Required Sample Size for Monitoring Stand Dynamics in Strict Forest Reserves: A Case Study

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Abstract.—Stand dynamics in European strict forest reserves are commonly monitored using inventory densities of 5 to 15 percent of the total surface. The assumption that these densities guarantee a representative image of certain parameters is critically analyzed in a case study for the parameters basal area and stem number. The required sample sizes for different accuracy and probability levels are calculated. The commonly applied inventory densities prove to be insufficient for both parameters considering a generally desired accuracy level of 5 percent ($p = 0.05$). Results indicate the need for a new reflection on the aspect of representativeness in the framework of forest reserve monitoring.

The most commonly applied method for long-term monitoring of the natural development of woody vegetation in strict forest reserves in Europe consists of a systematic grid of permanent circular plots in combination with a permanent core area (Albrecht 1990, Althoff *et al.* 1993, Broekmeyer and Szabo 1993, Bücking *et al.* 1986). The grid of circular plots provides information on the level of a forest reserve and on the different forest communities or types it consists of, each covering at least its minimum structure area (Koop 1989). The core area gives more detailed information on dynamic processes and covers at least some regeneration units within a forest community. This study focuses on the level of a forest reserve using a grid of circular plots for monitoring purposes. According to Albrecht (1990), such a grid needs to fulfill two aims: first, it should give a representative image of the forest reserve as a whole, and secondly, it should at the same time serve as a network of permanent monitoring plots. Thus, a single circular plot can be treated both as a sample unit and as an area for long-term monitoring of forest dynamics. To achieve both aims, the system of circular plots usually covers from 5 to 15 percent of the total surface of the forest reserve (Albrecht 1990, Althoff *et al.* 1993, Kätzler 1984, Stuurman and Clement 1993). The plots are re-inventoried in 10-year intervals (Albrecht 1990, Stuurman and Clement 1993).

In this study, only the first aim is dealt with for the forest reserve of Liedekerke in Belgium. The objective is to determine the sample size needed to obtain a representative image of this particular forest, in order to evaluate the commonly used inventory density in strict European forest reserves. Therefore, two widely applied parameters (stem number and basal area), globally characterizing forest ecosystems and their natural dynamics, are considered. Sample sizes are determined and compared assuming different accuracy and probability levels for both parameters. To examine their temporal evolution, the results on sample size are compared with those found 10 years later.

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MATERIALS AND METHODS

Study Site

The forest reserve of Liedekerke is located in the central part of Belgium and covers an area of 22.5 ha. The elevation ranges between 24 and 36 m above sea level. Its western and northern boundaries are formed by the state forest of Liedekerke (54 ha); the east and the south sides are bordered by pasture and farmland.

A moderately wet, loamy soil occurs throughout the forest, together with some very wet sites in the small valleys. The mesorelief is rather uniform, except for some local depressions.

The forest ecosystem belongs to the Querco-Betuletum type (Quercion) (Noirfalise 1984). Dominating tree species are birch (*Betula pendula* and *B. pubescens*) (approx. 55 percent) and indigenous oak (*Quercus robur* with some *Q. petraea*) (approx. 15 percent).

The forest reserve is a remnant of the ancient "coal forest" or "Carbonaria Sylva." Up to the middle of the 20th century, it was subjected to regular coppicing while heathland still covered more than 40 percent of the surface. The most recent human intervention, which dates back to World War II, consisted of widespread felling by the local population for firewood. For more than 50 years now, this ecosystem has remained unmanaged, which makes it unique for Belgium. During its evolution since the 1940's, it showed a steady regression of the heath, culminating in its disappearance in 1970, and a progression of coppice elements into the upperstory (De Cuyper 1993).

Determination of Sample Size

In 1986, a 40- x 50-m grid was installed on a part (12.9 ha) of the forest reserve having a rather homogeneous and uniform forest structure and composition. To investigate sample size for future monitoring of the woody vegetation, 31 circular plots were randomly selected with the intersections of the grid forming their centers (fig. 1). Their size was fixed at 700 m^2 (radius 15 m). Pardé (1961) advises sample sizes between 400 and 800 m^2 for similar homogeneous forest types of comparable age. Such large sample plots were chosen for two reasons. The first reason was to minimize the variance of the estimated parameters caused by the dimension of the sample plot (Rondeux 1993). The second reason was related to their permanent monitoring objective. Because stem number changes in time, larger sample plots have a higher probability of fulfilling the requirement to include a minimum number of trees per plot. Kramer and Akça (1982), Richter and Grossmann (1959), and Spurr (1952) point out that an individual plot should contain at least 25 to 30, 12 to 14, and 20 to 30 trees per plot, respectively. With approximately 70 to 130 trees per circular plot, this particular forest reserve, which is still in its pioneer stage, amply met this requirement.

The first inventory of these 31 plots, covering 17 percent of the total surface, was made in 1986. Every tree with a dbh exceeding 2 cm and taking root in the plot was taken into account. The trees were identified and their diameters were measured with an accuracy of 1 mm. Usually only trees with a dbh ≥ 5 cm are included in the calculation of the mean basal area (Albrecht 1990, Hocke 1996, Kätzler 1984, Stuurman and Clement 1993). To investigate the impact of smaller dbh ranges on the sample size, special attention is given to trees with a dbh ≥ 2 cm. In 1996, the same measurements were repeated.

To determine the sample size (n) for a certain accuracy level (E%) of the parameters mean stem number and mean basal area of all trees, the following formula for simple random sampling can be used, provided the data set approaches a normal distribution (Rondeux 1993, Schreuder *et al.* 1993):

$$n = \frac{t\Delta(s\%)\Delta}{(E\%)\Delta + \frac{t\Delta(s\%)\Delta}{N}} \quad (1)$$

where s% is the coefficient of variation (= standard deviation divided by the mean of one of the parameters previously mentioned), N the total number of plots needed to cover the whole surface (= population), and t the t-value that can be extracted from the table of a t-distribution for a certain p-value or probability level and

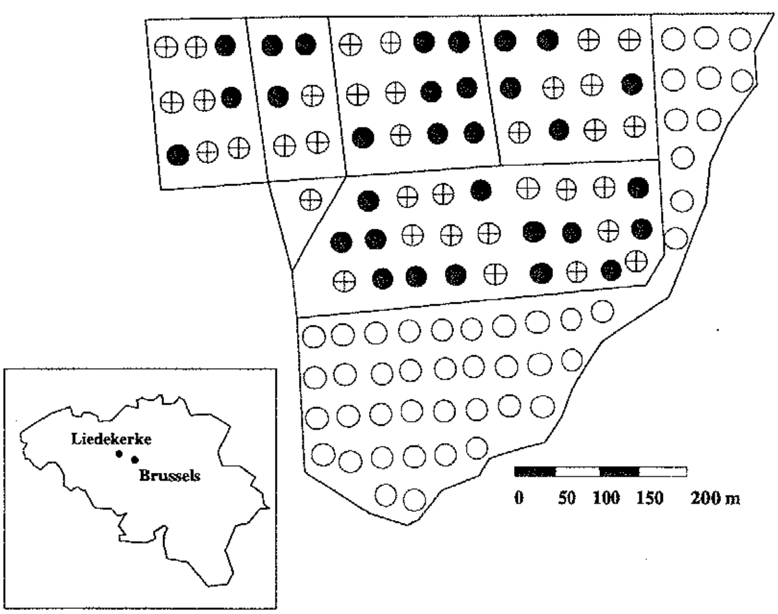

Figure 1.—*Distribution of the circular plots in the forest reserve of Liedekerke; ● = randomly selected plots inside the homogeneous part; ⊕ = non-selected plots inside the homogeneous part; ° = plots outside the homogeneous part.*

for the number of degrees of freedom. The Central Limit Theorem (CLT) states that a random sample n taken from any distribution approaches a normal distribution if n can increase without bound. Since this is usually not the case because most populations are finite, the CLT is arguable (Schreuder *et al.* 1993). Therefore, normality was tested by means of the Kolmogorov-Smirnov (Lilliefors) test considering a p-value of 0.05.

If the population is infinite or

$$\frac{N - n'}{N} \geq 0.95 \qquad (2)$$

where n' is the number of plots that were inventoried, then the second part of the denominator of (1) equals zero (Rondeux 1993).

RESULTS

Sample Size of the 1986 Inventory

The four data sets of stem number and basal area of all trees (dbh ≥ 2 cm and ≥ 5 cm) of the 1986 inventory in the 31 circular plots (= n') approach a normal distribution (Kolmogorov-Smirnov (Lilliefors) p > 0.2), so formula (1) could be applied. The total surface of the considered part of the forest reserve (12.9 ha) divided by the surface of a single circular plot (700 m^2) defines the population N = 183. This means that for a full inventory of the area, theoretically 183 circular plots are necessary. This population proved to be finite ((N-n')/N = 0.83 thus ≤ 0.95).

For each data set, sample size was calculated in function of a variety of accuracy and probability levels (degrees of freedom = ∞) (table 1).

Table 1.—*Sample size of the 1986 inventory for basal area and stem number, considering two dbh ranges and various levels of accuracy (E%) and probability (p) (expressed in numbers of circular plots and the corresponding percentage of the total surface of the homogeneous part of the forest reserve)*

Data set	Parameter	Dbh	Mean	E%	Number of circular plots			Percentage of total surface		
					p = 0.1	p = 0.05	p = 0.01	p = 0.1	p = 0.05	p = 0.01
		Cm	*m²/ha*	*Percent*	- - - *Number* - - -			- - - *Percent* - - -		
1	Basal area	≥ 2	23.2	10	5.5	7.7	12.9	3.3	4.4	7.1
				5	20.1	27.3	42.5	11.5	15.3	23.6
				1	138.2	149.0	161.6	76.2	81.7	88.8
				0.1	182.4	182.6	182.8	100	100	100
2	Basal area	≥ 5	22.4	10	6.7	9.4	15.6	3.8	5.5	8.8
				5	24.1	32.4	49.6	13.7	18.1	27.4
				1	144.8	154.3	165.2	79.5	84.9	91.0
				0.1	182.5	182.7	182.8	100	100	100
		Cm	*Number /ha*	*Percent*	- - - *Number* - - -			- - - *Percent* - - -		
3	Stem number	≥ 2	1,844	20	6.4	9.0	14.9	3.8	4.9	8.2
				10	23.2	31.2	48.0	13.2	17.5	26.3
				5	67.1	82.6	107.4	37.3	45.5	59.2
				1	171.2	174.5	178.0	94.3	95.9	97.6
				0.1	182.9	182.9	182.9	100	100	100
4	Stem number	≥ 5	1,347	20	5.6	7.9	13.2	3.3	4.4	7.7
				10	20.5	27.8	43.3	12.1	15.3	24.1
				5	61.4	76.5	101.3	34.0	42.2	55.9
				1	169.6	173.3	177.3	93.2	95.4	97.6
				0.1	182.9	182.9	182.9	100	100	100

The required sample size needed to give a representative image of the forest reserve depends on the considered parameter.

For the basal area and the dbh range ≥ 2 cm, an inventory of 28 out of 183 plots or 15.3 percent of the total surface is sufficient for an accuracy level (E%) of 5 percent and a probability level of $p = 0.05$. In other words, in 9.5 cases out of 10, a random sample of 28 of the possible 183 plots results in an estimated mean basal area situated in an accuracy-interval of 5 percent around 23.2 m^2 per ha. For the dbh range ≥ 5 cm, the necessary plot density increases to 18.1 percent of the total surface, which makes the inventoried surface of 17 percent (31 plots) insufficient. In general, the area needed for the inventory of trees with dbh ≥ 5 cm is only slightly higher than for trees with dbh ≥ 2 cm (0.5 to 3.8 percent of the total surface). More than three-quarters of the total surface should be inventoried to reach an E% level of 1 percent, while an inventory of at least 3.3 percent of the total surface guarantees an E% level of 10 percent.

For the stem number, the sample size reaches 42.2 percent (dbh range ≥ 5 cm) and 45.5 percent (dbh range ≥ 2 cm) of the total surface for an E% level of 5 percent and a p-value of 0.05. Practically useful sample sizes for monitoring purposes are reached only at an E% level of 10 percent or more. The inventoried surface of 17 percent allows an E% level of 10 percent and a p-value of 0.05 for a dbh range ≥ 5 cm. This surface is slightly insufficient for a dbh range ≥ 2 cm. In contrast to the basal area, measuring trees with dbh ≥ 2 cm generally leads to a supplementary inventory area between 0.5 and 3.3 percent of the total surface in comparison with trees with dbh ≥ 5 cm.

Sample Size of the 1996 Inventory

The four data sets of 1996 (n' = 31 circular plots) of all trees showed a normal distribution (K-S (Lilliefors) $p > 0.2$ and K-S (Lilliefors) $p = 0.1697$ for the data set of stem number and dbh range ≥ 5 cm) so that formula (1) could be applied.

For each data set, sample size was calculated in function of a variety of accuracy and probability levels (degrees of freedom = ∞) (table 2).

Table 2.—*Sample size of the 1996 inventory for basal area and stem number, considering two dbh ranges and various levels of accuracy (E%) and probability (p) (expressed in numbers of circular plots and the corresponding percentage of the total surface of the homogeneous part of the forest reserve)*

Data set	Parameter	Dbh	Mean	E%	Number of circular plots p = 0.1	p = 0.05	p = 0.01	Percentage of total surface p = 0.1	p = 0.05	p = 0.01
		Cm	*m²/ha*	*Percent*		*Number*			*Percent*	
1	Basal area	≥ 2	28.1	10	6.7	9.5	15.8	3.8	5.2	8.7
				5	24.3	32.8	50.2	13.3	18.0	27.5
				1	145.0	154.7	165.5	79.5	84.8	90.7
				0.1	182.5	182.7	182.8	100	100	100
2	Basal area	≥ 5	27.6	10	7.3	10.2	17.1	4.0	5.6	9.4
				5	26.1	35.1	53.3	14.3	19.2	29.2
				1	147.5	156.6	166.8	80.8	85.8	91.4
				0.1	182.6	182.7	182.8	100	100	100
		Cm	*Number /ha*	*Percent*		*Number*			*Percent*	
3	Stem number	≥ 2	1,124	20	6.3	8.9	14.9	3.8	4.9	8.2
				10	23.0	31.1	48.0	12.6	17.0	26.3
				5	66.7	82.4	107.4	36.6	45.2	58.9
				1	171.1	174.5	178.0	93.8	95.6	97.6
				0.1	182.9	182.9	182.9	100	100	100
4	Stem number	≥ 5	979	20	7.8	10.9	18.2	4.9	6.0	10.4
				10	27.7	37.1	56.0	15.3	20.8	30.7
				5	76.2	92.3	116.8	42.2	51.0	64.1
				1	173.3	176.1	178.9	95.4	97.0	98.1
				0.1	182.9	182.9	183.0	100	100	100

Again, the sample size needed to give a representative image of the forest reserve proves to depend on the considered parameter.

The 1996 inventory of 31 plots is insufficient to be representative for the mean basal area of the forest reserve for an acceptable E% level of 5 percent and a probability level of p = 0.05. At least 18 percent (dbh range ≥ 2 cm) or 19.2 percent (dbh range ≥ 5 cm) of the total surface needs to be inventoried. The necessary sample size—2.7 percent and 1.1 percent, respectively—has increased in comparison with 1986. In general, the area needed for the inventory of trees with dbh ≥ 5 cm is only slightly higher than for trees with dbh ≥ 2 cm (0.2 percent to 1.7 percent of the total surface). The 1996 inventory is nevertheless sufficient for an E% level of 5 percent but with a lower probability level of p = 0.1; it is also sufficient for a lower E% level of 10 percent but with a higher probability level of p = 0.01.

Again, the sample size for stem number is generally much higher than for basal area. Thirty-one plots are just sufficient for an E% level of 10 percent and a probability level of p = 0.05, considering the dbh range ≥ 2 cm. Just as for the basal area, sample size has increased for the dbh range ≥ 5 cm in comparison with 1986 for the same accuracy. However, for the dbh range ≥ 2 cm, sample sizes have remained the same or decreased. In contrast to the 1986 inventory, measuring trees with dbh ≥ 5 cm requires a supplementary surface ranging from 0.5 to 5.8 percent of the total surface in comparison with trees with dbh ≥ 2 cm.

DISCUSSION

To obtain an accuracy level or interval of 5 percent of the mean basal area, a sample size of about 15 to 19 percent of the total surface of this particular forest reserve is needed (p = 0.05). Such an accuracy level is usually accepted and striven for (Zöhrer 1980). These plot densities seem to be higher than those that are commonly used in The Netherlands (10 percent) (Stuurman and Clement 1993) and most German states (10 to 12.6 percent) (Albrecht 1990, Althoff 1993), but are still meaningful for application. However, for the mean stem number and the same accuracy and probability level, sample size increases to an unpractical level of about half of the total surface. Even if the accuracy level is lowered to 10 percent, still more than 15 to 20 percent of the total surface needs to be inventoried. Kölling and Otter (1987) found a similar difference between both parameters concerning sample size (table 3).

Considering a sample size of around 5 percent, comparable accuracy levels of 20 percent for the mean stem number were found for both dbh ranges and inventory periods (p = 0.05) (tables 1 and 2). Also, for the mean basal area, a sample size of around 5 percent led to almost

Table 3.—*Accuracy level (E%) for the mean basal area and the mean stem number in function of sample size, considering a probability level of p = 0.05 (Kölling and Otter 1987)*

Sample size	Accuracy level (E%) Basal area	Stem number
Percent of total surface	*Percent*	*Percent*
4.0	9	24
5.8	9	21
10.2	5	19

the same accuracy level of 10 percent for both dbh ranges and inventory periods (p = 0.05). On the other hand, raising the accuracy level to 5 percent resulted in a sample size of ± 1.5 to 2.0 times that found by Kölling and Otter (1987). The fact that the sample size for stem number is systematically higher than that for basal area may also have an ecological background. Young trees have a much higher influence on stem number than on basal area. The latter is mainly determined by mature and older trees and is less sensitive for young trees. The occurrence of young trees can be very variable due to dynamic processes in the forest ecosystem. This spatial variability, combined with the different sensitivity of both parameters for young trees, is reflected in the coefficient of variation, which is systematically higher for stem number than for basal area. Because the coefficient of variation is a principal component in formula (1), the same difference is expressed in the required sample size.

In general, doubling the accuracy level from 10 to 5 percent for the basal area and from 20 to 10 percent for the stem number increases the required sample size ± 3.5 times, for the same probability level. This practically confirms the general conclusion of Zöhrer (1980), who states that by quadrupling the sampled area the accuracy will be doubled. This conclusion is inherent to formula (1) and indicates homogeneity of the stand for a certain parameter (s% becomes very small so that factor 1/(E%)2 is the most influential). On the other hand though, doubling the accuracy level from 10 to 5 percent for the stem number increases plot density only ± 2.5 times, contradicting the homogeneity presumption.

Except for data set 3, the required sample size is systematically higher in 1996 than in 1986 (tables 1 and 2). This evolution is probably explained by the natural development of the forest ecosystem from a rather homogeneous regeneration phase to a more varied and complex forest structure and composition. This development is reflected in a higher coefficient of variation and thus in a higher required sample size.

CONCLUSION

The required sample size for achieving a certain desired accuracy or precision is very much dependent on the considered parameter, in this case basal area and stem number. This study indicates that specification of the parameter is necessary when dealing with representativeness and that generalization needs to be avoided. For these two parameters, it appears to be questionable that a representative image of the forest reserve can be obtained by sampling only 5 to 15 percent of the total surface. Even for this young forest, characterized by its large stem number of more than 1,000 trees per hectare, the necessary sample size is fairly high, especially considering the parameter stem number. Therefore, it can be expected that by applying such plot densities in forest reserves with a far lower stem number, this conclusion will be even more distinct. Moreover, due to dynamic processes of decreasing and increasing stem number and basal area, necessary sample size changes in time, which implies that a fixed number of plots always holds the risk not to meet the requirement of representativeness. The evaluation of the representativeness of each measured parameter after a forest reserve inventory seems to be indispensable. The calculation method applied in this study can serve as a useful tool.

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