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Photogrammetry in Forestry - Tool for Effective Inventory and Planning

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ABSTRACT

The application of photogrammetry is not as usual in forestry as it is in other fields. The presented paper shows one of a variety of possible applications belonging to the field of forest inventory.
The interpretation of colour infrared aerial photographs in combined with the use of photogrammetry enables one to ascertain data that is needed for planning in forestry. The obtained information, stored and handled in a Geographic Information System (GIS), leads to maps representing the actual situation of a forest district. These maps are more accurate and detailed than this is possible using the conventional mapping procedures in forest management planning. The map information and data which has been additionally interpreted and measured from aerial photographs supports the forest manager and is advantageous during the fieldwork. Due to this fieldwork is less time-consuming.
The presented procedure provides the forest management and the forest rangers in a rational and fast manner with actual information about their district. The availability of the data in a GIS enables a more thorough work by using this information selectively and orientated to actual problems as they arise.

1. INTRODUCTION

For photogrammetrists carrying out conventional photogrammetric procedures, trees and forests are normally obstacles without any significant information. In contrast for the forester *using* photogrammetric technique these objects are quite informative.
Especially by using Colour-Infrared (CIR)-aerial photographs up to a scale of 1:12 000 it is possible to recognize different tree species and their vitality, to predict the age of trees and to measure parameters such as tree height and crown size. Except for the last point all the above mentioned information is a result of aerial photo*interpretation*, which is always an important aspect of forest photogrammetry. The objects of interest are frequently not exactly contoured and show a normal natural variation in shape and appearance. Therefore, to obtain successful results, it is absolutely necessary that the analysis of CIR aerial photographs in this field is carried out by an aerial photointerpreter with forestry education and empirical knowledge. Furthermore suitable aerial photographs and a zoom-stereoscope with good optic quality are required (VDI, 1993).
Which are now the most interesting inventory-parameters in forestry and how are they established normally (without photogrammetric methods)?
Most of the data is collected during the forest management planning. The forest management planning is a medium term plan at a district level. In the Federal Republic of Germany (FRG) it is repeated every 10 years. This kind of inventory is devided into three parts. Firstly the inventory to assess the actual situation in the forest district, secondly the control to examine the success of the previous plan and finally the plan for the following 10 year period, which is based on the results of the current inventory. Remote Sensing techniques can be used effectively in the actual inventory of forest management planning. Therefore the inventory will be dealt with in greater depth.
Traditionally the forest survey is carried out terrestrially. In the FRG two procedures are in use. A standwise inventory concept and a sample based inventory concept. Each with its pros and cons (see TZSCHUPKE, 1991). The established parameters are shown in table 1. Also shown are the possible uses of aerial photographs to determine forestry relevant information and the possibilities of visualising this information in a GIS.
The use of aerial photographs during the conventional terrestrial survey is not very intensive. Normally the forest manager is supported with black and white aerial photographs in a scale 1:10 000 showing the actual situation in the forestry district. Recently, due to costreductions, the forest administration often uses existing black and white aerial photographs in a scale 1:18 000 which are less suitable as they are produced not for inventory purposes but for the actualisation of topographic maps. In the field,

the forest manager uses these photographs for orientation, for stand description and delineation (SCHWILL, 1980). The stand borders on the map are updated by hand to the actual situation using the aerial photographs (in flat terrain) and/or with some additional measurements carried out on foot with only the add of a compass.

Information group		Analysis in CIR aerial photographs by:	Visualisation in a GIS
Natural site		-	+
Topography of landscape		measurement	+
Economical site		-	+
Forest functions		interpretation	+
Basic structures of forest districts	- area	measurement	+
	- tree species	interpretation	+
	- standing volume	regression function	+
	- yield	difference	+
	- spatial arrangement	interpretation	+
	- natural age class	interpretation	+
	- timber quality	-	+
Other equipment	- forestry workers	-	°
	- machines	-	°
	- management	-	°
	- paths/roads	measurement	+

Table 1: Important information groups for forest management planning, the possibility to obtain this by analysis of aerial CIR-photographs and the possibility for visualisation in a GIS.

A more intensive use of aerial photographs is possible (table 1) and has proven advantages (BOON, 1962; HILDEBRANDT, 1970) but is rarely used in practice. The reasons for this are poor and/or outdated aerial photographs, insufficient equipment and deficits in forestry education, but also psychological barriers (TZSCHUPKE, 1983; WOLFF, 1992).

An additional point, which seems to be of interest for an intensification in the use of photogrammetry in forestry is the use of GIS by the forest administrations. They hope to accelerate the actualisation and production of thematic maps and expect to find answers to specific and complex questions with the help of a GIS.

It seems unreasonable to use old and often inaccurate maps for digitalisation, especially if the data from these maps is used over a long period of time and other possibilities of data evaluation exist. This seems cheaper at present but is unlikely to be in the long run. The various software for analytical plotters (e.g. PHOCUS, Co. ZEISS) is linked to many GIS and CAD-Systems so that the plotters are ideal for the evaluation of spatial data.

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The possibilities of obtaining the necessary information for forest management inventory through the use of aerial photointerpretation and photogrammetry is the subject of a research project[1] at the Department for Remote Sensing and Landscape-Informationsystems at the Albert-Ludwigs-University of Freiburg in the FRG.

2. MATERIAL AND METHOD

2.1 Research area

The forest district of Backnang (30km north-east from Stuttgart) was selected as research area. The reasons were the topographic (hilly) and forest (mixed, structured stands) conditions in this area and the timely coincidence of the planned aerial photo flight with the forest management inventory in the forest district of Backnang. Due to this coincidence it was possible to use the terrestrial evaluated data of a sampling inventory (design: 100m × 200m, permanent, systematic, r = 12m), called "Betriebsinventur" (see FVA BADEN-WÜRTTEMBERG, 1992), carried out by the personnel of the forest management as ground truth, and so to reduce fieldwork during the project. Also a comparison between a solely terrestrial and a solely aerial stand description and delineation could be carried out due to this coincidence.

2.2 Aerial Photographs

The aerial photo material used is shown in table 2. Before starting the aerial photo flight a terrestrial control point signalisation took place. The results of the following aerotriangulation with a mean error in xy of ± 4.4 cm and z of ± 13.4 cm can be regarded as very good. Taking into account focus and scale, the values that can be expected are ± 6 cm in xy and ± 18 cm in z (KRAUS, 1982).

film type:	KODAK Aerochrome Infrared 2443
medium scale:	approx. 1 : 7 000
forward overlap:	60%
side overlap:	30%
flight direction:	north - south
camera:	ZEISS RMK TOP 30
lens:	ZEISS TOPAR 305mm
date:	30.07.1992

Table 2: Specification of the aerial photographs used.

2.3 Hard- and Software

The analysis of the aerial photographs was carried out on an analytical plotter PLANICOMP P3/PHOCUS (ZEISS Co.) supported by a MICROVAX 3100 (DIGITAL Co.). This plotter is capable of graphic superimposition (VIDEOMAP 2). With the help of this, information relating to the actual progress of work or information collected from other sources (e.g. digitized thematic maps) is available for the operator during his work. Geometric and attribute data is directly available for use in a GIS. GIS PC-ARC/INFO (ESRI Co.) has been used in the project. A CALCOMP 9100 (CALCOMP Co.) was

[1]: The project titeld "Optimizing the Forest-Management Inventory System with permanent sample points through the use of analytical photogrammetry" is financed by the Ministry for rural site, food, agriculture and forestry Baden-Württemberg (Az.: 51-0430.6) and the German Resaerch Society (DFG) (Az.: Oe 113/6-1/2).

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used to digitize the maps. The graphic output was carried out with a HP 7550 penplotter (HEWLETT-PACKARD Co.).

2.4. A summary of the planned procedure

The following steps show the ideal procedure:

1) An aerial photo flight with CIR filmmaterial including a control point signalisation before starting if necessary (depending on the accuracy expected).
2) Interior, relative and absolute orientation of the models.
3) Digitizing of given borders, that are not visible by aerial photointerpretation and preparing them for the graphical superimposition at the analytical plotter.
4) Interpretation, delineation and description of stands, stand structures, sample plots as well as single trees.
5) Transformation of the photogrammetric evaluated data into a GIS readable format, creating a database and printing provisional maps and data lists.
6) Terrestrial evaluation of some sample plots to obtain data for the phase two variables needed for the regression functions.
7) Prediction of standing volume by using the aerial evaluated data and the regression functions.
8) Verification, correction and completing of maps and information concerning stands during the fieldwork carried out by the forest manager and the forest ranger.
9) Correction and updating of the GIS database and if necessary the inclusion of new stand boundaries using additional photogrammetric measurements.
10) Output of the actual maps and attributed information.

In this research it was not possible to follow the above mentioned guidelines. The terrestrial inventory in the forest district of Backnang was already partially completed as the research study began. Therefore the terrestrial measured trees had to be identified in the aerial photographs and not as usual the other way round. For the same reason point 8 could not be properly put into praxis.

2.5 Procedure

The following refers mainly to point 4 ff in chapter 2.4.
Before the photointerpreter can begin, the working area and the boundaries, that have to respected while delineating stands (e.g. boundaries between two owners), are graphically superimposed. By delineating stands, the photointerpreter takes into account forestry parameters such as tree species, their composition in stands and natural age classes. The areas delineated will be described by the characteristics shown in table 3. Moreover he delineates and describes structures of the stands (diameter ∃ 30m) and single trees, which are of interest to the forest district (table 3).
In principal it is possible to use information taken from former stand delineations which in the best case are available in a digital form. Then the graphical superimposition of former stand boundaries will make the updating of the data to the actual situation easier and faster.
To measure tree parameters at the sample plots the location of the desired area has to be marked in the aerial photograph with the help of graphic superimposition. To do this the measure mark of the analytical plotter is positioned automatically in xy. The photointerpreter has only to correct the height (z) in the 3D-model. Then he has to delineate and to describe all tree crowns which have their uppermost point within the sample area. The description of the sample trees was carried out by using the characteristics shown in table 4.

assessment level	parameters	classes
stand	natural age class stand structure age structure canopy cover form of mixture stand type mixing proportion	6[2] 3[3] 4[4] 6[5] 8[6] 17[7]
structures	blanks mixture groups forest edges	2[8] 6[9] 3[10]
single trees	reserved trees oaks from middle forest standing dead trees	2[11] 1 2[12]

Table 3: Parameters obtained during aerial photointerpretation.

given parameters	number of sample plot centre of sample plot (coordinates) radius of sample area
parameters of single trees	tree specie tree class of Kraft tree vitality chlorosis strong dead branches peculiarities (e.g. topbreak) crown area(coordinates) uppermost point (coordinates) number of the tree
other	ground points (coordinates))

Table 4: Parameters for estimation of standing volume evaluated during the aerial phase of the inventory.

PHOCUS serves for gathering spatial and attribute data. Therefore the photointerpreter is able to enter the attribute data directly. The attribute data is connected with an object by measuring a point, carrying the coded information, which can either be the uppermost point (sample trees or trees of special

[2]: culture, dense young stand, pole sized stand, timber stand (weak, medium, strong), old forest stand
[3]: one layer, two layers, various layers
[4]: same age, uneven-aged: treewise, in small areas
[5]: aggregated, closed, sparse, thinly stocked, gappy
[6]: pure stand, mixing of single trees, mixing in herds, in groups, in hursts, in small stands, in rows, in strips
[7]: stand type
[8]: regenerated, not regenerated
[9]: deciduous trees or conifers predominant, dominant, suppressed
[10]: conifers, deciduous trees, mixed
[11]: pine, larch
[12]: conifers, deciduous tree

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interest) or a point inside a delineated area (stands). The advantage of creating such an information point is that it serves afterwards as a label point in the GIS. This allows the collected information to be directly available. Actual, provisional (not all of the needed information is available by Remote Sensing) maps (stands, stand structures, sample areas, ...) and data lists (stand description, ..) can be produced.
In the field an inventory group has now to evaluate data from those sample areas, that are necessary to define regression functions for the volume prediction using a two-phase sampling technique.
To find the sample areas in the field the inventory group is equipped with an ultrasonic range finder, a compass and crown maps of the respective areas. A Global Positioning System (GPS) is also very useful in finding specified sample plots in the field. An other practicable method to locate sample areas in the field using photogrammetric measured orientation points is described in KÖHL and SUTTER (1991).
The following step applies the regression functions, founded on the correlations between first phase aerial variables (crownsize, tree height, ...) and second phase terrestrial variables (diameter at breast height, tree volume, ...), in order to estimate the standing volume. This part of the research is not finished yet. Therefore it is not dealt with in greater depth in this paper.
At this point the forest manager starts with his field work. Accompanied by the forest ranger and supported with actual maps and information about stand structure and volume, he has to verify the maps and descriptions and to correct these if necessary. In each case he has to complete the data collected with remote sensing with additional information that is not visible in aerial photographs (e.g. natural regeneration, understorey, ...). During this work a plan for the next 10 year period was formulated. After this final field work the GIS database will be updated. The management of a forest district can use the complete dataset from this point onwards.
As mentioned it was not possible in the actual research to follow our own guidelines (see chapter 2.4). For identification of the sample trees in the aerial photographs, which are actually terrestrial measured, their position (defined by distance and azimuth to the sample area centre)
was graphically superimposed with a point. Because these points in the aerial photographs do not always lie inside a previously delineated crown polygon and if they do lie inside one can not be sure that it is the polygon of the respective tree, a verification is necessary.
For this identification a selective procedure was practised. Firstly points of trees with a breast-height diameter (b.h.d.) ∃ 30cm are shown with the use of graphical superimposition. These trees, which are the highest, are easy to identify in the aerial photographs. Therefore the photointerpreter is able to realise shifting vectors between the aerial and terrestrial sample areas. This allows him to match terrestrial and aerial sample plots. These problems occur because terrestrial sample are frequently misplaced in the field. It is not rationally possible to locate the desired sample position as accurately as it is, using photogrammetric methods. The same procedure is used for trees with a b.h.d. of < 30cm and ∃ 15 cm and those < 15 cm. After the application of this step the prerequisites for regression functions are fulfilled.

3. RESULTS

The motivation for drawing stand boundaries is similar, when comparing stand maps resulting either from terrestrial or aerial (photogrammetric) measurements. In contrast differences are frequent in the location of the boundaries.
The photogrammetric measurement of stand boundaries is more accurate than the terrestrial. This difference in accuracy is very often considerable in the case of new boundaries between young stands (cultures) and old forest stands.
The following points show reasons for the need to correct photogrammetric measured boundaries:

- Insignificant differences in composition of tree species and/or tree age will not always be realised by the photointerpreter or, and this case occurs more frequently, it is not considered as significant enough to draw a stand boundary.
- Small variations in site index that form a continuous contrast to neighbouring areas (e.g. old stone-pit) are not recognizable for the photointerpreter without additional information.
- Faults in interpretation (e.g. tree species are not correctly interpreted).

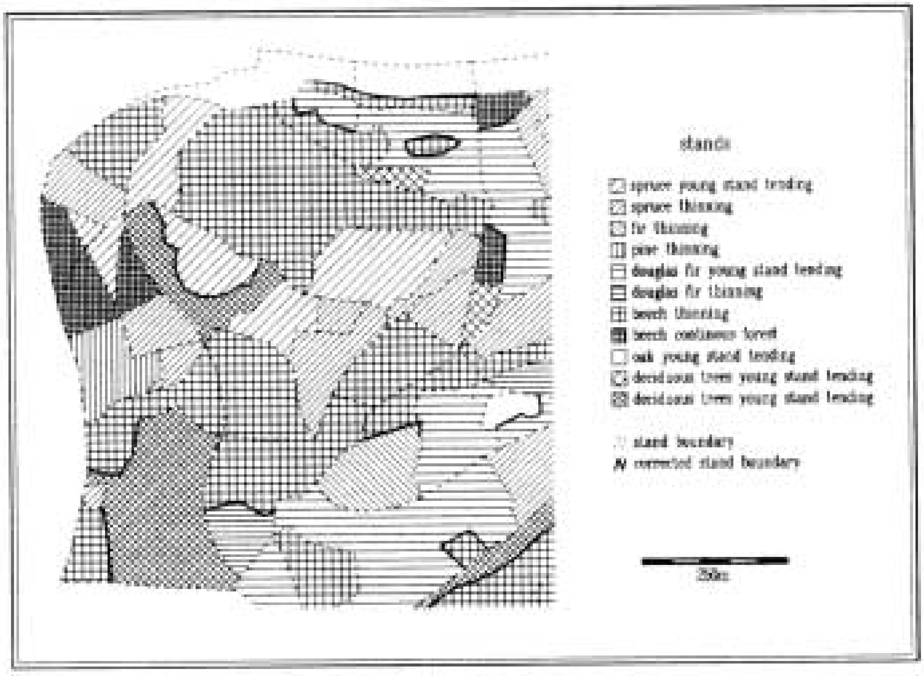

Figure 1: Part of a stand map showing tree species. Emphasized are stand boundaries that were drawn in addition to the photogrammetric measured boundaries during fieldwork.

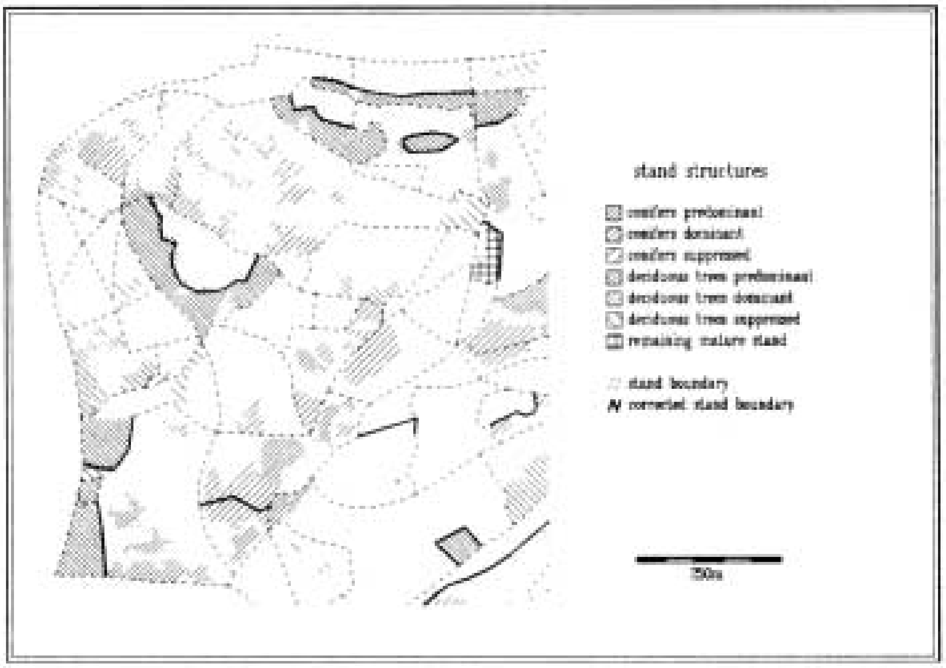

Figure 2: Part of a structure map. Emphasized are stand boundaries that were drawn in addition to the photogrammetric measured boundaries during fieldwork.The structures were mapped without fieldwork or additional information.

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Figure 1 and 2 show that those boundaries, that have been added to the photogrammetric measurements during the field work carried out by the forest manager and ranger are often identical with structural boundaries, that have been delineated during the photogrammetric measurements.
This indicates, that the reason for drawing a stand boundary was seen as significant for the forest manager in field but was considered insignificant for the photointerpreter.
Regarding the interpretation of tree species, natural age classes and stand structure types in CIR-aerial photographs, the results of aerial photointerpretation can be considered as satisfactory. Faults in photointerpretation can not be avoided. Especially young leaf stands are very difficult to interpret in CIR aerial photographs. Crops are visible in aerial photographs and can be delineated as an area, but it is not possible to recognize anything about the tree species of crops.
Aerial CIR photographs allow more realistic assessments of the composition of trees. The birds-eye view gives a better perspective over large areas. This can be seen as an advantage.
The time needed for photointerpretation, photogrammetric measurements and the production of provisional maps is approximately 1 day/ 100ha. For correcting and updating the data and producing the final maps approximately ½ a day/100ha is needed.
Only partial results are presented from the estimation of standing volume. This part of the research has not yet been finished.
The automatic positioning of the measuremark in the analytical plotter to mark the sample areas is not a problem. Problems arise when combining the aerial delineated crowns with the terrestrial measured trees.

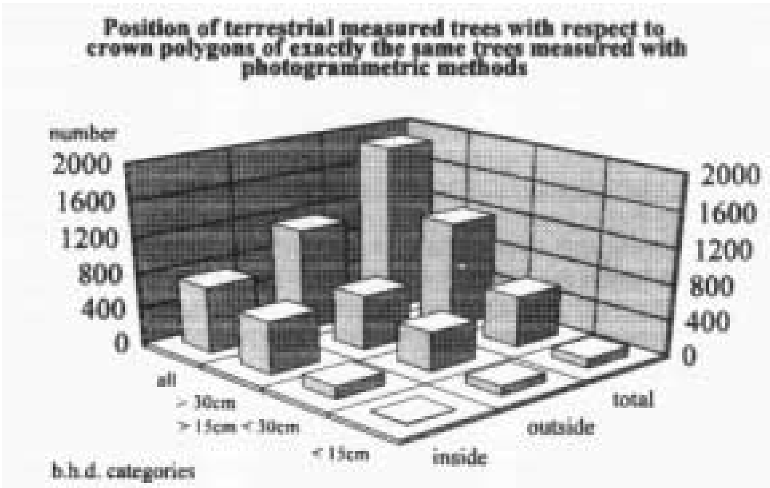

Figure 3: Number of trees, whose terrestrial measured location was inside the photogrammetric delineated crown polygons of the respective trees.

In the best case the point, that marks the terrestrial measured tree, lies inside the crown polygon belonging to this tree. But this is not normally the case (figure 3).
The reasons for the above mentioned problem are as follows:

- Inaccurate location of sample areas using terrestrial measurements result in displacements between terrestrial and aerial sample areas (it is possible to exclude inaccurate sample plots in the aerial photographs because of the good results of the absolute orientation (see chapter 2.2)).
- In the case of crooked trees it is possible that the point that marks the terrestrial position of a tree lies outside the crown polygon which is visible in the aerial photograph even though the position of the tree was correctly located in the field.
- By delineating crowns in aerial photographs it may occur, that parts of one crown are considered as two or more trees.
- In aerial photographs it is not possible to see understorey trees.

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In most of the above mentioned cases the identification of the terrestrial measured trees was possible by using the terrestrial ascertained data (tree species, tree height, b.h.d.). The reliability of this identification depends on the diameter at breast height (figure 4), which is strongly correlated to the crown size which is visible in aerial photographs. 98% of the trees with a b.h.d. of ∃ 30 cm were identified. This proportion falls for trees with a b.h.d. between 15 cm and 30 cm to a level of 81% and for trees with a b.h.d. smaller than 15 cm to 42%.

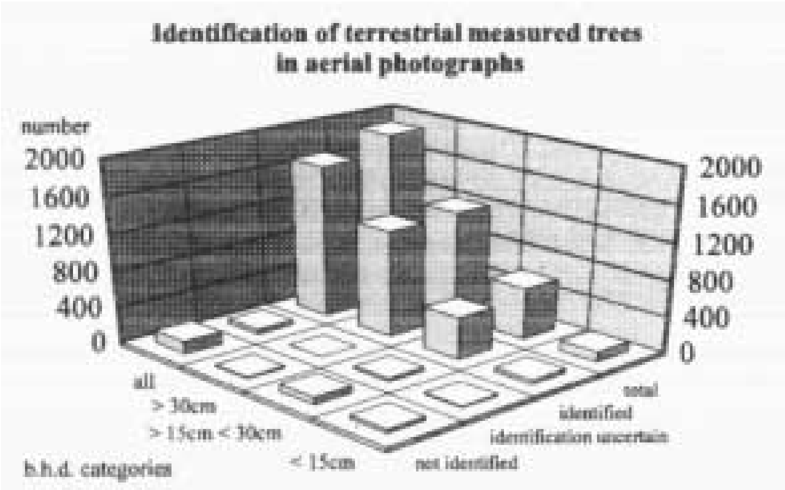

Figure 4: Number of terrestrial measured trees that could be identified in the aerial photographs.

The medium displacement between terrestrial measured tree location and the photogrammetric measured tree top was 3.07 m (variance 2.55 m). This explains the lower level of identification of trees with a small b.h.d. Even slight displacements between terrestrial and aerial sample positions can lead to terrestrial tree positions being marked outside the small crown polygons.
The identification is simplified if single mixture trees are present in the sampling area, or one of the trees dominates. Then the photointerpreter is quickly able to recognize direction and distance of the shifting vector between terrestrial and aerial sample position.
The average time needed for delineating and describing the trees according to table 4 in one sample area is 10 minutes. Including the time for identification of the terrestrial measured trees the average time required is 25 minutes.

4. DISCUSSION

The analysis of CIR aerial photographs using a combination of photointerpretation and photogrammetric methods enables one to produce stand maps and stand descriptions reproducing the actual situation. The forest manager, who normally prepares such maps can use the prepared maps from the beginning of his fieldwork. Such maps can be more detailed and accurate than those using the normal mapping procedures in forest management planning. With the help of these maps the forest manager gets a first impression of his planning object before starting with his field work (GADOW, 1993).
The necessary corrections of aerial information can be reduced through the use of existing information in the form of maps etc. The remaining faults are normally easily recognized in the field. The necessary corrections are carried out quickly and normally without any problems. The drawing of new stand boundaries during the field work has recently been simplified through the mapped stand structures.
Furthermore the stand structures shown in the maps give important indications for the planning procedure. For example they show the forest manager parts of a stand that need to be more intensively planned. Therefore the forest manager's work proceeds more smoothly. This additional map information also has advantages for the local forest rangers in their daily work

The presented procedure provides the forest management with actual and detailed maps sooner than it is possible with the conventional terrestrial forest management planning procedure. Such maps are one of the most important results of forest management planning (SCHÖLMERICH, 1993). Due to storage and handling of the data in a GIS, the forest management and the forest rangers are able to use the evaluated information selectively and orientated to actual problems. For subsequent inventories the data is available in a digital form. Therefore it can be used for graphical superimposition at an analytical plotter, that will allow updating to be carried out more quickly in the future.
The photogrammetric technique enables the user to implement nearly any sampling design in aerial photographs (GROSS et al., 1993). Problems may arise by building correlations between terrestrial measured variables and aerial measured variables from single trees. It is not possible in each case to locate exactly the same tree in the field as well as in the aerial photographs, which is a prerequisite for regression functions. However these problems do not exclude the application of regression functions for the estimation of standing volume in general.

5. CLOSING REMARKS

The presented project shows only one of a variety of applications for the use of photogrammetry in forestry. A good overview of possible applications is given in OESTEN et al. (1991) and PRÖBSTING (1994).
Nearly all these applications are similar in two points, apart from the fact that they are dealing with specific forest questions. Firstly, photogrammetry is used only as a tool and secondly it is used by foresters, specialised in Remote Sensing but normally not educated as photogrammetrists.
The combination of specific (forestry) knowledge accompanied with experience in aerial photointerpretation and photogrammetry also enables specific applications in other fields. CIR aerial photographs contain a vast amount of information. Compared with other Remote Sensing mediums (e.g. satellite imageries) they show a high geometric resolution and a satisfactory spectral resolution. They are flexible with respect to the acquisition date, in scale and the film used. Specialized photointerpreters (experts) are able to master the information contained in CIR aerial photographs.

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