ARBETSRAPPORT

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CARABAS – production line

INDIVIDUAL TREES

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Dianthus
Digital Information Analysis

SKOGFORSK

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Introduction

Acquisition of reliable and accurate data is an essential component in any forest management planning system. Traditionally, a combination of manual field measurements are used to supply data to predict forest yield. However, multi-functional demands on planning systems to deliver support for a range of decisions related to industrial utilisation of wood imposes new requirements on the available data. More specifically, data is needed to supply site- and tree-level variables for models of wood properties. Breast height diameter is one of the most fundamental of these variables. The objective of this study was to evaluate the possibility of using the CARABAS production line to predict diameter distribution of individual trees.

The project was carried out in collaboration with The Swedish National Space Board, Holmen Skog AB, Skogforsk, FOI Swedish Defence Research Agency and Dianthus. The work performed by Skogforsk was financed jointly by Skogforsk and the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (contract #23.2/2/2001–0943).

MATERIALS

Description of the experimental area

The trials were carried out on land owned by Holmen Skog, which is located in the Ämten area of Sweden and comprises 2 × 2 km2 of forest land (map reference 8FNO, southwest of Finspång).

The topography of the area is characterized by undulating and, in parts, quite hilly forest land (>15-degree gradient), with a fairly high microtopographical variation. The ground roughness ranges from flat to rocky terrain, sometimes containing large boulders, extensive rocky outcrops, exposed bedrock, and geological faults and displacements.

The soil is thin for the most part and is generally dry/mesic, with a field cover of cowberry (Vaccinium vitis-ideae), heather and lichen. In hollows, the ground comprises a mix of moist/wet marshland, with cover mostly consisting of species such as sedges, sphagnum mosses, Polytrichum commune and Broom fork-moss (Dicranum scoparium). Illustrations of these ground conditions are shown in figure 1.

Figure 1.
Photos illustrating the ground conditions in the trial areas. (Photo: Björn Hallberg, Chalmers University of Technology, CTH).

CARABAS DATA

Images from eight flight paths (images collected by the Swedish Defence Research Agency (FOI) in week 46, 2003) were assembled by Björn Hallberg, CTH (Hallberg et al., 2005) using the incoherent-scatter imaging process. What is meant by incoherent-scatter imaging here is that the new image is created in pixels generated by the mean value of the amplitude of all the images from the different flight paths. The aggregated RT90 geocoded CARABAS image (pixel size of 1×1 m^2) for Dianthus comprises an amplitude image in 32-bit floating-point format.

FIELD DATA

Field data comprises both sample data and GPS harvester data collected in conjunction with harvesting, after the CARABAS image has been generated. The sample data was used to create a functional relationship between amplitude and stem volume in individual trees. The harvester data was used as a standard for evaluating methods for estimating the diameter at breast height (DBH) of individual trees.

SAMPLE DATA

Skogforsk collected data on 40 circular sample plots, the radius of each being 10 m. On each sample plot data was recorded on tree species, diameter at breast height (DBH), and the individual position of all the trees. In addition, tree height was also recorded on a number of trees selected at random. The position of each individual tree was determined by noting the bearing and distance to the respective GPS-positioned sample-plot centre. Data on a total of 644 trees was recorded.

Ten of the 40 sample plots were discarded; five because the image data had been corrupted by human activity, and the other five because of low positioning precision.

HARVESTER DATA

Bucking data was collected by the Holmen Skog's harvesting team on four demarcated logging sites, the positions of which had been determined by GPS (see figure 2). The area of the sites varied between 2.5 and 3.4 ha.

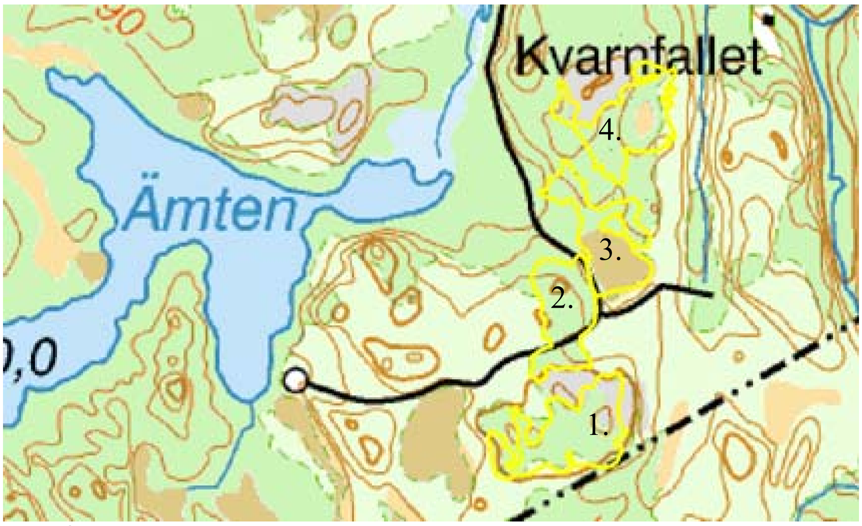


Figure 2.
The areas outlined in yellow are the sites on which GPS-positioned harvesting data was collected.

For each harvested tree, data was collected on tree height, DBH, tree species, and stem volume (m^3 solid i.b.). The recorded position of each tree determined the position of the respective harvester at the time of harvesting (see figure 3).

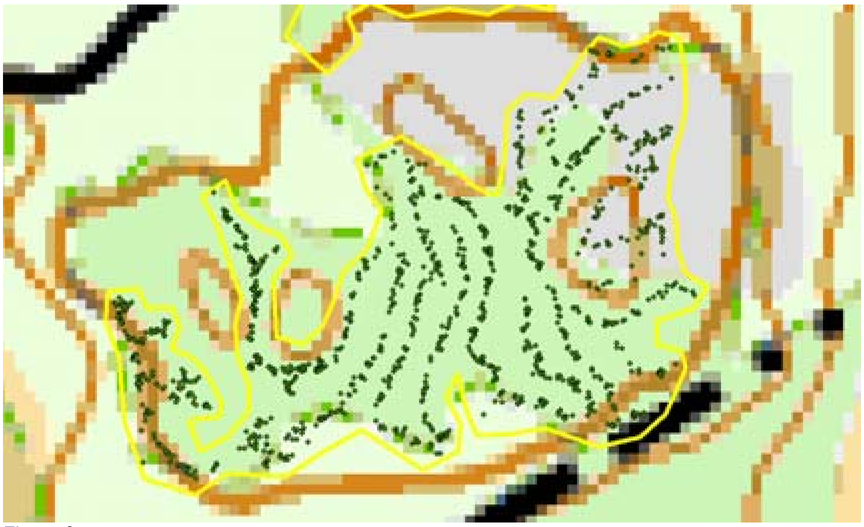


Figure 3.
Tract 1. The dots pinpoint the position of the harvester when logging individual trees.

Skogforsk was responsible for data-collection planning, collation, and validation of the harvester data.

DERIVED STEM VOLUME OF TREES IN THE SAMPLE PLOTS

The stem volume of each tree in the sample plots was calculated on the basis of the functional relationship between the diameter and stem volume (m^3 solid i.b.), as determined by the harvester data collected on the individual trees. The functional relationship was derived from linear regression analysis and the following model (Holm, 2002):

$$\ln(V_k) = \alpha + \beta \times \ln(D_k)$$

$$\Rightarrow$$

$$V_k = e^{\alpha + \beta \times \ln(D_k)}.$$

where,

V_k and D_k are the stem volume (m^3) and DBH, respectively, for tree *k*.

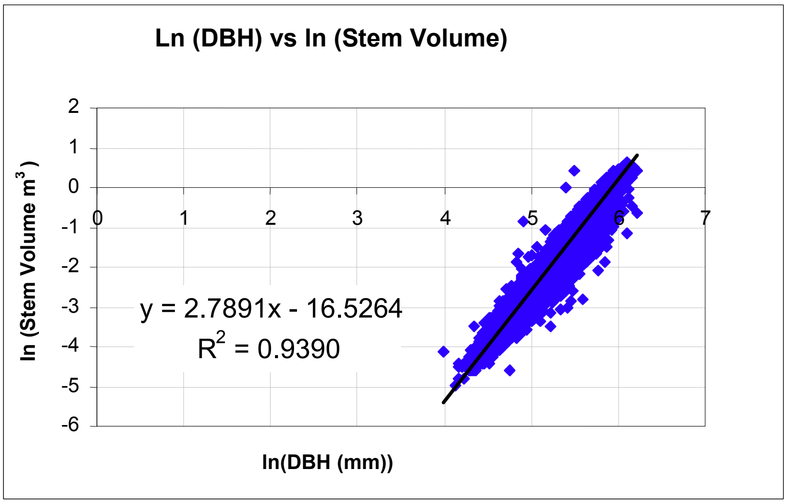


Figure 4.
Correlation between stem volume and DBH .

To obviate any logarithmic bias, the following volume correction factor was used (Holm, 2002):

$$v.c.f. = \frac{\sum_{k=1}^{m} V_k}{\sum_{k=1}^{m} \hat{V}_k},$$

This was applied to all the calculated stem volumes, where, V_k is the stemvolume for tree k derived from the bucking-computer data, and $\hat{V}_k$ is the predicted volume derived from the functional relationship [1].

Method

Analysis and execution of the work were divided into the following steps:

- Spatial correlation of image data with trees measured in the sample plots
- Detection of individual tree
- Estimation of diameter distribution in harvested stands

CORRELATION OF IMAGE DATA WITH TREES MEASURED IN THE FIELD

Sample-plot data was used to create functional relationships between the tree parameters and the image data. However, before these functional relationships can be created, we have to match the recorded GPS positions with the image data. The mismatching we want to minimize are the systematic errors that mainly occur in GPS readings of the sample-plot centre, and the large-scale errors in the height model used in geocoding. However, errors of a more random nature, such as those occasioned by small-scale topographical variations, and possible measuring errors in bearing and distance readings, cannot be resolved by the matching procedure described here.

The matching procedure is largely based on the description given in Björn Hallberg's document: Enskilda träd Ämten BH.doc (Hallberg, 2004).

The following steps must be performed for matching each individual sample area:

1. The incoherent-scatter aggregated images must be over-sampled to a pixel size of $1/6 \times 1/6$ m^2, which is achieved by bi-cubic interpolation (used by Press et al., 1992).
2. The respective sample area (entire area) must be moved gradually within an envelope of ∀ 5 m from the original position. The correlation between the estimated stem volumes (from Function [1]) and the corresponding pixels in the image data must be calculated for each new position.
3. The positions of the individual trees must be moved by the distance in the x- and y-axes relative to the original position (*dx* & *dy*) that gives rise to the strongest correlation.

After the spatial matching of each sample area has been completed, the amplitude in the over-sampled image is extracted from the pixel that is closest to the respective tree. Figure 5 shows the stem volume of the individual trees plotted against the extracted amplitude.

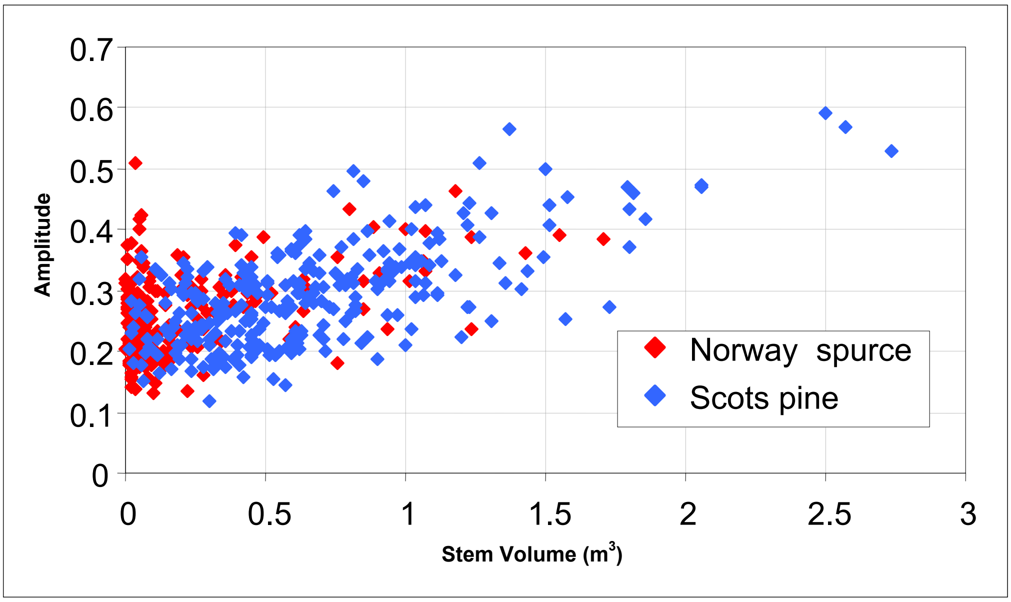


Figure 5.
Showing amplitude against stem volume for the individual trees on the spatially matched sample areas.

We suspect that trees with a DBH smaller than 200 mm (equivalent to a stem volume of 0.18 m^3) are difficult to detect in the CARABAS data and thus cause a high level of scatter. Consequently, the functional relationship created in linear regression analysis has been based on a minimum stem volume of 0.18 m^3 (see figure 6).

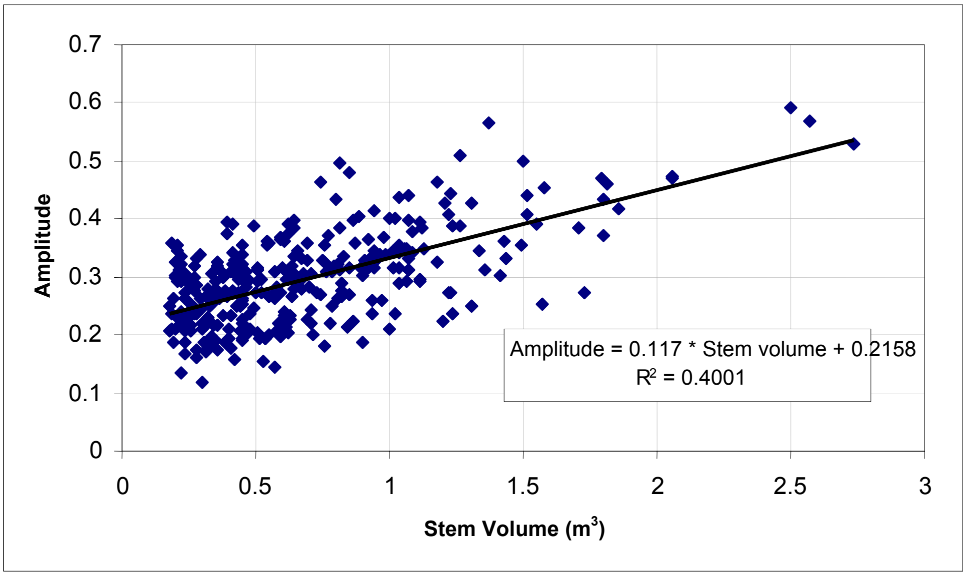


Figure 6.
Functional relationship between amplitude and stem volume for a minimum stem volume of 0.18 m^3.

An additional spatial correlation has been completed, this time with all trees having a DBH of under 200 mm being excluded from the material.
Figure 7 shows the functional relationship produced from linear regression analysis in which trees with a stem volume of under 0.18 m^3 have been excluded from the material, prior to spatial correlation.

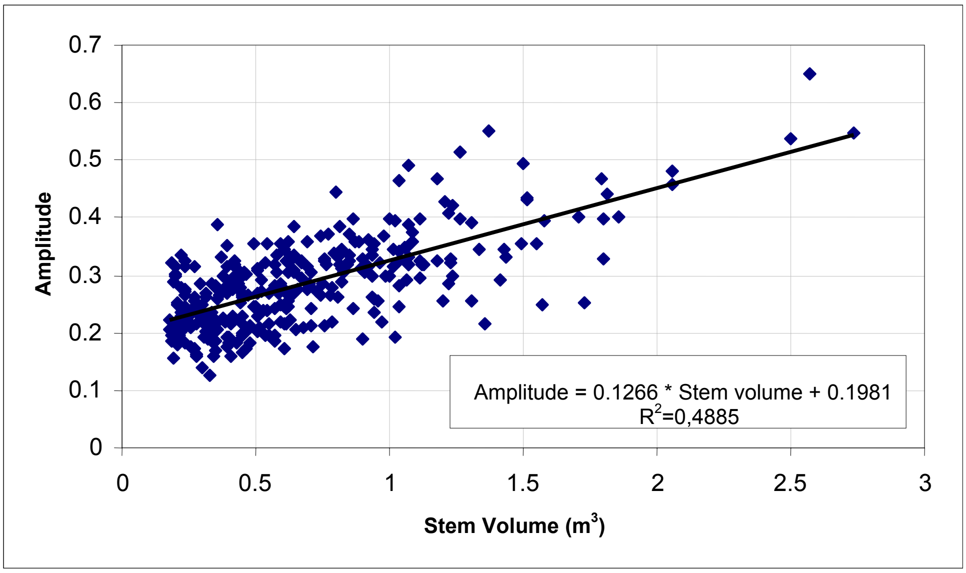


Figure 7.
Functional relationship between amplitude and stem volume in which trees having a stem volume of under 0.18 m^3 have been excluded from the material prior to spatial correlation.

DETECTION OF INDIVIDUAL TREES AND ESTIMATING THE DBH

The detection of individual trees was achieved using a max-detector within a 3 × 3 envelope in the bi-cubic, oversampled (1/6 × 1/6 m^2) incoherent-scatter, aggregated CARABAS image. The max-detector will only detect a tree if the amplitude of the centre pixel in the 3 × 3 envelope is higher than in the other pixels. The DBH of the detected trees has been predicted by using the inverse of the function in figure 7 and the inverse of Function [1]. The predicted DBH of the detected trees is symbolized in figure 8.

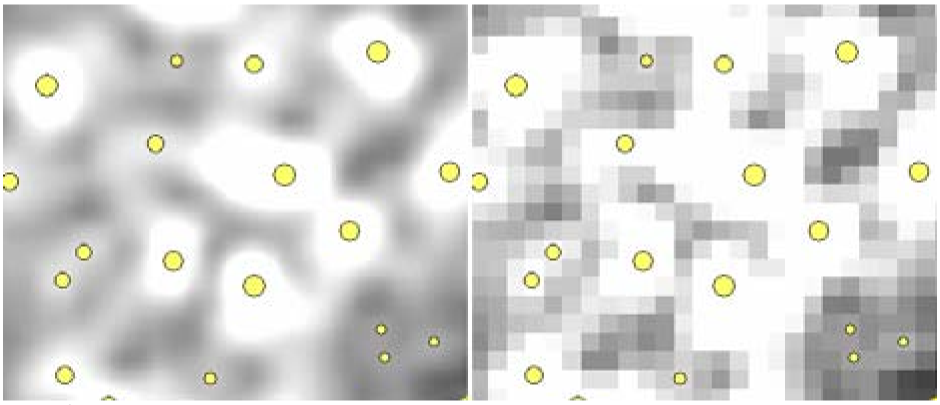


Figure 8.
Symbolizing the predicted DBH of trees detected using a max-detector within a 3 × 3 envelope in the bi-cubic, oversampled (1/6 × 1/6 m²) incoherent-scatter aggregated CARABAS image.

The diameters of the yellow dots are proportional to the predicted DBH. The oversampled image is shown on the left; the corresponding image with the original pixel size of 1 × 1 m is shown on the right.

ESTIMATING THE DIAMETER DISTRIBUTION

The DBH of individual trees detected using the method described above was estimated in all four logging tracts. This was followed by calculation of the diameter distribution, and this was compared with the diameter distribution recorded during harvesting. Figure 9 shows a preliminary comparison of estimated and measured diameter distribution in logging tract 1. The comparison reveals a relatively heavy overestimation of the DBH, which can probably be explained by the functional relationship in figure 7 not having been created using CARABAS-image max-points, but instead using those points where *all* the trees with a DBH exceeding 200 mm correlate most closely with the image data. We therefore multiplied the estimated diameters by a simple calibration factor, in order to adjust the estimated diameter distribution to the recorded distribution. A calibration factor of 0.72 was calculated by dividing the highest-frequency *measured* diameter classes by the highest-frequency *estimated* classes for logging tract 1. The same calibration factor was then used in the other tracts.

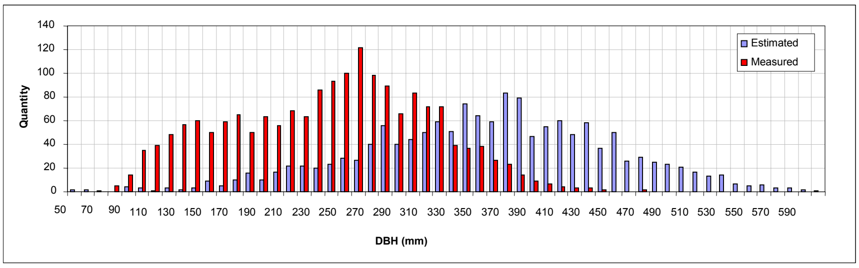


Figure 9 A.
Preliminary comparison between estimated and measured diameter distribution in logging tract 1.

Results

CORRELATION OF IMAGE DATA WITH DATA RECORDED IN THE FIELD

The results of the spatial correlation between trees measured in the sample plots and the aggregated CARABAS image are shown in figures 10–14. As well as symbolization of the DBH of the trees measured in the field, the estimated diameter of the detected trees in the sample plot is also symbolized (in accordance with section: *The detection of individual trees and estimating the DBH*).

The estimated diameter has been corrected by means of the calibration factor described under: *Estimating the diameter distribution.*

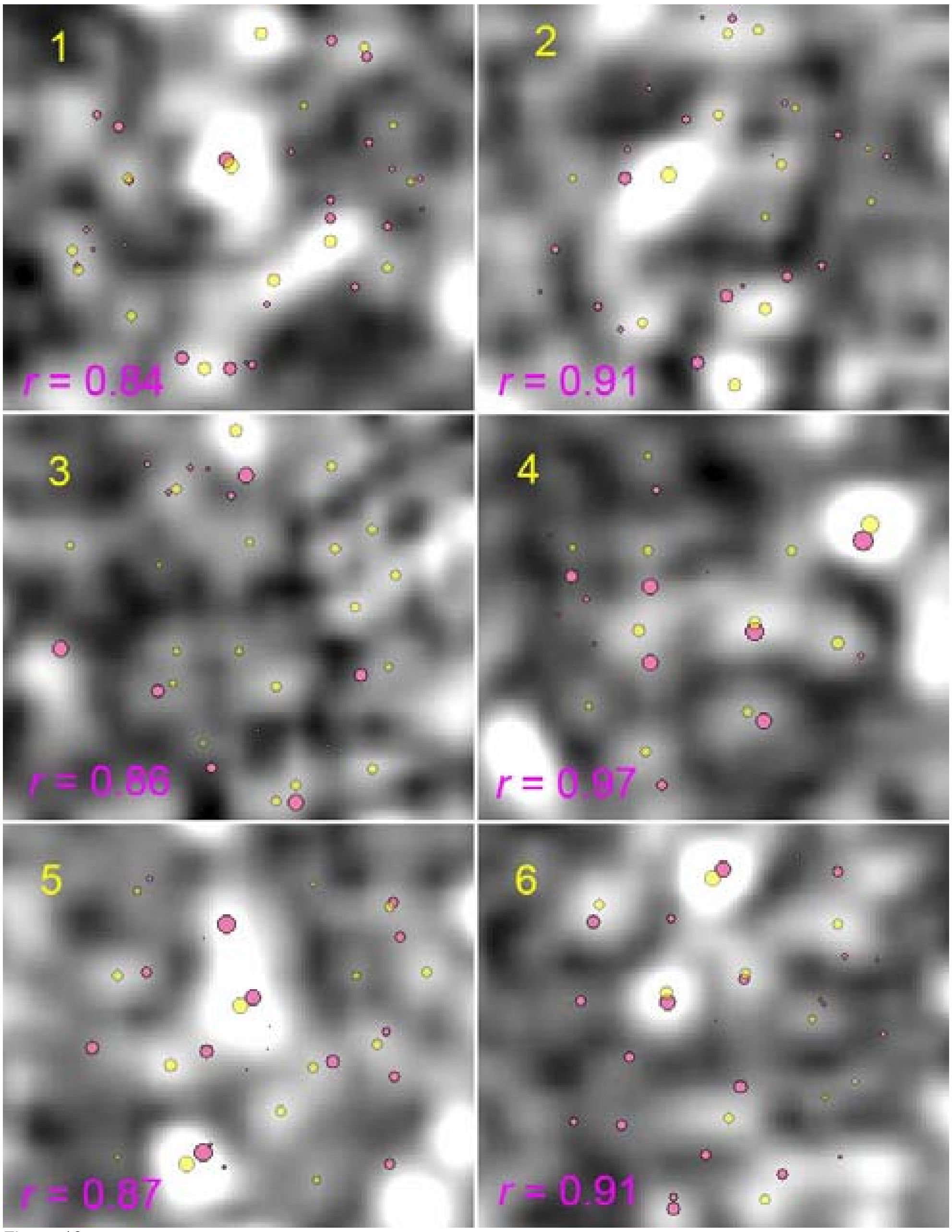


Figure 10.
Spatially correlated trees in sample plots 1–6. The pink dots symbolize the DBH in measured trees, and the yellow dots the estimated DBH in trees detected.

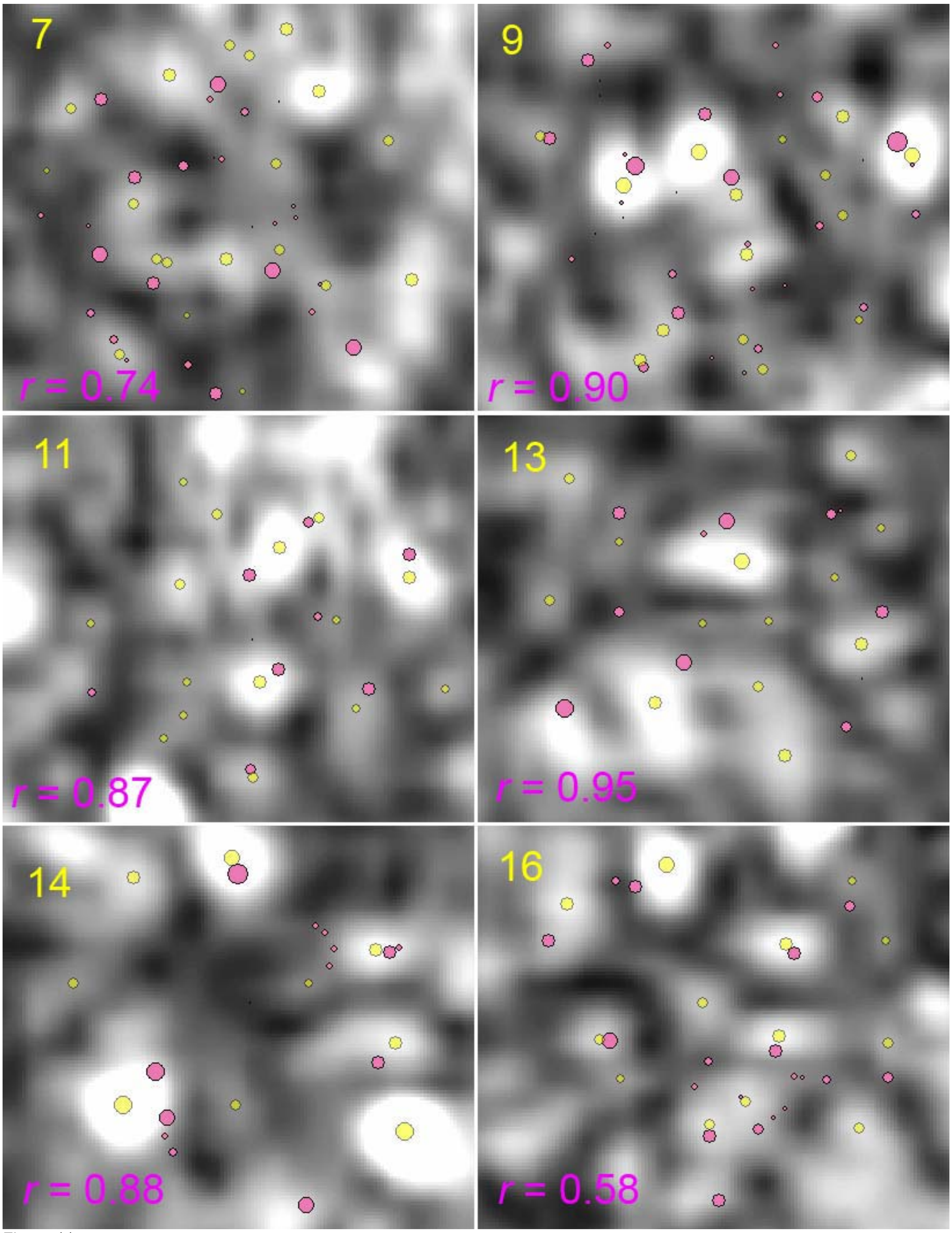


Figure 11.
Spatially correlated trees in sample plots 7–16. The pink dots symbolize the DBH in measured trees, and the yellow dots the estimated DBH in trees detected automatically. In addition, the maximum value for spatial correlation is given for each image.

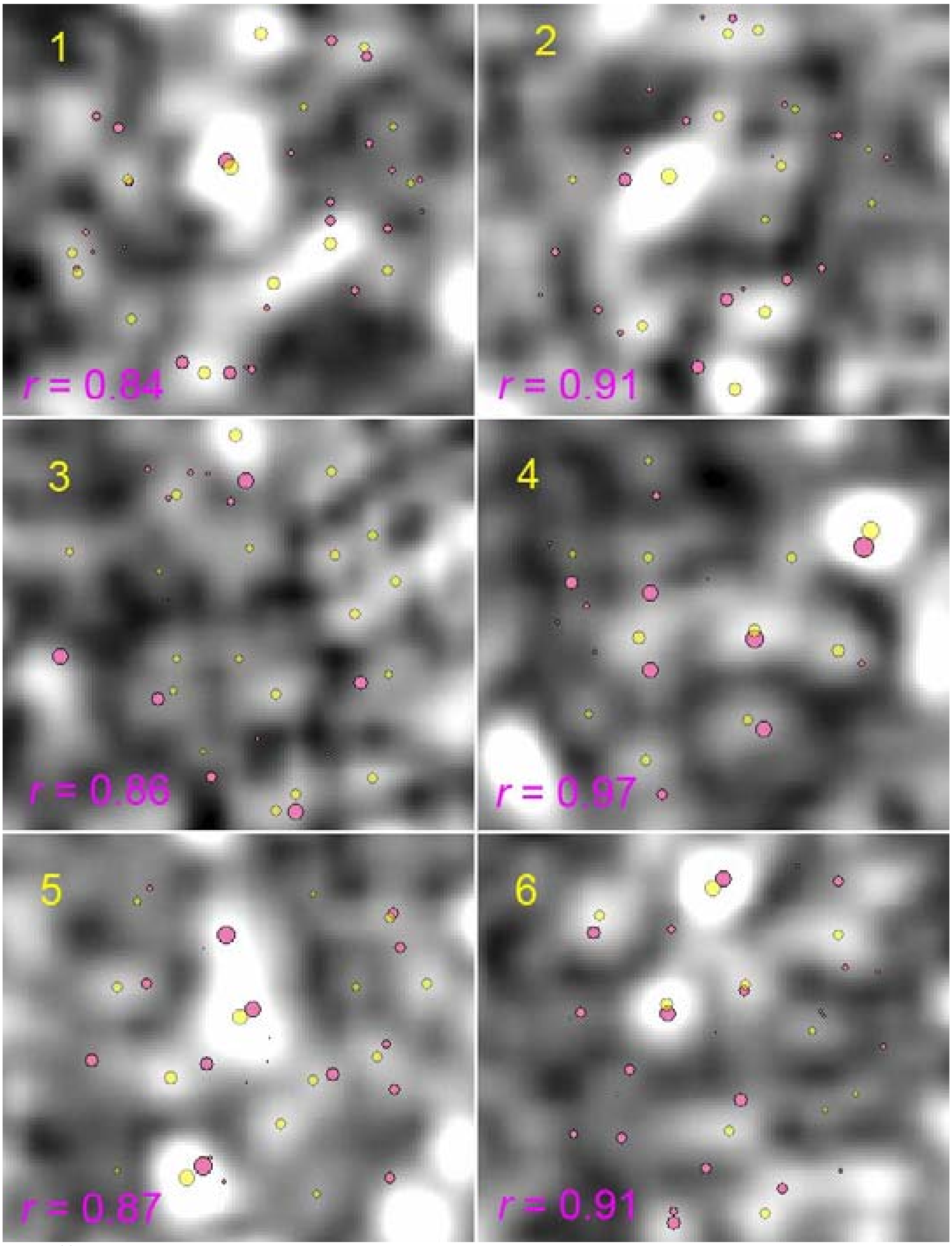


Figure 12.
Spatially correlated trees in sample plots 1–6. The pink dots symbolize the DBH in measured trees, and the yellow dots the estimated DBH in trees detected.

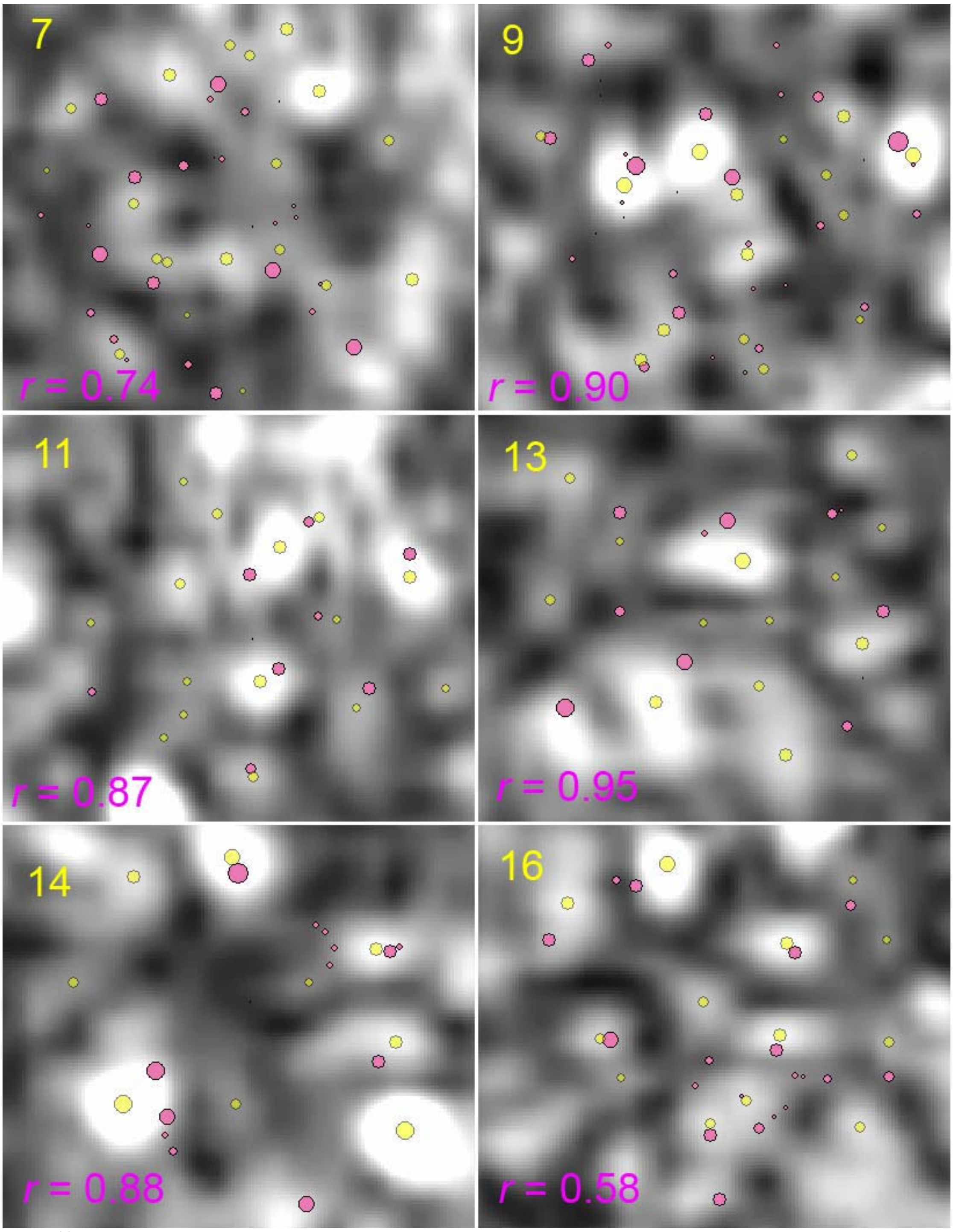


Figure 13.
Spatially correlated trees in sample plots 7–16. The pink dots symbolize the DBH in measured trees, and the yellow dots the estimated DBH in trees detected automatically. In addition, the maximum value for spatial correlation is given for each image.

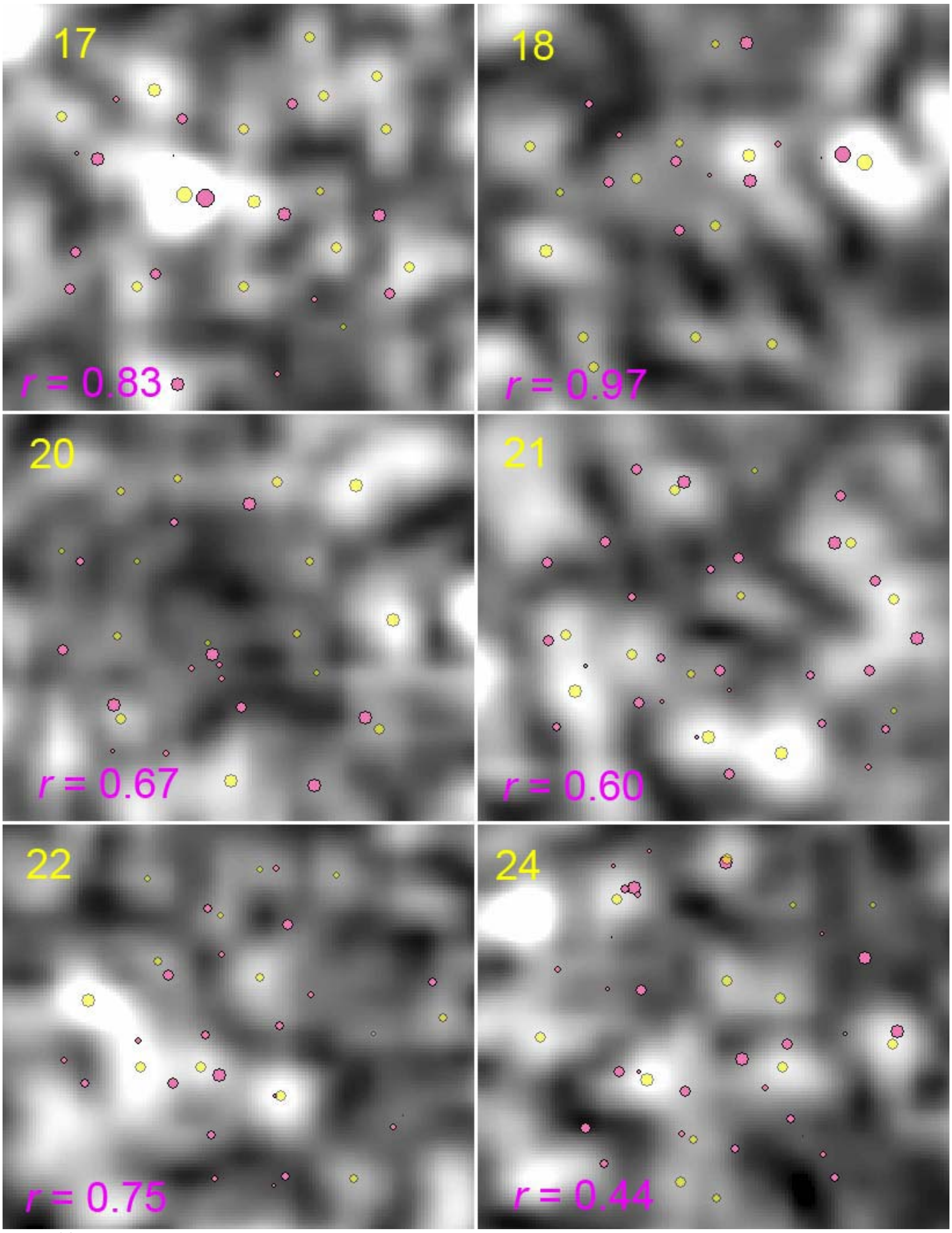


Figure 14.
Spatially correlated trees in sample plots 17–24. The pink dots symbolize the DBH in measured trees, and the yellow dots the estimated DBH in trees detected automatically. In addition, the maximum value for spatial correlation is given for each image.

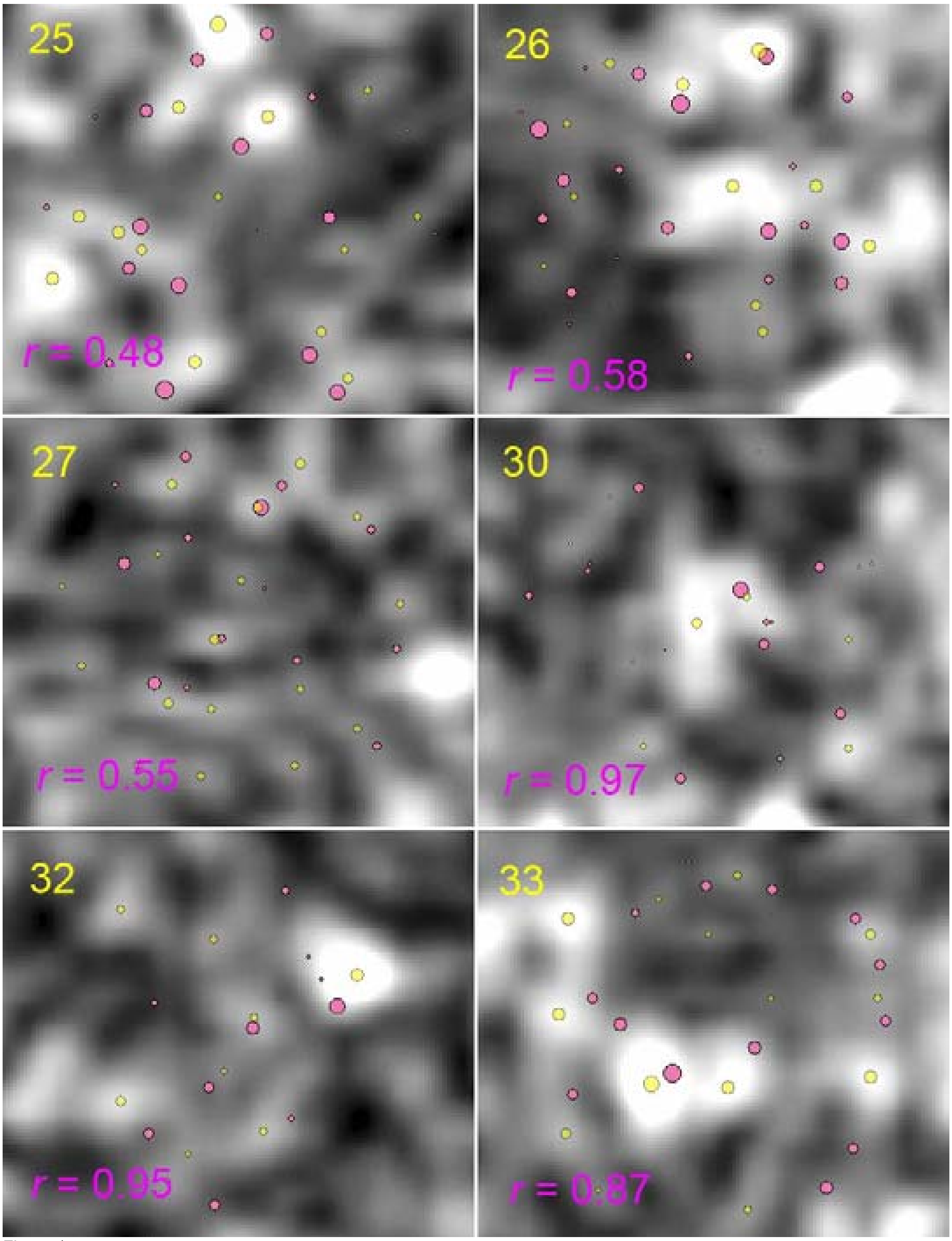


Figure 15.
Spatially correlated trees in sample plots 25–33. The pink dots symbolize the DBH in measured trees, and the yellow dots the estimated DBH in trees detected automatically. In addition, the maximum value for spatial correlation is given for each image.

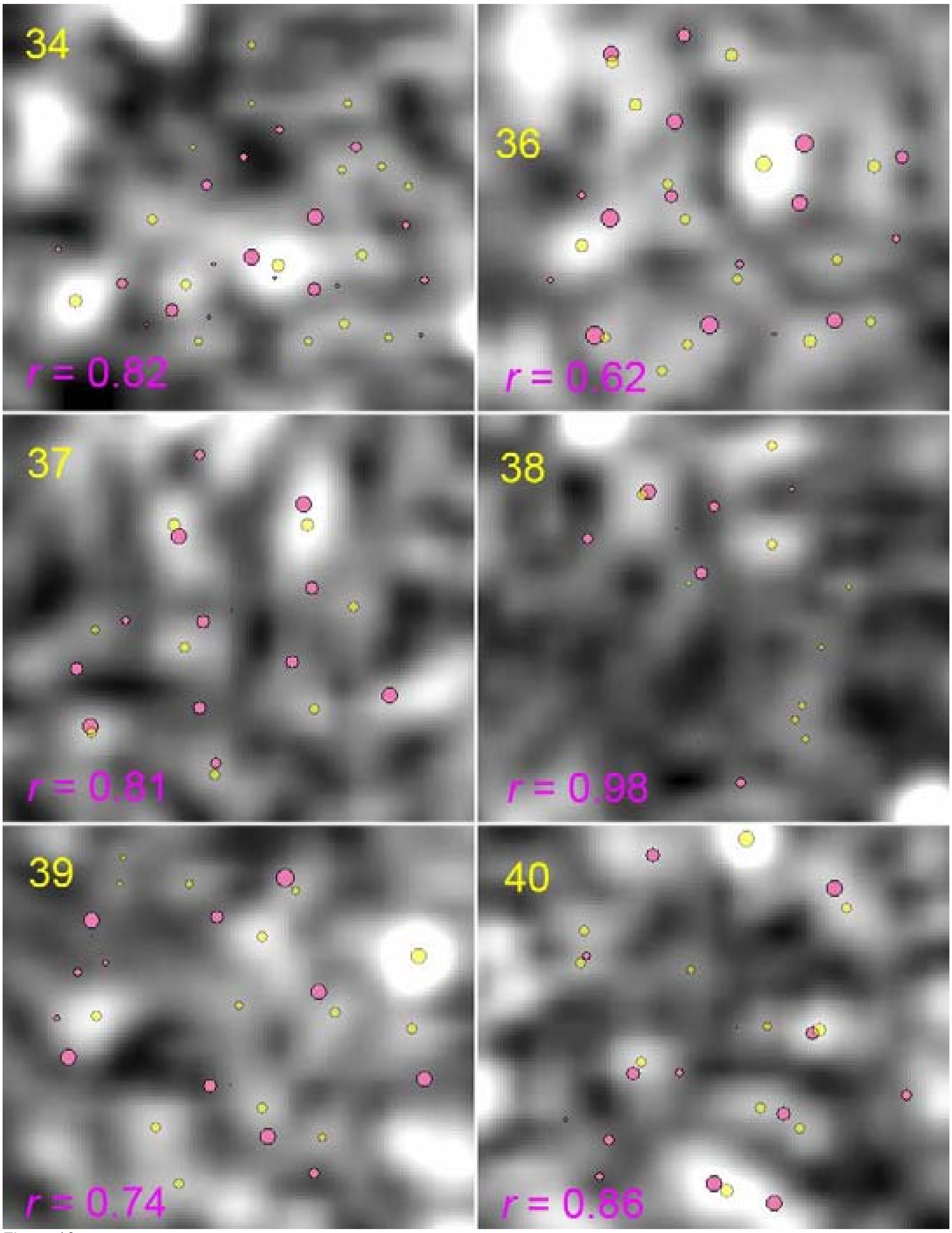


Figure 16.
Spatially correlated trees in sample plots 34–40. The pink dots symbolize the DBH in measured trees, and the yellow dots the estimated DBH in trees detected automatically. In addition, the maximum value for spatial correlation is given for each image.

ESTIMATING THE DIAMETER DISTRIBUTION

Comparisons between the estimated diameter distribution and the measured distribution for logging tracts 1–4 are shown in figures 15–18. The estimated diameters have been corrected using a calibration factor as described under section: *Estimating the diameter distribution.* Statistics on the estimated and measured number of trees, together with the DBH, in logging tracts 1–4 are shown after figure 18 below, in table 1.

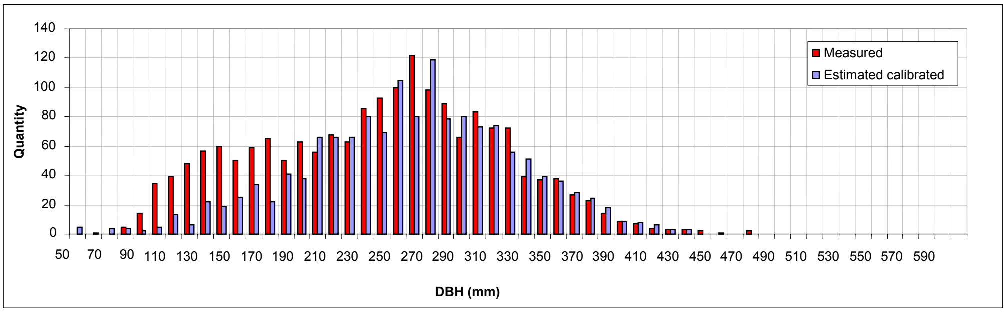


Figure 17.
Comparison between measured and estimated diameter distribution in logging tract 1.

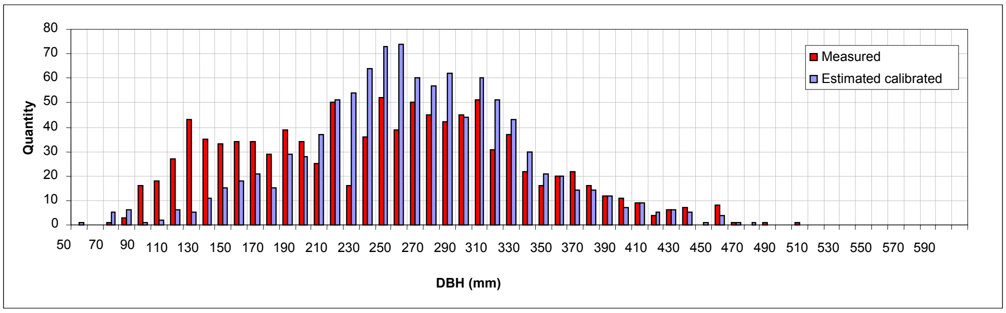
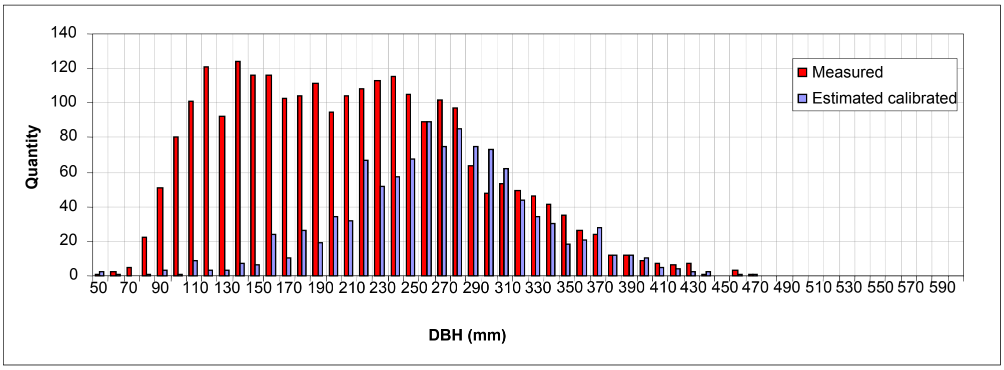
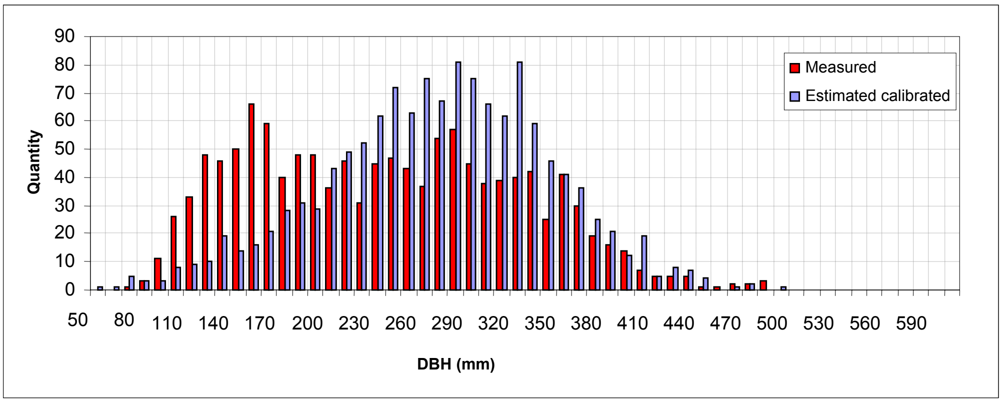


Figure 18:
Comparison between measured and estimated diameter distribution in logging tract 2.



Figur 19.
Comparison between measured and estimated diameter distribution in logging tract 3.



Figur 20.
Comparison between measured and estimated diameter distribution in logging tract 4.

Table 1.
Statistics on the estimated and measured number of trees, together with the DBH, in logging tracts 1–4.

	Number of trees	Mean diameter	Standard deviation	Number of trees with DBH>200 mm	Mean diameter >200 mm	Standard deviation >200 mm
Estimated #1	1 480	253	66	1 175	277	48
Measured #1	1 821	233	74	1 227	276	48
Estimated #2	1 043	253	68	844	276	52
Measured #2	1 021	235	85	652	287	57
Estimated #3	1 108	264	62	962	280	48
Measured #3	2 521	207	78	1 285	270	52
Estimated #4	1 333	264	72	1 092	288	53
Measured #4	1 255	231	85	740	290	56

Discussion

In more than a third of the 30 sample plots used, even after spatial correlation it is difficult to observe any matching between the CARABAS data and the individual trees. Because of this, and the fact that the trees in the sample plots seldom match up with local maxima in the CARABAS image, the functional relationship produced will always overestimate the stem volume in trees detected using a max-detector.

There is good correspondence between what an observer would consider to be a tree in the aggregated CARABAS images and the trees detected using a max-detector. Many smaller trees fail to be detected by this method, but such trees would escape detection regardless of the method used. Owing to the physical limitations of CARABAS and the given conditions, it is apparently difficult to resolve all trees having a DBH of less than 200 mm.

It seems likely that the topographical conditions in the forest tracts, which include a fairly high microtopographical variation, with rocky outcrops and stony terrain, also create problems in the detection of individual trees. The focus on an individual tree will differ in images recorded in different directions, due to fluctuating back-scatter geometry, and the tree will either be wiped out when the image is compiled or will create ghost trees. The reduced quality of the back-scatter geometry can also give rise to drastically impaired radar response from individual trees. Another problem is the possibility of large stones or boulders being mistakenly interpreted as a tree. All these factors can combine to explain why the image quality in this study is inferior to that in earlier trials in the Remningstorp experimental park in west Götaland (Hallberg et al., 2005a), the results of which were from terrain that was relatively flat.

The results shown in figure 6 demonstrate that there is a correlation between CARABAS image amplitude and individual tree volumes for trees having a diameter exceeding 200 mm, even if the image is not of the best quality. We have attempted to estimate diameter distribution but the results are difficult to interpret. The most favourable results among the four logging tracts were those from tract 1, the main explanation for this being that the calibration factor had been applied to this data.

The number of small trees was underestimated in all of the tracts, largely because the relationship between volume and image amplitude does not apply to trees having a diameter of less than 200 mm. As regards large trees (>350 mm in diameter), estimation of diameter distribution was pretty good in all of the tracts; however, as regards trees having a diameter of 200–300 mm, CARABAS overestimated the number of trees in tracts 2 and 4, but underestimated the number in tract 3. It is difficult to explain the differences that occurred in the results among the tracts, but it appears that the variation in the true DBH distribution (with tract 3 having a larger number of small trees) does not give rise to such wide variations in the CARABAS data—in other words, the distribution function for CARABAS data is largely the same in all of the tracts. This is probably because many trees are close to the noise level in the CARABAS images, rendering detection of these trees unreliable.

For more accurate estimation of the tree-size distribution, we need a better signal-to-noise ratio in the images (ie, either larger trees, or an improved image quality—obtainable, for example, in areas with reduced topographical variation). Alternatively, better detection methods must be developed so that the noise level in the images can be taken into account to concentrate on detecting larger trees.

Conclusion

Further studies are needed to improve the method for producing a functional relationship between stem volume and amplitude for individual trees. This is absolutely vital if we are to avoid the somewhat dubious, but not totally unjustified, calibration factor for diameter distribution.

There is a clear correlation between stem volume and amplitude in the incoherent-scatter, aggregated CARABAS images. This has also been demonstrated convincingly and coherently in the study conducted by Björn Hallberg at Chalmers (CTH) on data from the Remningstorp experimental area in Västergötland in southern Sweden (Hallberg et al., 2005a). The most recent findings confirm that the correlation is strongest in trees having a DBH exceeding 200 mm, even if the correlation between image amplitude and stem volume is not quite as strong in the readings presented here, probably as a result of greater topographical variation (see Hallberg et al., 2005b, for further discussion).

The findings show that performing yield calculations based on CARABAS images is unsatisfactory if the DBH of many trees is under, or marginally over, 200 mm, because of the difficulty of seeing trees clearly against the background noise in the images. Yield calculations based on CARABAS data should be more reliable in stands containing larger and thicker trees in regeneration felling (where the mean DBH is greater than 300 mm).

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