{\text{expected crown area}} \qquad (1)$$

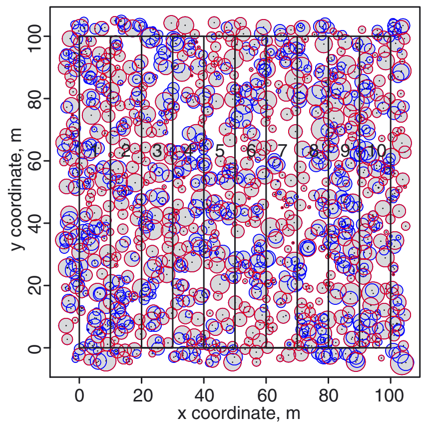

Figure 2. Crown map of a simulated forest stand and ten sample plots. Red circles show visible trees and blue circles invisible ones. The shadowed area demonstrates the canopy closure.

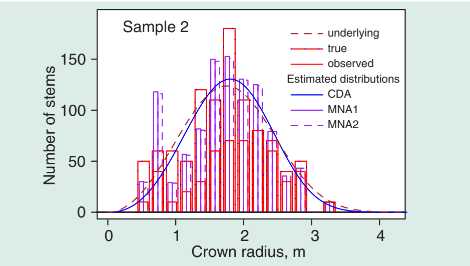

Figure 3. True and estimated distributions of crown radii in one sample.

Approaches

Continuous distribution approach (CDA, situation B)

A weighted distribution is fitted to the observed sample of visible crowns. The weight is the probability of a tree being covered by the crown of a larger tree (Fig. 1), which was derived under the stated assumptions. The distribution of crown areas is obtained by writing the obtained parameter estimates to the corresponding unweighted distribution, and the number of stems is estimated using Eq. 1.

Multinomial approach 1 (MNA1, situation A)

In this approach, weights are calculated for the observations of the sample and no assumptions about the distribution are needed. The weight of each observation is the inverse of its probability for being observed (Fiq 1). If the sampling probability of visible trees is known (e.g., if all visible trees of a fixed area have been observed), dividing the weights with the sampling probability is an estimator for the numbers of stems, which are summed up to estimate the total number of stems in the stand.

Multinomial approach 2 (MNA2, situation B)

If canopy closure is known in MNA1 the number of stems can be estimated either by the approach of MNA1 or by using Eq. 1. In MNA2 such a value of the sampling probability is searched that makes these two estimates equal. This leads to a multinomial approach that uses the same input information as CDA.

Table 2. The colums show, respectively, the measured canopy closure, true number of stems, true number of visible trees, and the four estimates of the number of stems obtained by CDA ($\hat{N}_1$), MNA1 ($\hat{N}_2$), MNA1 and Eq. 1 ($\hat{N}_3$), and MNA2 ($\hat{N}_4$) in the ten samples of Fig. 2.

Sample	cc	N	$N_{visible}$	$\hat{N}_1$	$\hat{N}_2$	$\hat{N}_3$	$\hat{N}_4$
1	0.733	1140	510	1039	1149	1151	1151
2	0.664	990	530	965	1041	1033	1029
3	0.676	870	440	765	898	843	821
4	0.683	1090	490	1092	919	1099	1219
5	0.631	880	470	786	851	858	861
6	0.690	990	480	1043	899	1056	1148
7	0.568	820	530	885	953	925	910
8	0.630	910	430	836	794	865	909
9	0.769	1030	440	1074	901	1127	1260
10	0.727	1010	490	939	1128	1054	1021
Mean				943	953	1001	1033
95% Lower bound				868	881	928	936
95% Upper bound				1017	1026	1074	1130
Bias (total)				-57.5	-46.8	1.1	32.9
RMSE (total)				128	120	112	152
Bias (sampling error eliminated)				-30.5	-19.8	28.1	59.9
RMSE (sampling error eliminated)				70.8	102	56.8	104

Main results and discussion

- The RMSE of the number of stems was at a low level with all approaches and the bias was not statistically significant.
- The estimator based on crown cover (Eq. 1) gave slightly more accurate estimates of the number of stems than the estimator of MNA1.
- In situation B, CDA and MNA2 performed equally well. The former gives always a smooth continuous distribution but a faulty assumption about the distribution may violate the estimates. The latter does not need such an assumption but it provides non-zero frequencies only for diameter classes present in the sample. Thus, CDA is suggested for small samples ands MNA2 for large ones.
- In real datasets the assumptions are surely invalid to some degree and the results of this study can be regarded as an upper bound for the accuracy.
- Since the approaches are based only on the stated assumptions, not on some species or area-specific models, the method is equally applicable in all areas and with all tree species.
- The approaches could be further developed in order to work with the distribution of heights.

Conclusions

General approaches were presented for taking into account the censoring of sample trees when observed from the air. It performed well in a situation where the stated assumptions were valid. The proposed approach can be further developed to take into account other reasons for censoring (e.g. that low density laser beam does not find all small visible trees or that trees smaller than pixel size are not detected from aerial photographs), if one is able to derive the probability of observing a visible tree as a function of crown area.

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