CHAPTER 16

INVENTORY BY COMPARTMENTS

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16.1 BASIC CONCEPTS AND BACKGROUND

Inventory by compartments is the method typically used for acquiring data for traditional forest management planning purposes. It is based on the concept of the forest stand, which is traditionally defined as a geographically contiguous parcel of land whose site type and growing stock is homogenous (e.g. Lihtonen 1959 p. 9, Ilvessalo 1965 p. 159, Davis and Johnson 1987 p. 29, Poso 1994 p. 95). In this context, compartment can almost be considered a synonym for forest stand, but a compartment must be also a suitable cutting unit or treatment unit for silvicultural measures and need not necessarily be as homogenous as a forest stand.

Detailed forest management plans cannot be produced without compartment-wise estimates of site characteristics and growing stock and without silvicultural treatment proposals for each compartment. The latter must be made within the field inventory, because otherwise the planner has no way of ensuring that in the optimum solution to the forest management planning problem every compartment will be treated silviculturally in a feasible manner. Models describing forests and forestry in forest management planning packages (e.g. MELA, Siitonen et. al. 1996) are merely simplifications of reality.

Sampling theory could be used to estimate the sample size needed to attain a certain required level of accuracy in estimates of growing stock, but if the compartments are small the sample sizes become so large that the inventories will be too expensive. In Nordic countries and in Central Europe, where compartments are rather small, a solution to the problem has been found in terms of a subjective method called "inventory by compartments", which is partially based on visual assessment of the growing stock.

Inventory by compartments will be illustrated in this chapter by describing a Finnish application. The area of forestry land in Finland is about 26 million ha, of which 60% is owned by private persons. All the forests owned by the state or by

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forest companies have been inventoried. Almost all the privately-owned forests have been inventoried at least once by forestry centres, and at the moment the databases of the forestry centres cover about 11 million ha of forest. The average area of a compartment in southern Finland is about 1.5 - 2 ha. Compartments under 0.5 ha are not used unless the area is environmentally valuable.

16.2 HISTORY OF THE INVENTORY METHOD IN FINLAND

Inventory by compartments is the oldest method for conducting inventories of forest areas. The basic ideas were developed in Central Europe long before the days of mathematical sampling theory (Loetsch and Haller 1973 pp. 7-9). Management planning by stands began in the state-owned forests of Finland in 1907 (Lihtonen 1959 p. 289). Inventory by stands in the early 20th century differed markedly from inventory by compartments as it is performed today, mostly on account of the availability of base maps and the existence of two inventions: aerial photography and the relascope. If no base maps were available for a particular area in earlier times, a land survey had to be included in the inventory. In Finland, aerial photographs were first used for making forestry maps in 1946. Delineation of the compartment borders is much easier with aerial photographs than with base maps and field measurements. The relascope was invented in Austria in 1947 (Loetsch and Haller 1973 p. 8). Before this, the volume of growing stock had to be assessed on the basis of visual estimates of stand density and a few tree height measurements (Ilvessalo 1965). The relascope solved the problem of measuring stand density, and following its invention just a few sample plots have needed to be measured at subjectively selected locations in each compartment. These sample plot measurements can then be subjectively weighted to calculate the mean basal area (m^2/ha), mean diameter, mean height and mean age of the growing stock in a compartment. Volumes of growing stock by tree species can be taken from stand volume tables based on estimated basal areas and mean heights (Nyyssönen 1954).

16.3 INVENTORY BY COMPARTMENTS TODAY

16.3.1 The inventory method

Forest companies in their own forests and the Forest and Park Service in the state-owned forests have now replaced traditional inventory by compartments with a continuous updating approach, so that large inventory projects carried out at regular intervals are no longer needed. Instead, the forest resource database is updated immediately after cutting or the implementation of a silvicultural measure in a compartment and the increment in the growing stock is updated by means of growth models.

The forestry centres still continue the tradition of inventories by compartments at 10 – 15 year intervals in private forests, but again the old inventory data are updated by mean of growth models before the new inventory. The first step in the inventory is delineation of the compartment borders using digital aerial photographs, base maps and the old inventory data. The old inventory data are also used in the field inventory, being valuable for assessing site characteristics, for example. In the field work, a surveyor visits every compartment, checks the compartment borders, measures 2-8 sample plots at subjectively selected locations in each compartment (Figure 16.1) and makes proposals for silvicultural treatment over the next 10-year planning period. The sample plots are relascope plots (relascope factor usually 1 or 2) in thinning and mature stands, and circular plots (usually of radius 4 m) in seedling stands.

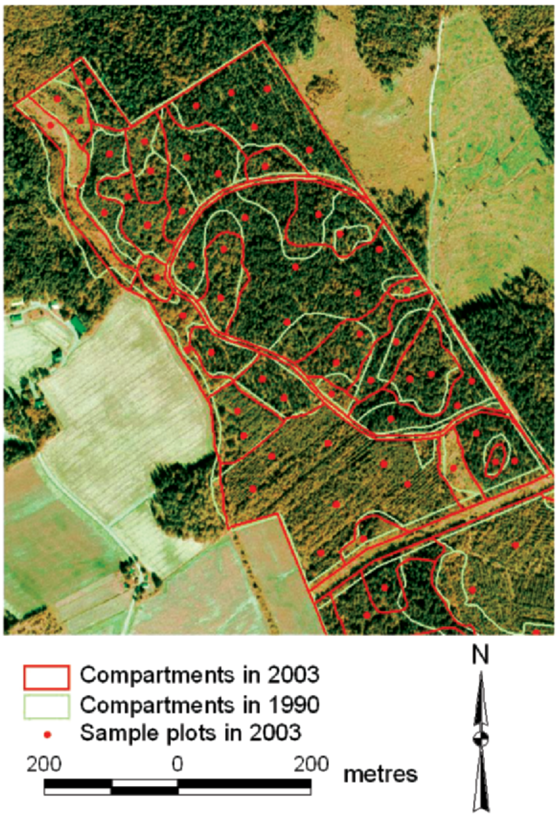

Figure 16.1 Compartments identified in the inventory by compartments in 1990 and 2003, and sample plots measured in the 2003 inventory in a forest located near Riihimäki in southern Finland that is managed by Finnish Forest Research Institute. (Aerial photograph 2001, © FM-Kartta Oy).

The relascope plots are used for estimating the basal area (G, m^2/ha), mean diameter (D, cm), mean height (H, m) and mean age (T) of the growing stock, all recorded by tree species and tree storey. Mean diameter is the diameter of the basal area median tree. Mean heights and mean ages are usually measured only for one or two representative median trees in the whole compartment and not for every sample plot. For young stands, the number of stems (N, stems/ha) is measured instead of the basal area on fixed-radius plots. Even though several sample plots may be measured in order to estimate the mean characteristics, only one mean value for each tree species and tree storey is recorded for each variable in a compartment. Mean values are calculated using field computers. The original plot-level values are not stored in the compartment database.

16.3.2 Estimation methods

The estimation of stem volume, volumes by timber assortments and growth consists of the following stages.

1. Prediction of diameter distribution.
2. Selection of representative trees (model trees) from the theoretical diameter distribution.
3. Prediction of volumes and increment for the model trees.
4. Summation of compartment-level results.

Prediction of diameter distribution

The diameter distribution in thinning stands or mature stands is usually estimated by means of regression models predicting the parameters of the Weibull distribution (see Mykkänen 1986 and Kilkki et al. 1989). (Weibull distribution models actually predict the basal area distribution, but the term diameter distribution is used here for simplicity.) Other methods for estimating diameter distributions in addition to those based on parametric density functions have been developed recently (for distribution-free methods, see Kangas and Maltamo 2000a and 2000b, and for non-parametric methods based on a database of known diameter distributions, see Haara et al. 1997). Tree height distributions are employed in seedling stands instead of diameter distributions.

Selection of representative trees from the theoretical diameter distribution

Usually 10 representative trees (model trees) are selected systematically at fixed distances from the predicted diameter (or height) distribution and the number of stems represented by each is derived from the cumulative basal area distribution and the basal area of the model tree itself, so that the sum of the basal areas of model trees is equal to the measured basal area for the tree species and storey.

Prediction of volumes and increment for the model trees

The total height of each selected model tree is estimated by mean of general height models calibrated by reference to the measured height of the basal area median tree. Stem volume is predicted by means of general volume functions, using diameter and height as regressors. Volumes by timber assortments are estimated with tables as a function of tree diameter and height. Volume increment is predicted using tree-level diameter and height increment models.

Estimation of compartment-level results

The number of stems represented by each model tree is derived as described above, and the compartment-level results are obtained simply by summing the estimated tree-level values multiplied by the representative factor.

16.4 ACCURACY OF THE INVENTORY BY COMPARTMENTS METHOD AND SOURCES OF ERROR

Inventory by compartments is still the most efficient inventory method for acquiring data for the purposes of detailed forest management planning. Another reason for its popularity is that the unit of assessment is intended to be the same as the smallest unit of forest management. The delineation of compartment borders and the making of proposals for cuttings and other silvicultural measures can also be regarded as the preliminary stages of forest management planning. Despite its popularity, however, the inventory method has also been criticized. It is considered expensive, the inventory results are not always accurate enough, and their accuracy cannot be estimated on the basis of measurements made in the inventory.

Main reason for the problems is that even a visually highly homogeneous compartment can show considerable variation in sample plot basal areas, and thus also in volumes, if sample plot sizes are kept at practical level (Figure 16.2). In inventory by compartments surveyors seldom measure sample plots in locations where the characteristics of the growing stock reach or come close to local maximum values, or if they do so, then they also balance out these local maxima with local minima. This procedure reduces random variation in the compartment-level characteristics of the growing stock as compared with probabilistic sampling, but the compartment-level results will be biased if the surveyor’s impression of the average amount of growing stock along the route that he walks differs from the real situation. The largest compartment-level errors, however, arise from the fact that surveyors do not visit every part of the compartment. Unless a surveyor walks through the compartment in parallel to the trend in a given characteristic of the growing stock, quite large errors are very likely to occur.

Several studies have been published on the reliability of inventory by compartments. The sources of error mentioned include:

- random and systematic measurement errors (e.g. in observing basal areas and locating compartment boundaries)
- “sampling errors” when locating the relascope plots (quotation marks needed to indicate that this is not true sampling error, because the locations are selected subjectively
- model errors in estimating diameter distributions, tree heights, stem volumes etc.

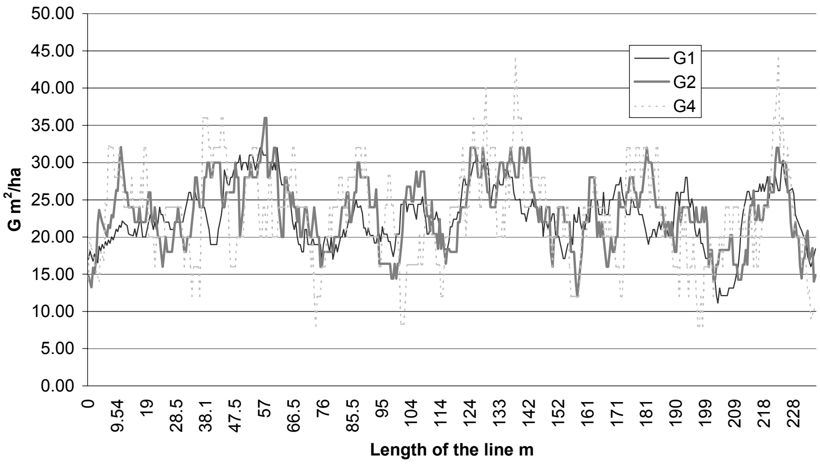

Figure 16.2 Basal areas of relascope plots located on a straight line through a homogeneous spruce stand in southern Finland (Koivuniemi 2003), calculated with relascope factors 1, 2, and 4 (G1, G2 and G4, respectively). The mean diameter and mean height of the growing stock were 23 cm and 17 m.

According to these publications, the magnitude of the measurement and "sampling" errors (RMSE, root mean square error) for the mean volume estimate is approximately 25% (Table 16.1). The errors depend on the surveyor, however, and RMSE's may vary from less than 15% to more than 40%. In addition, systematic errors occur, these being up to 20% at the surveyor level (Haara and Korhonen 2004). Experienced surveyors are usually able to collect data with higher precision than unexperienced ones, whereas it has been shown that training does not improve the quality of the data produced by experienced surveyors (Ståhl 1992).

The accuracy of the results over the whole area inventoried can be estimated and systematic errors in compartment-level estimates can be reduced if the traditional inventory by compartments method is supplemented with an inventory based on probability sampling (Lindgren and Jonsson 1978, Laasasenaho and Päivinen 1986 and Jonsson et al. 1993). Estimation of the accuracy of the inventory results for the whole area is based on stratification and a two-stage sampling procedure in which the area is stratified into homogeneous groups of compartments and stage 1 consists of the sampling of compartments from the strata and stage 2 of systematic sampling of circular or relascope plots within each selected compartment. The accuracy of the inventory results can also be calculated for each stratum.

Table 16.1. Biases (b) and standard deviations (s) of errors in the estimation of growing stock characteristics made in inventories by compartments, according to Finnish studies (Haara and Korhonen 2004). Relative values in percentages are shown in parentheses. The characteristics studied were D_{gM} = diameter of the basal area median tree, G = basal area, H_{gM} = height of the basal area median tree, and V = mean volume.

Characteristic of growing stock	Statis-tic	Study Poso (1983)	Laasasenaho and Päivinen (1986)	Pigg (1994)	Haara and Korhonen (2004)
D_{gM} (cm)	b		-1.0 (-4)	-0.8 (-4.8)	0.4 (2.4)
	s		2.2 (10)	2.5 (14.1)	2.3 (12.6)
G (m^2/ha)	b		-0.1 (-1)	0.2 (1.2)	0.5 (2.7)
	s		3.3 (16)	2.8 (18.5)	3.9 (19.6)
H_{gM} (m)	b		-0.6 (-3)	-0.2 (-2)	-0.01 (-0.05)
	s		2.1 (11)	1.7 (14.1)	2.4 (15.7)
V (m^3/ha)	b				2.4 (1.6)
	s	36-66 (29-38)	32-37 (17-24)		37.5 (24.8)

The compartment-level estimates can be calibrated using regression techniques. In the simplest such technique, the compartment-level estimates achieved by an objective inventory method are predicted as a function of the estimates achieved by the traditional inventory by compartments method.

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