

# Tracking Disturbance-induced Changes in Stand Development at Irregular Measurement Intervals in the Järvelja Forest Experiments

ALLAN SIMS<sup>1\*</sup>, AHTO KANGUR<sup>1</sup>, MARIS HORDO<sup>1</sup>, ANDRES KIVISTE<sup>1</sup>, KALEV JÕGISTE<sup>1</sup> AND KLAUS VON GADOW<sup>2</sup>

<sup>1</sup> Institute of Forest and Rural Engineering, Estonian University of Life Sciences, Kreutzwaldi 5, 51014, Tartu, Estonia; \* E-mail: allan.sims@emu.ee; fax +3727313156

<sup>2</sup> Burkhardt Institute, Faculty of Forestry, Georg August University, Büsungenweg 5, D-37077 Göttingen, Germany

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## Abstract

Long-term sample plots have been used to study pathways of succession, and its mechanisms and causes. These observations are relevant not only to communities protected from human interference, but also to managed forests, where the objective is to explain response patterns following specific harvesting operations. The establishment and maintenance of a series of permanent plots requires a firm commitment beyond short-term economic fluctuations and political changes; nevertheless, such long-term experiments may be abandoned prematurely because of a lack of funding or changing policies. One aspect which has received little attention in the past is the “revival” of previously abandoned field plots. This paper analyses data from the Järvelja long-term forest experimental field plots which were abandoned in 1959 and “revived” in 1995 and 2004. This study distinguishes between two kinds of disturbance: natural and anthropogenic. The impacts of both kinds of disturbance are evaluated in terms of weight (quantity of biomass) and type (relative size of outgoing trees). Finally, the study evaluates density-dependent mortality or *self-thinning* using Reineke’s limiting line and Nilson’s stand sparsity. Our analysis found Nilson’s approach better suited for interpreting the limiting relationship in mixed forests and for estimating maximum density for different stand and site types; therefore, this topic will be pursued in future studies based on the extensive database of the Estonian Forest Research Plots Network.

**Key words:** long-term forest experiments, measurement gap, Reineke’s limiting line, Nilson’s stand sparsity

## Introduction

Sustainable management of forest resources is based on empirical research. The aim of the early field experiments was to measure timber yields at different stages of forest development (Schwappach 1890). Some of these experiments have been re-measured for over a century, even during times of war, providing valuable information on long-term developments. It is often postulated that permanent plots are required in studies of long-term vegetation dynamics (Bakker et al. 1996), which is an especially valid assumption in forest ecosystems with long-living tree communities.

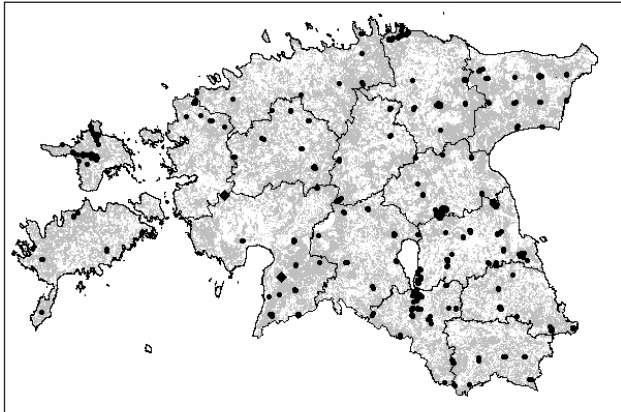
Berry et al. (1998) state that “quick fixes” and “one-time efforts” are not very helpful in ecosystems research. They argue that piecemeal efforts do not provide the required information about long-term response. They provide arguments in favour of a continuous, long-term observational infrastructure sup-

ported by long-term policies, budgets and research perspectives.

The establishment and maintenance of a series of permanent plots requires a firm commitment beyond short-term economic fluctuations and political changes. Nevertheless, it may happen that experiments which were originally designed for long periods of time are prematurely abandoned because of a lack of funding or changing policies.

Today, forest science is based mostly on empirical data, which should be measured systematically. In Estonia, the Network of Estonian Forest Research Plots (Figure 1) was gradually formed during the past 20 years upon the initiative of several Estonian scientists. This network comprises several different long-term forest monitoring, research and experiment series: a) long-term growth and yield study plots in Järvelja (Kangur et al. 2005), b) thinning experiments in Järvelja (Tullus and Reisner 1998), c) a series of long-

term afforestation plots on abandoned oil-shale quarries (Korjus et al. 2007), d) a series of forest restoration experiments, and e) the network of permanent sample plots for forest growth modeling in Estonia (Kiviste and Hordo 2003).



**Figure 1.** Map of Estonia showing the areas covered by forests (Peterson 2003) and locations of research plots

As an example, the Estonian Forest Research Plots Network currently contains 730 continually-re-measured permanent field plots for modelling forest growth. Table 1 shows the distribution of the plots according to site and forest types. The forest type is characterized by the dominant tree species. “Pine”, for example, refers to a forest where *Pinus sylvestris* either occurs as the only species or dominates by total volume. Such an infrastructure is often considered a national asset (Hasenauer 2006).

Examples of forest experiments conducted over more than a century, providing an uninterrupted se-

**Table 1.** Summary of the Estonian Forest Research plots, presented by group of types and dominant tree species (by volume)

Group of types	Pine	Spruce	Birch	Other	Total
<i>Full drained swamp forests</i>	13	11	11	0	35
<i>Meso-eutrophic forests</i>	28	94	12	1	135
<i>Alvar forests</i>	5	2	1	0	8
<i>Heath forests</i>	47	0	0	0	47
<i>Mesotrophic forests</i>	246	32	13	1	292
<i>Dwarf-shrub-sphagnum paludified forests</i>	7	1	0	0	8
<i>Grass fen forests</i>	0	0	7	0	7
<i>Nemoral forests</i>	0	30	54	43	127
<i>Bog moss forests</i>	13	0	0	0	13
<i>Herb-rich mixed forests on wet clay soils</i>	3	21	27	7	58
<b>In total</b>	<b>362</b>	<b>191</b>	<b>125</b>	<b>52</b>	<b>730</b>

ries of observations, are the extensive permanent networks maintained by a number of European forest research institutes (Hasenauer 2006). The extensive databases and data sets of different research series in the Estonian Forest Research Network have already provided scientists with much useful information, which has been presented at international conferences and published in international journals (Sims et al. 2006, Kangur et al. 2007). Nevertheless, the importance of combining data from earlier research series together with currently available materials is of high importance in long-term forest research.

One aspect which has received little attention is the use of previously abandoned field plots: Is it worthwhile to “revive” them and to continue with re-measurements after a long interval of abandonment? Missing data are a part of research. Data may be missing for several reasons, and there are alternative ways of dealing with these information gaps. When a previously abandoned experiment is re-established after a long time, the challenge is to make use of the entire period of observation, including the “observational gap”. In this paper, we will propose ways of estimating the missing data for the entire development of the experimental plots.

Accordingly, the objective of this study is to present examples of such abandoned experiments with an estimate of the disturbance occurrence during the measurement gap and the potential forest density for an experiment with one species and two species. We will then show examples of previously abandoned experiments which have recently been re-measured.

***Long-term experiments with irregular measurement intervals***

Irregular measurement intervals in forest growth studies are quite common. They often occur when previously abandoned field plots are “revived”, i.e. re-measured after long periods of time during which no observations are available. When analysing disturbances for irregular measurement intervals, the observed time interval between re-measurements does not match the desired modelling interval. Thus, modelling annual tree growth and survival based on data with irregular measurement intervals requires specific interpolation of the independent variables during such “measurement gaps”, as demonstrated by Nord-Larsen (2006). Our study is not concerned with tree growth; however, but with recognizing forest disturbances during irregular measurement intervals.

***Reviving old field experiments at Järvselja***

The history of empirical forest research in Estonia can be traced back to the 19th century. Well-de-

signed and -documented field experiments for forest research purposes were begun after the establishment of the Järvelja Forestry Training and Research Centre in 1921 (Mathiesen and Riisberg 1932). The Järvelja experimental forest is located in the South-Eastern region of Estonia near Lake Peipsi (at 58°16'N, 27°18'E).

Among the early long-term forest experimental series in Järvelja are growth and yield experiments initiated by Andres Mathiesen (Kasesalu 2003) and thinning experiments initiated by August Karu and Lembit Muiste (Tullus and Reisner 1998). Long-term forest growth and yield monitoring plots were established between 1922 and 1935. The rectangular experimental plots were relatively small, covering between 400 and 600 m<sup>2</sup>. The small plot size was offset by a high number of replicates in the same stand. The experimental sites were selected such that all forest sites and dominant tree species in the Järvelja region were represented. The basic stand parameters were measured and trees on the plots were numbered.

Originally, re-measurement intervals in the experimental areas were planned to range between five to ten years. However, because these areas were used in the field training of forestry students, they were re-measured more frequently during the first decade. The measurement data were stored in handwritten data journals and experiment case files. The last of these handwritten records dates back to 1959. Some of the plots were re-measured in 1977, 1984, and 1995, but for the majority of the growth and yield plots, no measurements were done between 1959 and 2004.

During the late 1990's, it was decided to systematically "revive" the old field plots, most of which had been abandoned in 1959. Altogether, 65 previously abandoned plots which were recently "revived" and re-enumerated after almost 50 years without re-measurements. The distribution of these plots over the different site types and for the different forest types, characterized by the dominant species as in Table 1, is presented in Table 2.

The first step involved the transformation of the old handwritten entries into a digital format, which was necessary for statistical analysis and for storing the

**Table 2.** Summary of 65 Järvelja Research plots, presented by group of types and dominant tree species

Group of types	Pine	Spruce	Birch	Other	Total
<i>Fully drained swamp forests</i>	5		1		6
<i>Meso-eutrophic forests</i>	6	4	1		11
<i>Mesotrophic forests</i>	22	13	1		36
<i>Nemoral forests</i>		2	2	3	7
<i>Bog moss forests</i>	5				5
In total	38	19	5	3	65

data in the multinational database, the Northern European Database of Long-Term Forest Experiments (NOLTFOX).

When analyzing and exploiting old data series like the one described above, one must be aware of possible constraints induced by uncertainties and inconsistencies in measuring and data recording. These inconsistencies can be classified according to the following categories:

1) *Changes in experimental design and measurement prescription.* During long period of observation, governmental policies and general research funding principles may change, which can have severe effects on financing, including termination, of ongoing long-term study projects. Old experimental designs sometimes cannot meet the demands of new research objectives, so new measurement prescriptions may be necessary. In Järvelja during the early years, the main focus was on compiling stand diameter distributions. Only a few tree heights were measured. However, soon a demand for yield tables arose, requiring tree heights for volume calculations. Subsequently, tree mapping was introduced in order to study forest spatial structures.

2) *High variability in measuring staff and assessment techniques.* Over long measurement periods different people are responsible for carrying out the fieldwork. The measurement accuracy within these series of consecutive enumerations may vary substantially due to changing staff. Furthermore, different measuring devices have been used over extended observation periods. In the early measurement years, tree heights were often measured using a theodolite. At the same time the heights of all the removed trees (representing the suppressed part of the plot) were measured with a measuring tape. These different methodologies could result in two different height-diameter relations.

3) *Changes in data recording and storing.* The biggest change in data recording was the replacement of the old handwritten experimental case files to digital data recording. During data conversion and digitizing it is possible to generate errors due to typing and misinterpretation of certain remarks in the old books. To minimize the likelihood of this type of error, special care was taken in the digitizing of the Järvelja experimental data. Outliers especially were double-checked (Hordo 2004). Nevertheless, some uncertainties still remain.

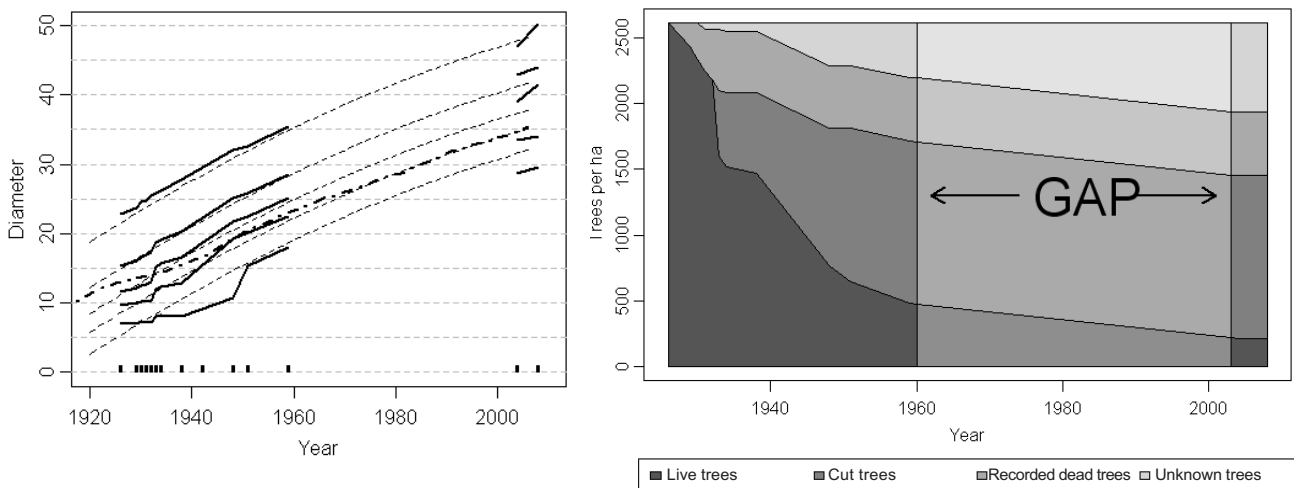
### *Recognizing disturbances*

In the context of this study, we distinguish between two kinds of disturbance. "Natural disturbance" refer to the number of trees which were found dead at

the end of a particular measurement interval. “Anthropogenic disturbance” refers to the trees removed during a thinning operation at the beginning of a measurement interval. Figure 2 shows a typical example of a research plot which had been measured during irregular time intervals between 1926 and 1959. The shortest interval between two successive measurements was one year. The longest interval, labelled “GAP”, where data are not available during the period between 1959 and 2004, was 45 years. The measurement years in Figure 2 are indicated by black dots just below the x-axis. The graph on the left presents the quartile lines of the diameter distribution and thus shows how the forest structure has changed during the past 82 years. A pine tree which in 1895 had reached breast height (1.3 m) was cut in 2006 for stem analysis to recover the complete history of diameter and height growth. In 1920, the tree belonged to the 75% quartile of the diameter distribution. In 2006 it was in the 25% quartile of the diameter distribution.

In Estonia, forest management activities are recorded in forest management plans, which provide an opportunity to recover some disturbance events. During the gap period, only sanitary cuttings were carried out in the stand, in 1974, 1976, 1977, 1980, 1996 and 1999. These cuttings removed only dead trees, but we do not know when these trees died and how many had died in a certain year. We also have no knowledge about the dimensions of the dead trees during the gap period. We know the number of trees that went missing during the gap interval and that the removed trees were not alive when cut.

For every re-measurement we calculated the accumulated number of trees cut and dead  $cNx_t = \sum_{i=1}^t Nx_i$ , where  $cNx_t$  refers to the accumulated number of trees separately for each cut ( $x=$ cut) and dead ( $x=$ dead) trees at enumeration period  $t$ ,  $Nx_i$  is number of trees at enumeration period  $i$ ;  $t$  is measurement interval (years). The number of unknown trees for a particular tree species is obtained from the initial total number of



**Figure 2.** Empirical (solid lines) and predicted/smoothed (dashed lines) quartiles of diameter distribution over time for research plot M046\_11\_01 (left). The stem analysis for one pine tree is presented as a dash-dot line. The plot had been measured during irregular time intervals between 1926 and 1959, and again in 2004 and 2008 (black spots at the bottom line; the measurement years are shown in Table 3). The development of live trees and cumulative outgoing trees are shown in the graph on the right

The right-hand graph on Figure 2 shows the development of the live trees and the accumulated number of outgoing trees per ha during the 82-year observation period. At every enumeration all trees were measured, including dead snags. When trying to analyse dead trees for the entire 82-year period, during the gap period, only the number of dead trees is known, not their size distribution. Therefore, we need to distinguish between the dead trees that were recorded before 1960 and after 2004, and those that died during the gap period.

trees of that species minus the cut, recorded dead and live trees. For this plot no measurements are available between 1959 and 2004. Re-measurements started again in 2004, after a “gap” of 45 years. Relevant details about the available natural and anthropogenic disturbances are listed in Table 3.

The weight of a disturbance may be described by the ratio between removed and total basal area. We designate this variable using the symbol  $rG$ . The preference of a disturbance refers to the relative tree size removed from the population. Murray and Gadow

**Table 3.** Details about the natural and anthropogenic disturbances in research plot M046\_11\_01

Year	Area (ha)	Number of trees per ha			Basal area m <sup>2</sup> per ha			Cumul. trees per ha				
		live	cut	dead	live	cut	dead	rG	NG	unknown	cut	dead
1	2	3	4	5	5	7	8	9	10	11	12	13
1926	0.06	2617			35.65			0.00	0.00			
1929	0.06	2433		183	36.97		1.54	0.04	1.75	1		183
1930	0.06	2333		100	37.54		1.21	0.03	1.32	1		283
1931	0.06	2250		33	37.22		0.22	0.01	2.46	51		316
1932	0.06	2183		67	37.33		0.50	0.01	2.25	51		383
1933	0.06	1600	500	83	32.70	4.56	0.78	0.14	1.90	51	500	466
1934	0.06	1517	67		32.48	0.99		0.03	1.43	67	567	466
1938	0.06	1467	50		35.14	0.36		0.01	3.25	67	617	466
1942	0.06		433			6.87		0.00	0.00		1050	
1948	0.06	767			30.13			0.00	0.00	1050	1050	466
1951	0.06	650	117		28.24	3.27		0.10	1.47	1167	1167	466
1959	0.06	483	67	17	25.47	2.19	0.36	0.09	1.63	1234	1234	483
2004	0.06	217			25.13			0.00	0.00	1234	1234	483
2008	0.06	217			27.92			0.00	0.00	1234	1234	483

(1991) used the difference between the mean diameters of the removed and the remaining trees, divided by the diameter standard deviation of the whole stand to describe the type of thinning. In this study, we are using the so-called NG ratio, which is defined as follows:

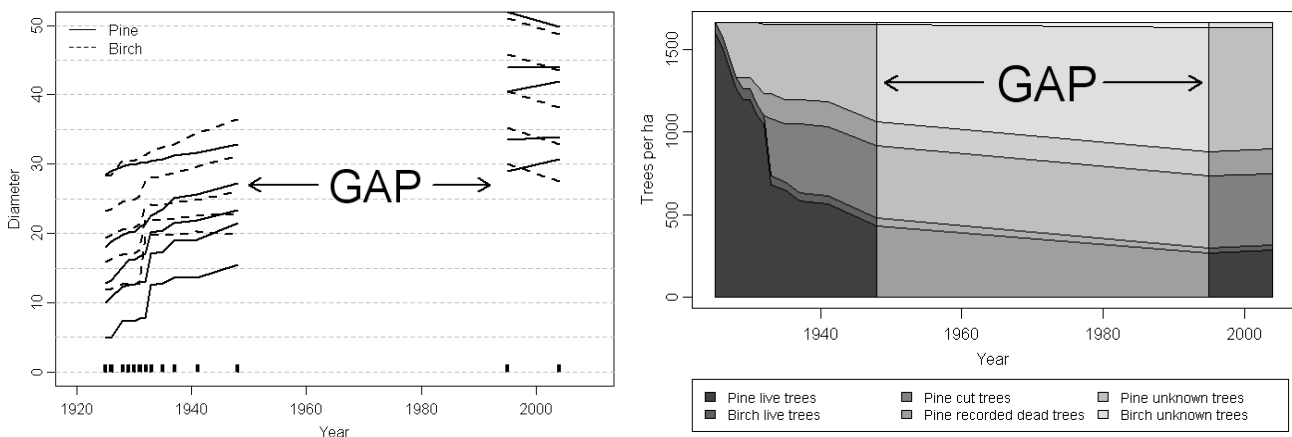
$$NG = \frac{rN}{rG} = \frac{N_{thin} / N_{tot}}{G_{thin} / G_{tot}} \quad (1)$$

where  $N_{thin}$  and  $N_{tot}$  are removed and total stem number, respectively;  $G_{thin}$  and  $G_{tot}$  are removed and total basal area, respectively. The values for rG and NG for the different measurement years are shown in columns 9 and 10 of Table 3. Evidently, the thinnings were usually weak to moderate, ranging from 1 to 14 percent of basal area removed. The NG-ratio varied between 1.32 and 3.25, indicating very low thinnings.

We also recovered disturbances for an experiment involving a mixed forest with two tree species. Figure 3 shows two graphs which correspond with pure pine plot data presented in Figure 2. The two tree species are *Betula pendula* (denoted Birch in Table 4) and *Pinus sylvestris* (denoted Pine in Table 4).

The graph shows that initially the birch was dominant, which is quite common in a Pine/Birch community. After 79 years of observation, birch has lost its dominance, and both distributions are similar.

Table 4 presents relevant details of a representative plot with two species. The number of birch trees was reduced to about one half of the original number during the 79-year observation period. The number of pine trees decreased from 1600 per ha in 1925 to 283 per ha in 2004. Only 17 percent of the pines survived during the observation period.



**Figure 3.** Development of the four quartiles of the diameter distribution of pine and birch for research plot M274\_04\_02 (left) and development of outgoing trees (right). The plot had been measured (spots at bottom) during irregular time intervals between 1926 and 1959, and again in 2004 and 2008

**Table 4.** Details about the natural and anthropogenic disturbances in research plot M274\_04\_02

Year	Area (ha)	Species	Number of trees (per ha)			Basal area (m <sup>2</sup> per ha)			rG	NG	Cumul. trees per ha		
			live	cut	dead	live	cut	dead			unknown	cut	dead
1	2	3	4	5	5	7	8	9	10	11	12	13	14
1925	0.06	Pine	1600			28.47			0.000	0.000			
1926	0.06	Pine	1517			29.04			0.000	0.000	83		
1928	0.06	Pine	1267			28.47			0.000	0.000	333		
1929	0.06	Pine	1200		67	28.34		0.57	0.020	2.658	333		67
1930	0.06	Pine	1200			28.34			0.000	0.000	333		67
1931	0.06	Pine	1100		50	28.10		0.53	0.018	2.364	383		117
1932	0.06	Pine	1050		17	27.63		0.24	0.009	1.799	417		133
1933	0.06	Pine	683	350	17	22.67	5.48	0.08	0.197	1.773	417	350	150
1935	0.06	Pine	650			22.57			0.000	0.000	450	350	150
1937	0.06	Pine	583	67		22.96	1.35		0.056	1.842	450	417	150
1941	0.06	Pine	567			23.00			0.000	0.000	467	417	150
1948	0.06	Pine	433	17		20.61	1.19		0.055	0.676	583	434	150
1995	0.06	Pine	267			33.19			0.000	0.000	750	434	150
2004	0.06	Pine	283			36.47			0.000	0.000	733	434	150
1925	0.06	Birch	67			2.23			0.000	0.000			
1926	0.06	Birch	67			2.29			0.000	0.000			
1928	0.06	Birch	67			2.54			0.000	0.000			
1929	0.06	Birch	67			2.56			0.000	0.000			
1930	0.06	Birch	67			2.56			0.000	0.000			
1931	0.06	Birch	67			2.68			0.000	0.000			
1932	0.06	Birch	50			2.54			0.000	0.000	17		
1933	0.06	Birch	50			2.61			0.000	0.000	17		
1935	0.06	Birch	50			2.65			0.000	0.000	17		
1937	0.06	Birch	50			2.71			0.000	0.000	17		
1941	0.06	Birch	50			2.90			0.000	0.000	17		
1948	0.06	Birch	50			3.13			0.000	0.000	17		
1995	0.06	Birch	33			4.58			0.000	0.000	33		
2004	0.06	Birch	33			4.11			0.000	0.000	33		

The basal areas has been increasing due to tree growth and decreasing due to mortality and mortality-preemptive removal of some small trees that were still alive but were expected to die in the immediate future. Therefore, the values of rG and NG can be evaluated only during a particular harvest event, i.e. if we can identify the trees which were leaving the system during a specific measurement interval. The calculation scheme is described by the example with one species (Table 3) and will not be repeated here.

**Stand density in long-term experiments**

Populations of trees growing at high densities are subject to density-dependent mortality or *self-thinning* (Mohler et al. 1978). For a given average tree size, there is a limit to the number of trees per hectare that may co-exist in an even-aged stand (Nilson 2006). This limiting relationship is site- and species-specific, and the topic is highly relevant to research dealing with natural disturbances. Estimating the potential density of forest stands is one of the most difficult problems to

solve, mainly because data from untreated, fully-stocked stands, such as the previously abandoned plots in Järvselja, are very rare. We analyse the potential density using two approaches, the conventional limiting relationship and Nilson’s stand sparsity.

**Reineke’s limiting line**

The relationship between the average tree size (increasing over time) and the number of live trees per unit area (declining over time) may be described by means of a so-called limiting line. A convenient model for this limiting relationship was used by Reineke (1933):

$$N_{max} = \alpha_0 Dg^{\alpha_1} \tag{2}$$

where  $N_{max}$  is maximum number of surviving trees per ha,  $Dg$  is quadratic mean diameter,  $\alpha_0$  and  $\alpha_1$  are empirical parameters.

The parameters of eq (2), which in its logarithmic form is linear, can be obtained from fully stocked, unthinned trials, such as the spruce growth series estab-



lished in Denmark (Skovsgaard 1997, p. 97 et sqq.) or the *Correlated Curve Trend* (CCT) series of growth experiments established by O'Connor (1935) in South Africa (refer to Gadow 1987, for a description of the CCT experiments and examples of Reineke's limiting line fitted to the data from unthinned CCT experiments).

**Nilson's stand sparsity**

In the case of a regular spatial distribution of the trees within a forest, the average distance between the trees may be estimated by the square root of 10 000 (the square metres in one hectare) divided by the number of trees per ha. Nilson (1973) thus defined *L*, the *stand sparsity* or distance between regularly placed trees as follows

$$L = \frac{100}{\sqrt{N}} \tag{3}$$

where *N* is the number of trees per hectare. For a triangular placement of trees the corresponding formula would be

$$L = \frac{200}{\sqrt{3 \cdot N}} \tag{4}$$

Nilson (2006; see also Hilmi 1957) argues that the most simple and logical relation is expected between variables of the same dimension, which is not the case in eq (2), but is the case in eq (3). Therefore, Nilson (1973) proposed to estimate the potential density using the following relationship

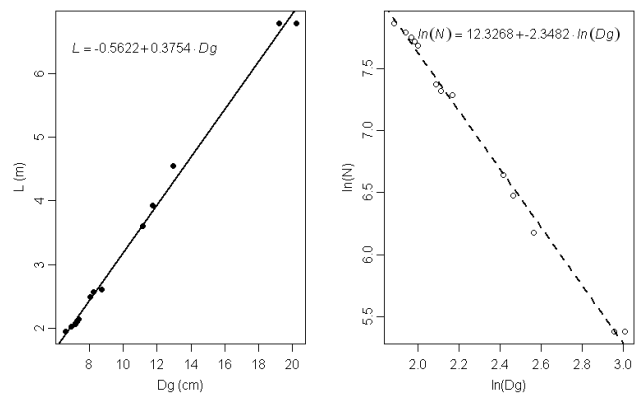
$$L = a + b \cdot Dg \tag{5}$$

where *L* is the stand sparsity, and *Dg* is the mean squared diameter of the trees in a stand; *a* and *b* are empirical parameters.

**Estimating potential density**

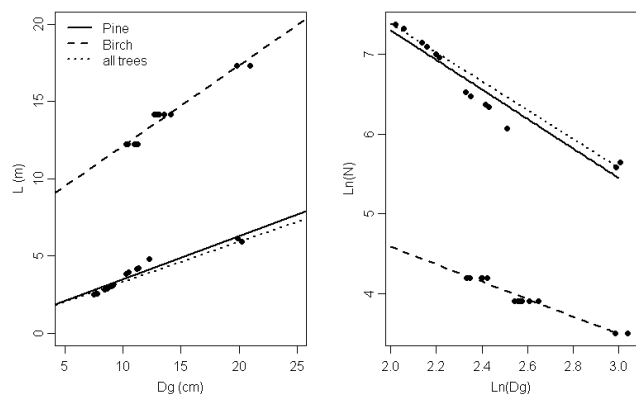
Considering the high cost of maintaining a series of unthinned, densely-stocked stands, such data are usually not available. To overcome this deficiency, various indirect methods have to be used to estimate the limiting line. Gadow and Hui (1993) compared different methods for estimating potential density for unthinned stands of *Cunninghamia lanceolata* from the southern region of China, including the approaches used by Goulding (1972), Sterba (1975) and Clutter and Jones (1980).

We do not need such sophisticated estimation techniques because our long-term experiments had reached the limiting density. No live trees had been removed in the plots during the period 1926 to 1932 and again during the last 49 years (only the very smallest were harvested pre-emptively, i.e. assuming that they would die anyway). Figure 4 shows the estimated limiting relation for plot *M046\_11\_01*, – pure pines stand in a Mesotrophic forest.



**Figure 4.** Nilson's Stand Sparsity estimated using eq (3, left) and Limiting Line eq (2, right) for plot M046\_11\_01

The corresponding analysis for the Pine/Birch experiment *M274\_04\_02* is presented in Figure 5. It is interesting to note the differences in the slopes and intercepts of the limiting relationships for pine and birch, given the specific relative proportions of tree numbers during the entire measurement period. In 1925, there were 67 birch and 1600 pine trees per ha. Thus four percent of the trees were birch and 96 percent pine. In 2004, ten percent of the trees were birch.



**Figure 5.** Nilson's Stand Sparsity estimated using eq (3, left) and Limiting Line eq (2, right) separately fitted for birch and pine trees in plot M274\_04\_02

Birch and pine are both light-demanding species and their shade tolerance decreases rapidly growing out of the seedling stage. At the beginning of the plot enumeration, the diameter distributions in Figure 3 show that the birch trees were dominant. This effect can also be seen in the early *Dg*-values of pine and birch in the left graph of Figure 5. Later on, after reaching a *Dg* of more than 20 cm, the mean diameters of pine and birch trees are almost equal. This result is not (only) due to growth, but mainly due to higher mortality of the pines in the lower ranges of the diameter distribution.

The slope parameter values of the stand sparsity line are indicative of the mortality rates for a given increase in Dg. The values in Figure 5 are 0.28 for pine and 0.52 for birch, and 0.26 for the whole population. The slope for pine slightly exceeds the slope for the whole stand. This implies a higher pine mortality rate per unit of Dg increase. The beauty of Nilson's stand sparsity, in contrast to the widely used Reineke line, is that it allows such clear, easily understood interpretations.

### Discussion and conclusions

Pickett et al. (1987) distinguish between pathways, causes and mechanisms of vegetation change in order to explain the dynamics of succession. They define a pathway as a temporal pattern of vegetation change and a cause as an agent, circumstance or action responsible for successional patterns. Permanent field plots can provide observations about pathways of succession, but may also generate hypotheses on mechanisms and causes. This is especially relevant if the communities are protected from human interference, but is also valid in managed forests where the objective is to explain particular response patterns following specific harvesting operations.

In this study, we defined the problem of analyzing disturbances for irregular measurement interval within the general context of forest research in Estonia. We presented examples of previously abandoned experiments which have recently been re-measured, and proposed a method which can be used to estimate historical disturbances on a specific field plot and during a particular measurement gap.

Considering the enormous investment and its usefulness for environmental research, the national importance and scientific relevance of the Estonian Forest Research database is evident. Valuable observations have been diligently collected by several generations of scientists, providing information about forest structure (Mathiesen and Riisberg 1932, Tullus and Reisner 1998, Kangur et al. 2007), disturbances and ecosystem dynamics in the different forest types (Kiviste et al. 2005). The maintenance of such a key database is considered to be of national importance in most countries today (Sims et al. 2006).

The history of empirical forest research in Estonia began with the establishment of well-designed and documented field experiments in the Järvelja Forestry Training and Research Centre in 1921. Among the early long-term forest experimental series in Järvelja are growth and yield experiments established by Andres Mathiesen between 1922 and 1935 (Kasesalu 2003). The measurement data were stored in handwritten data journals and experiment case files. The last of these

handwritten records dates back to 1959. During the late 1990's it was decided to systematically "revive" the old field plots most of which had been abandoned in 1959. This study has shown ways to analyze human and natural disturbances for specific measurement intervals using variables which allow interpretation of the weight of the disturbance as well as its type.

We have also been able to show potential densities for a pure pine plot and a mixed pine/birch experiment using the common Reineke line and Nilson's stand sparsity. The slope parameter values of the stand sparsity line are indicative of the mortality rates for a given increase in Dg. This study has shown a higher pine mortality rate per unit of Dg increase in the mixed plot. The advantage of Nilson's stand sparsity, in contrast to the widely used Reineke line, is the fact that both variables have the same unit, which facilitates interpretations.

The natural decline of the number of surviving trees in an unthinned forest is usually characterized by intermittent brief spells of high mortality, followed by long periods of low mortality. The process is not a continuous one (Boardman 1984, Gadov 1987, p. 21). Stochastic models have been used in some cases to mimic these processes. However, for the purpose of simulating alternative silvicultural regimes, it is generally assumed that natural mortality is a continuous process. Based on the analysis in this paper, we are convinced that Nilson's approach is very useful in estimating the maximum density in Estonian forests, for different stand and site types. This topic will be pursued in future studies based on the extensive database of the Estonian Forest Research Plots Network.

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## ИССЛЕДОВАНИЕ ИЗМЕНЕНИЙ В ХОДЕ РОСТА ДРЕВОСТОЕВ ОБУСЛОВЛЕННЫХ НАРУШЕНИЯМИ ЛЕСА НА БАЗЕ НЕРЕГУЛЯРНЫХ ИЗМЕНЕНИЙ ПОСТОЯННЫХ ПРОБНЫХ ПЛОЩАДЕЙ В УЧЕБНО-ОПЫТНОМ ЛЕСНИЧЕСТВЕ ЯРВСЕЛЬЯ

А. Симс, А. Кангур, М. Хордо, А. Кивисте, К. Йыгисте и К. Ф. Гадов

### Резюме

На основе повторных измерений постоянных пробных площадей можно получить информацию о сукцессии леса, а также обосновать гипотезы её механизма и причин. Это относится не только к лесным сообществам, защищенным от человеческого вмешательства, но также и к хозяйственным лесам, где проводится изучение результатов специфических операций пользования лесом.

Закладка постоянных пробных площадей и проведение их долговременных наблюдений требует твердо держаться основной цели исследования в условиях кратковременных экономических колебаний и политических изменений. Однако эксперименты, первоначально разработанные для длительного промежутка времени, могут быть преждевременно оставлены из-за недостаточного финансирования или изменения политики. Одним из аспектов, получившим мало внимания в прошлом, является “возрождение” ранее заброшенных постоянных пробных площадей. В этой работе анализируются данные долговременных лесных экспериментов в учебно-опытном лесничестве Ярвселья, заброшенных в 1950-е годы и „возрожденных“ в 1995 и 2004 годах.

В данном исследовании рассматриваются два вида лесных нарушений: естественное и антропогенное. „Естественное нарушение“ леса обуславливается количеством деревьев, которые были мертвыми к концу определенного интервала времени. „Антропогенное нарушение“ леса обуславливается количеством деревьев, которые были вырублены в течение данного интервала времени. Величины обоих видов воздействия на лес оценивались исходя из количества биомассы и относительных размеров отпадающих деревьев. Наконец, в данной работе гибель при предельной густоте (самоизреживание) анализируется по закономерностям, установленным Рейнке и Нильсоном. По данным этой работы, подход Нильсона является более предпочтительным для интерпретации зависимости самоизреживания в смешанных лесах и для оценки максимальной густоты для разных древостоев и условий местопроизрастания.

**Ключевые слова:** долговременные лесные опыты, разрыв между измерениями, линия самоизреживания по Рейнке, редкость древостоя по Нильсону