Production of Even-Sized Hybrid Aspen Plants from Root Cuttings: Transplanting, Height Grading and Planting Dates

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Abstract

At present in Finnish nurseries, hybrid aspens are reproduced from root cuttings by transplanting the sprouted cuttings to the large plugs (trays with 380-400 cm^3 cell volume). Sprouting time of cuttings varies within and between clones a lot. This causes problems in the production of aspen plants: the large height variation within a plant batch in nurseries and the high proportion of short plants (with minimum height of 40 cm). To produce more even-sized batches, plants were graded into height categories twice: first when transplanted them into small plugs and then into larger plugs. This procedure reduced the variation in the final height of graded batches in comparison with the batches transplanted directly into the large-volume containers. The variation in the height of hybrid aspens did not exceed the variation in a reference silver birch batch, however. The use of short plants for plug-to-plug transplanting changed the growth rhythm of the plants, resulting in later cessation of the height growth. One solution to the problems is to plant hybrid aspens in summer at the time of plug-to-plug transplanting. The height growth of these plants increased and the shoot tip dieback inhibited in comparison with plants that were grown for a longer period in the nursery, frozen-stored and then planted in the spring or early summer of the following year.

Keywords: grading, height, hybrid aspen, planting, *Populus,* root cutting

Introduction

In the course of the last decade, the paper industry has shown an interest in using hybrid aspens (*Populus tremula* L. × *Populus tremuloides* Michx.) for paper manufacturing. Hybrid aspens are produced both from seeds and vegetatively, but vegetative reproduction is preferred since e.g. clonal plants remain unchanged from generation to generation. Hybrid aspens are produced vegetatively by micropropagation and shoot cuttings, but the most efficient method is to raise the new generation from root cuttings.

In Finland, silver birch (*Betula pendula* Roth) has been produced in containers for the last 30 years. Nursery growing practices for silver birch have improved greatly over the years and it is now possible to raise seedlings that are quite uniform in height. The situation is less advanced for hybrid aspen. It is important that similar improvements to those made with birch should be achieved with aspen.

To reproduce hybrid aspens by means of root cuttings, Stenvall *et al*. (2004) described the operational practice used in Finnish nurseries at present. First, 2-10 mm thick roots of 2-year-old stock plants are cut into pieces 3-4 cm in length. The cuttings are then planted horizontally into flats or plastic containers (e.g. trays with 110-115 cm^3 cell volume) filled with a peat-sand mixture. The root-cutting flats or containers are kept in a heated greenhouse with regular irrigation until the cuttings have sprouted. When sprouted cuttings are about 1-10 cm in height, they are transplanted into larger-volume plastic containers (e.g. trays with 380-400 cm^3 cell volume), in which the plants are raised until the end of the growing-season (about 4 months). Both between and within the clones there is a large variation in the sprouting time, *i.e*. the time needed to develop shoots from cuttings (Stenvall *et al*. 2004). If all of the sprouted cuttings are transplanted at the same time into the final growing containers, the transplants will have varying sizes, a factor which frequently causes problems for the growing of plants in nurseries. The varying sizes of the plant material within a tray and between trays make proper irrigation and fertilization difficult. Plants have to be irrigated and fertilized based on the needs of the tallest plants, with the result that shorter ones receive an excessive amount of water or nutrients, which can disturb their development. In some cases, taller plants shade and intercept the irrigation water, thus adversely affecting the growth of the smaller plants (Landis 1989). The height variation within a batch at the end of the growing-season is often large, thus they need to be graded before dispatch for field planting. Based on recommendations made for silver birch seedlings, the minimum size of spring-planted aspens raised in 350-380 cm^3 plugs is 40 cm (Rikala 2002). Shorter plants have to be culled. Thus, there is a need to establish a technical procedure for producing uniform 'target'-sized hybrid aspen in the nursery.

Conventionally, aspens, like all other tree seedlings in Finland, are planted during a short period in May. The optimum size of spring planted dormant broadleaf seedlings is 40-70 cm, and they are raised in 350-380 cm^3 plugs (Rikala 2002). Recently, however, it has been shown that container seedlings of both silver birch (Luoranen *et al*. 2003) and hybrid aspen (unpublished result of Luoranen) can be planted during the summer, when the plants are short, leaf-bearing and actively growing, with no reduction in their survival or growth after planting. The growth of summer-planted seedlings is often even better than that achieved by spring-planted tall seedlings probably because soil temperatures are more favorable for root growth and because of new root growth is not restricted (Luoranen *et al*. 2003). The threshold soil temperature for root initiation is 8-13 ˚C in conifers in Finland (Vapaavuori *et al*. 1992, Iivonen *et al*. 1999). In Central Finland, soil temperatures attain these temperatures by mid-June (Luoranen *et al*. 2003), about one month after the time of spring planting. Many of the vegetatively propagated hybrid aspen plants produced by spring planting time are too short for field planting. However, it may be possible to continue growing of these plants in the nursery for planting the following spring and early-summer, thus increasing the number of target dimension plants that can be dispatched to the field.

The aim of this study was to develop new cultural practices that might lead to a reduction in height variation in plants of hybrid aspen, similar to the achievements made in reference silver birch. It was hypothesized that it would be possible to achieve this aim by varying the timing of transplanting of the sprouted cuttings and by grading the height of plant material at the time of plug-to-plug transplanting. In addition, the study attempted to determine if it would be possible to increase the number of plants dispatched by planting them either (i) in summer at the time of plug-to-plug transplanting (referred to below as SUMMER1), (ii) in the following spring when the plants would be leafless and dormant (SPRING), or (iii) in the following summer after a short growing period in the nursery, when the plants would be actively growing (SUMMER2).

Materials and methods

Plant production. These experiments were carried out at the Suonenjoki Research Station of the Finnish Forest Research Institute (62˚39'N, 27˚03'E, 142 m asl) in the summers of 2002-2004. During the production and summer planting season, the monthly mean daily temperatures were 11 (30-year average 9), 16 (14), 18 (17), 17 (14) and 9 (9) ˚C and the monthly precipitation 32 (38), 105 (68), 73 (84), 48 (80) and 36 (58) mm per month in May, June, July, August and September 2002, respectively. The temperature sum that accumulated during the 2002 growing season was 1458 (1220) d.d. The monthly mean daily temperatures during summer 2003, the summer that most affected the field performance of the plants, were 10, 12, 20, 14 and 10 ˚C and the monthly precipitation was 56, 72, 68, 81 and 28 m per month in May, June, July, August and September, respectively. The first autumn frost occurred on 20 September 2002 and 3 September 2002 and 2003, respectively.

Three hybrid aspen (*Populus tremula* L. × *Populus tremuloides* Michx.) clones, A, B and C, were selected for the experiment. The maternal parent of clones B and C belonged to *P. tremula* and originated in Finland (latitudes 57-60˚N), while their *P. tremuloides* parental parent trees were from Canada (latitudes 45-78˚N). The maternal parent of clone A was *P. tremuloides* from Sweden (57˚N) and its parental parent was *P. tremula* from Finland (60˚N). The 2-year-old stock plants that were grown in a field with mixture of sandy soil and peat were used.

In May 2002 the roots of the stock plants were washed, and roots with a diameter of ≥ 2 mm were cut into pieces 3 cm long. The root cuttings were set horizontally in plastic flats (59 cm × 22 cm × 6 cm) filled with a 3-4 cm layer consisting of a mixture of sieved sand and sphagnum peat (Kekkilän turvehiekkaseos, von Post 1-3, N:P:K 120:40:200 mg l^{-1} in expressed extract, Kekkilä Oyj, Finland). Due to the limited number of workers, cutting and planting of cuttings took several weeks. Table 1 presents planting dates of cuttings in the flats. To keep the humidity conditions constant, the flats containing the cuttings were covered with double polypropylene gauze. Due to the space constraints plants had to be grown under different places with different environmental conditions. The flats containing clones A and C were kept in three growth chambers (photoperiod (PP) 16 hours, temperature (T) 20 ˚C, relative humidity (RH) 80%) and the flats with clone B were kept in a heated greenhouse (PP 16 hours, T 23 ˚C and RH 46%), and the cuttings were watered daily with tap water.

Sprouting and rooting times of cuttings varied a lot. The cuttings have to be transplanted before rooting. Thus, it was needed several transplanting times. The dates (presented in Table 1), when transplantings were made, were decided when certain cumulative proportions of cuttings were sprouted (10%, 40%, 70% for first, second and third transplanting, respectively) and the height of them was at maximum of 3 cm. To reduce the within-tray variation, the cuttings were transplanted from the flats into plastic Plantek-64 (referred to hereafter as PL64, 64 cells per tray, 115 cm^3 per cell, 432 cells per m^2, Lännen Tehtaat, Finland) and to compare them to conventional production procedure a part of cuttings were transplanted into Plantek-25 (PL25, 25 cells per tray, 380 cm^3 per cell, 156 cells per m^2, Lännen Tehtaat, Finland) trays filled with fertilized sphagnum peat (von Post 1-3, N:P:K 120:90:150 mg l^{-1} in expressed extract, Kekkilä Oyj, Finland). Table 1 presents the total number of cuttings transplanted on each date. The trays were moved to an unheated greenhouse, where they were retained until the next phase of production procedure.

aphids with Decis 25 EC® as 0.05% liquid solution (deltamethrin 25 g l^{-1}, Berner Oy, Finland).

The reference silver birch seedling batch (4000 trays) was produced in the research nursery at Suonenjoki as described by Juntunen *et al*. (2002).

Measurements in the nursery. After planting, the sprouting of the planted cuttings was monitored weekly until mid- June. A cutting was considered to have sprouted when it had one or more visible leaves.

The height of the plants was measured to nearest 1 cm at weekly intervals after transplanting until 9th September based on a sample of plants from each clone and batch. The cessation of height growth for an individual plant was defined as the date at which it achieved 95% of its height growth. For each plant batch this was taken as a date by which 90% of the plants had ceased height growth. At the end of September 2002 the final height of all of plants in the trays used to estimate date of growth cessation was measured.

To get sample size about the same proportion of a batch, sampling approach was the following: if the number of trays in a group was more than 10, then 8 plants from every third tray were randomly selected; when the number of trays was between 5 and 10, 12 plants were selected from every second tray; and when there were fewer than five trays, all of the plants were selected to measurement.

Table 1. Planting dates of cuttings, number of planted and sprouted cuttings of hybrid aspen and plants transplanted either into Plantek-25 (PL25) or Plantek-64 (PL64) trays in the first (I), second (II) and third (III) transplanting times for each clone

	Planting dates of			Transplanting date					
				I 20 – 22 May		II 25 May – 3 June		III 10 -11 June	
Clone	cuttings	Cuttings	Sprouted	PL25	PL64	PL25	PL64	PL25	PL64
A	6 – 13 May	7748	4881	50	576	1150	1664	225	1216
B	13 – 15 May	2322	2061			250	576	275	960
C	29 Apr – 6 May	7981	4704	100	1664	375	1344	325	896

In the next phase, to reduce the variation of hybrid aspen batches, the plants raised in the PL64 trays were transplanted a second time into PL25 trays on 21 June, 27 June-1 July and 1-2 July for the first (I), second (II) and third (III) transplanting date, respectively. In this phase the tallest plants within the batch were approximately 21-25 cm. During the plug-to-plug transplanting the plants representing each clone were graded into three groups according to their height, as shown in Figure 1. After transplanting, the aspens were kept for about a week in the greenhouse, after which they were then moved outdoors. There they were irrigated regularly and fertilized with liquid fertilizer (Kekkilän Taimi-superex, water-soluble N:P:K 19:4:20, Kekkilä Oyj, Eurajoki) on four occasions. On 25 July the aspens were sprayed against

From silver birch batch, randomly selected 10 seedlings from 20 randomized trays were measured weekly intervals from pricking to the mid-September 2002. Height growth cessation was determined similarly as for aspen batches.

Planting experiment. The hybrid aspens of clone A and C were planted in a field (fine-sandy soil) experiment at Suonenjoki Research Station on 12 June 2002 (SUMMER1), 14 May 2003 (SPRING) and 19 June 2003 (SUMMER2). The plants chosen for the SUMMER1 planting were from the groups to be raised in PL64 trays. Those plants were field-planted at the time of plug-to-plug transplanting. The plants for the SPRING and SUMMER2 plantings were those that had been transplanted twice and grown throughout the production summer in the nursery. In mid-

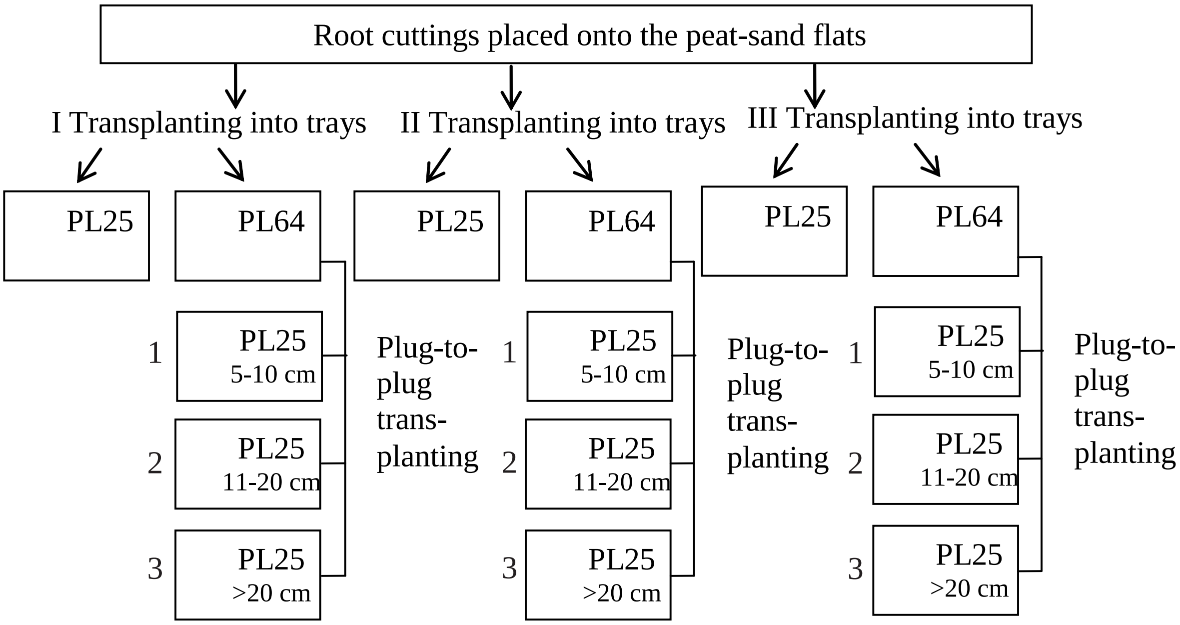

Figure 1. Production schedule of hybrid aspens from root cuttings with three transplanting times from flats to trays following plug-to-plug transplanting. In each flat-to-plug transplantings sprouted cuttings were transplanted into both Plantek-25 (PL25) and Plantek-64 (PL64) trays. In the plug-to-plug phase the plants were transplanted only from PL64 trays into PL25 trays but graded into three groups according to their height

October 2002 the SPRING and SUMMER2 plants were graded according to their final height (>40 cm or <40 cm) and then kept over the winter in plastic bags in the frozen storage at -3 °C and RH of 88-90%. The following May the taller (>40 cm) plants were planted and the shorter ones (<40 cm) were put back in the PL25 trays and raised in the nursery until planting on 19 June. After planting and at the end of the 2003 and 2004 seasons, the height of the plants was measured to the nearest 1 cm.

The experiment was established using a randomized complete block design with 10 plants (0.8 m between plants in a row, 0.5 m between planting dates) for each clone (subplot) per 3 plots (planting date) and 6 blocks, a total of 60 plants for each planting date and clone. The experimental area was fenced to provide protection against hares.

Statistical analysis. We compared the variation in the height of the reference birch and hybrid aspen batches transplanted either directly into PL25 trays or first into PL64 and later into PL25 trays for each transplanting time using the coefficient of variation (CV) and its standard deviation, which was calculated as

$$s_{CV} = \sqrt{\frac{CV^2}{2n}\left(1 + 2CV^2\right)}$$

where n is the number of samples.

In the planting experiment the differences in growth between the various planting dates were analyzed using mixed linear models, which take into account the correlations of the measurement units (plants) within the same experimental unit (subplot). The parameters were estimated using the restricted maximum likelihood method (REML). SPSS 12.0.1 for Windows was used for the computations.

For the data for each year and variable (height and height growth) the final model used was

$$y_{kijl} = \mu + d_i + c_j + cd_{ij} + b_k + \beta_{ki} + \gamma_{kij} + \varepsilon_{kijl}$$

where μ is the general mean, d_i is the fixed effect of planting date i, c_j is the fixed effect of clone j, cd_{ij} is the fixed interaction effect of clone i and planting date j, b_k is the random block effect, β_{ki} is the random main plot effect within block k, γ_{kij} is the random subplot effect for the subplot where clone j is planted on date i within block k, and ε_{ijkl} is the random effect (residual error) of plant l. The random effects are assumed to have zero mean and constant variance. The plants from each clone were in most cases placed in a subplot from one or two trays. Thus, in the subplot effect γ_{kij} both the tray effect (the correlation of the plants within the same tray) and the true subplot effect (the similarity of the growing conditions within the same subplot) were confounded.

Differences in the mortality between batches in the nursery and in the number of damaged plants for the different planting dates in the planting experiments were analysed by means of Kruskall-Wallis Tests in software SPSS 12.0.1 for Windows.

Results

Sprouting. The first cuttings sprouted between 4 and 14 days after planting to flats, depending on the particular clone (Figure 2). In total, 64, 80 and 61% of the cuttings sprouted and 31, 7 and 36% rotted in the case of clones A, B and C, respectively. The remainder of the cuttings did not rot but they also had not sprouted by the time of the final transplanting.

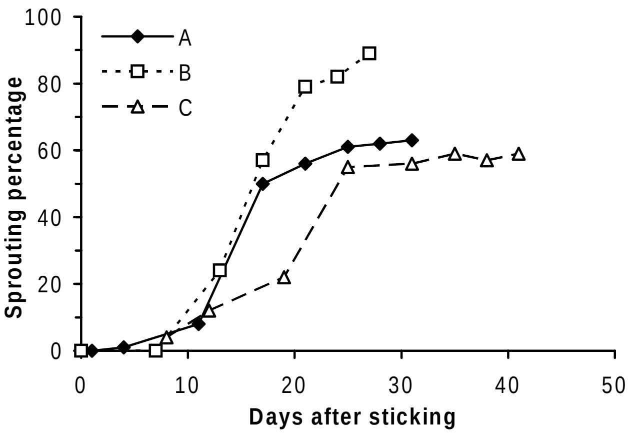

Figure 2. Sprouting of hybrid aspen root cuttings of three clones

Cessation of height growth in the nursery. The grading of plants affected the growth rhythm and cessation of their height growth. The growth of the plants that were short at the time of transplanting continued later into the autumn than the growth of the plants in the other two groups (Table 2). Height growth of aspens ceased later in all batches than the growth of silver birch (Table 2).

Variation within a height-graded batch. For plants transplanted during a specific period the batches in which the sprouted cuttings had first been transplanted into PL64 and later into PL25 and then graded by height resulted in more even-sized crops than if the sprouted cuttings were transplanted directly into PL25 (Table 2, Fig. 3). However, in most case, the variation within aspen batches was higher than variation in height of silver birch batch (Table 2). Mortality of plants was greater in PL25 than in PL64 (Table 2) in all clones. Within a clone there were no differences in mortality between batches transplanted into PL64 (Table 2).

Table 2. Dates when plants were transplanted either into Plantek-25 trays (0) or Plantek-64 trays (1-3) and dates when the height growth within a batch had ceased, proportion of dead seedlings within a batch at the end of the growing season, number of samples, mean, standard deviation (SD) and coefficient of variation (CV) and standard deviation of CV of final height in different hybrid aspen batches in each clone (A, B, C) compared with the reference silver birch batch at the Suonenjoki nursery at the end of September 2002. Hybrid aspens were transplanted directly into Plantek-25 trays (0) or plug-to-plug transplanted with height-graded (1-3) plants which were first transplanted into the Plantek-64 trays and then into the Plantek-25 trays in three transplanting time (I-III)

	Transplanting	Cessation	Mortality	N	Mean	SD	CV	s_{CV}
A-I-0	21 May	17 Aug	20	40	65	17	0.26	0.031
A-I-1	19 Jun	26 Aug	4	48	61	11	0.19	0.020
A-I-2	19 Jun	17 Aug	0	60	79	10	0.12	0.011
A-I-3	19 Jun	26 Aug	1	99	94	11	0.11	0.008
A-II-0	30 May	26 Aug	12	160	65	15	0.23	0.014
A-II-1	27 Jun	2 Sep	9	72	62	21	0.33	0.030
A-II-2	27 Jun	26 Aug	1	112	74	12	0.17	0.012
A-II-3	27 Jun	26 Aug	0	96	85	13	0.15	0.011
A-III-0	10 Jun	26 Aug	10	58	64	13	0.20	0.019
A-III-1	2 Jul	2 Sep	4	80	68	14	0.20	0.016
A-III-2	2 Jul	26 Aug	0	99	75	14	0.18	0.013
A-III-3	17 Jul	26 Aug	0	25	64	6	0.10	0.014
B-II-0	31 May	17 Aug	2	60	72	13	0.18	0.017
B-III-0	10 Jun	26 Aug	16	60	57	14	0.25	0.025
B-III-1	2 Jul	2 Sep	5	60	70	12	0.18	0.017
B-III-2	1 Jul	26 Aug	2	108	83	13	0.16	0.011
B-III-3	18 Jul	26 Aug	0	75	55	8	0.15	0.012
C-I-0	21 May	26 Aug	7	92	55	16	0.28	0.022
C-I-1	20 Jun	26 Aug	4	60	50	14	0.28	0.027
C-I-2	20 Jun	17 Aug	0	112	70	12	0.18	0.012
C-I-3	20 Jun	17 Aug	0	84	68	14	0.21	0.017
C-II-0	30 May	26 Aug	12	80	52	15	0.28	0.024
C-II-1	29 Jun	26 Aug	8	96	51	16	0.31	0.024
C-II-2	29 Jun	17 Aug	1	104	62	11	0.17	0.012
C-II-3	29 Jun	17 Aug	0	60	68	13	0.19	0.018
C-III-0	11 Jun	26 Aug	25	72	47	12	0.26	0.023
C-III-1	3 Jul	2 Sep	6	116	53	16	0.30	0.021
C-III-2	17 Jul	26 Aug	8	23	40	7	0.16	0.024
BIRCH		12 Aug		200	64	9	0.14	0.007

Field performance. In the autumn of 2003 the SPRING-planted hybrid aspens of clone A had higher proportion of shoot tip dieback than the aspens planted in SUMMER1 or SUMMER2 (Table 3). The following season the proportion of dieback increased in all of the treatments with no differences between the planting dates. Some of the plants died, but planting date had no significant effect on this outcome.

Significant differences in height and height growth were observed among planting dates and clones, but their interactions were significant only in height (Table 4). During the planting season of 2002 the SUMMER1 aspens grew by approximately 30 cm. These plants were still shorter than the SPRING-planted ones in the spring of 2003 (Figure 4). Both the SPRING and SUMMER2 plants grew by only a few centimeters in 2003. However, SUMMER1 aspens grew well in 2003 and 2004, and were much taller at the end of 2004 than those planted on other dates (Figure 4). Clone A grew better than clone C in the case of all planting dates (Figure 4).

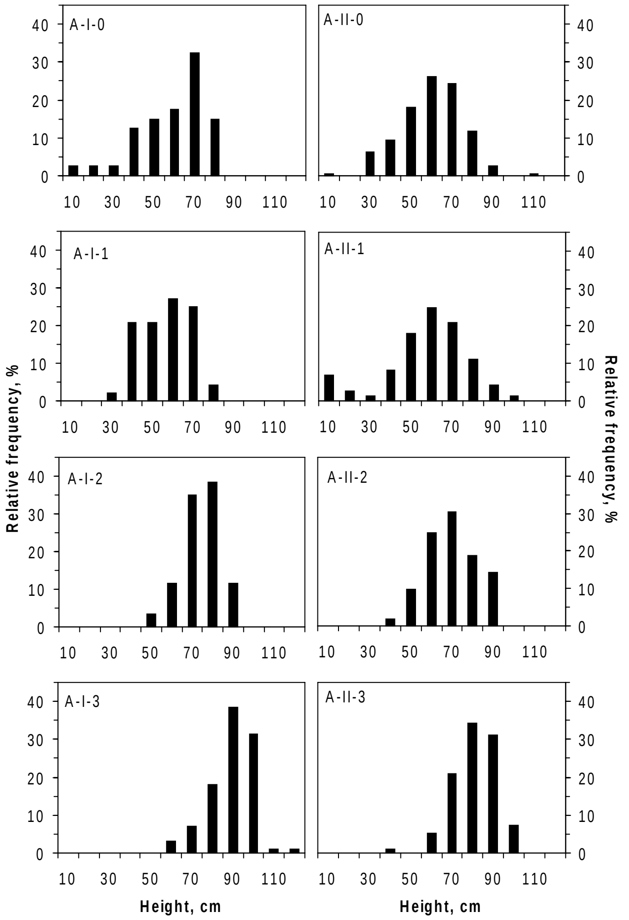

Figure 3. Relative frequencies of hybrid aspen plants of clone A in 10 cm-height classes at the end of the production year. Sprouted cuttings were transplanted on 20-22 May (I), on 25 May-3 June (II) or on 10-11 June (III) either directly into Plantek-25 trays (O) or first into Plantek-64 trays and when the tallest plants were about 20 cm into Plantek-25 trays by grading them into three height groups (1-3)

Table 4. Significances of the fixed effects (clone, planting date and interaction of clone and planting date) on the height or height growth in the different years after the planting of the hybrid aspens in the production summer (SUMMER1), the following spring (SPRING) and the following summer (SUMMER2) analyzed using the linear mixed model. * only for SUMMER1 and SPRING (= height at planting). ** only for SUMMER1

Source	*F*	*Sig.*
Height at planting		
Intercept	8587	<0.001
Clone	10.23	0.003
Planting date	1038	<0.001
Clone *x* date	12.7	<0.001
Height 2002*		
Intercept	2288	<0.001
Clone	3.84	0.051
Planting date	48.34	<0.001
Clone *x* date	46.01	<0.001
Height 2003		
Intercept	1700	<0.001
Clone	7.67	0.005
Planting date	111	<0.001
Clone *x* date	33.2	<0.001
Height 2004		
Intercept	203	<0.001
Clone	1.73	0.319
Planting date	18.5	0.033
Growth 2002**		
Intercept	175	<0.001
Clone	25.0	<0.001
Growth 2003		
Intercept	40.5	0.008
Clone	0.59	0.523
Planting date	42.6	0.014
Growth 2004		
Intercept	160.9	<0.001
Clone	28.7	<0.001
Planting date	89.1	<0.001

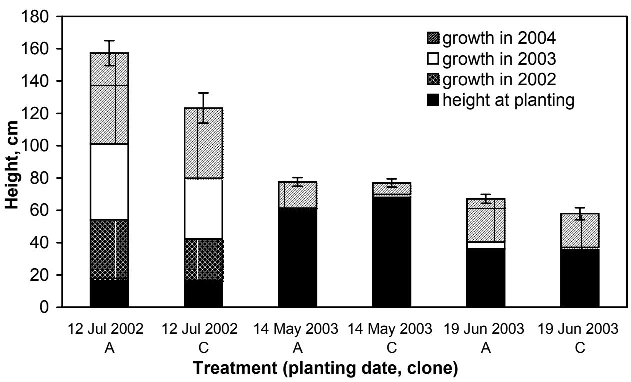

Figure 4. Height growth of hybrid aspen plants of clone A and C planted on different dates. Plants for first planting on 12 July 2002 were transplanted into Plantek 64 trays. Aspens planted on 14 May 2003 and 19 June 2003 were plug-to-plug transplanted, and graded according to height into >40 cm and <40 cm height groups. Both groups were frozen-stored over winter. After frozen-storage, aspens shorter than 40 cm were raised in the nursery until planting. Vertical bars indicate standard errors of block means

Table 3. Proportion of shoot tip dieback and mortality of hybrid aspen clones (A, C) planted in the production summer (SUMMER1), the following spring (SPRING) or the following summer (SUMMER2) in the autumn of 2003 and 2004

Clone and treatment	Dieback, %		Mortality, %	
	2003	2004	2003	2004
Clone A				
SUMMER1	0	10	0	2
SPRING	13	20	0	5
SUMMER2	0	13	2	3
p-value	<0.001	0.286	0.368	0.364
Clone C				
SUMMER1	0	22	2	2
SPRING	3	20	0	0
SUMMER2	3	15	3	3
p-value	0.362	0.626	0.364	0.598

Discussion

It was possible to produce more even-sized hybrid aspen batch by several transplanting times from rooting flats and then by transplanting them later from small trays to the larger ones and grading plants according to their height. Late transplanting time may, however, delay the cessation of height growth. However, by the described production procedure was not possible to achieve as low height variation as was in silver birch batches in Finland.

Our results that there are a considerable variation in sprouting between clones (Fig. 2) are similar to previous finding for this species (Stenvall *et al*. 2004, unpublished results of Zhang). Stenvall *et al*. (2004) showed that the most intensive period of shoot emergence occurs from 3 to 5 weeks after insertion. In this study, most of the cuttings sprouted during the third week after insertion (Fig. 2). A part of cuttings rot before sprouting. Clones A and C were retained in the growth chambers throughout the sprouting period. As a consequence of poor ventilation and high humidity levels in the chambers the cuttings became susceptible to rotting. Fewer cuttings of clone B rotted since they were kept in the greenhouse where the air humidity was lower mainly because the ventilation system was better than in the chambers. The air temperatures were 3 ˚C higher in the greenhouse than in the growth chambers, which may have helped to explain the better sprouting of clone B. Aarlahti (2003) has shown that high temperatures (up to 30 ˚C), especially the temperatures of the growing media, hasten sprouting and increase the sprouting percentage.

Both the sprouting time (i.e. transplanting date) and grading of plants affected the growth rhythm and cessation of height growth. The height growth of the hybrid aspens ceased between one and three weeks later than the growth of silver birch seedlings (Table 2). This also means that the frost-hardening of these aspen plants was probably delayed, since the cessation of height growth is a prerequisite for hardening (Weiser 1970). In comparising to silver birch, hybrid, aspen clones used in this study originated more southern since one of the parent of them was from latitude of 45-57 (the exact location is not known). The height growth of first-year woody plants usually ceases when they are old enough (large enough temperature sum accumulated) and night length is longer than origin specific critical night length (Koski and Sievänen 1985). The critical night length is longer for southern origin than for northern ones (Koski and Sievänen 1985). Thus, at Suonenjoki, the critical night length ceasing height growth of first-year hybrid aspens is longer than that of local origin of silver birch and then the frost hardening of aspen plants delays. This, on the other hand, can cause problems for timing of winter storage and later for field performance.

It was possible to reduce the variation in height within a hybrid aspen batch by using several transplanting times and by grading plants according to their height, but variation in the reference silver birch batch was lower in most cases (Table 2). Thus, our aim to reduce the variation in height by several transplanting times and height grading at the time of plug-to-plug transplanting was not completely achieved. Late sprouting and transplanting in June interrupted the growth rhythm of the plants which have to be taken into account when decisions are made concerning the method to be used for producing hybrid aspens from root cuttings. It may be necessary to study other methods that hasten sprouting, such as planting root cuttings in small-volume cells and increasing the temperature of the growing media in an attempt to potentially avoid some of those problems.

Spring planting increased the proportion of shoot tip dieback compared to plantings in first or second summer (Table 3). Shoot tip dieback has also been reported in earlier studies, especially in the case of spring-planted hybrid aspens (Hynynen *et al* 2002, unpublished data of Luoranen).

The results suggesting that the hybrid aspens planted in the production summer grew better than those planted the following spring agree with earlier results (unpublished data of Luoranen) and results of silver birch studies were summer and spring plantings were compared (Luoranen *et al*. 2003). There were clonal variation in height growth after planting and interaction of clones and planting dates were significant in height (Table 4). When there were only two clones in the planting experiment, it is not possible to generalize these results. However, the clonal variation has also been observed in earlier studies (e.g. Yu *et al*. 2001, Hynynen *et al*. 2002).

The SUMMER2 plants had grown a few centimeters by the time of planting. It was our hypothesis that these plants would have grown well if the soil temperature had favoured root egress and if the plants had been leaf-bearing at the time of planting. In the planting summer, however, the growth of these plants was poor. Lähde and Raulo (1977) showed that the height growth of one-year-old silver birch seedlings planted after bud break was poorer than the growth of seedlings planted when ‘dormant’ in the spring or the previous autumn. In the case of hybrid aspen, however, their growth was better than that of taller aspens planted in the spring before bud break (Figure 4), but not as good for those planted in SUMMER1.

The SUMMER1 plants were the ones, which had the tallest shoots at the time of plug-to-plug transplanting. In the case of the other planting dates (SPRING, SUMMER2) a high proportion of the plants belonged to the shorter height category during the production cycle (Table 2). The height growth of the shorter plants ceased in late-August or early-September (Table 2), and their frost hardening was probably also delayed and their frost hardiness was poor. Thus, they ran a greater risk of being damaged during the autumn frosts or when they were transferred in October into frozen storage. Thus, their shoot tips and roots may have been damaged, which in turn may have caused a shoot tip dieback after planting or root damage, both of which may have affected growth after planting.

One possibility to reduce variation in height within seedling batch is the short day treatment, which in the same time probably hasten the frost hardening of hybrid aspen plants. According to our unpublished results it could be an effective, but expensive method to control the height and variation of hybrid aspen plants.

Conclusions

It is possible to reduce variation (CV) in height in aspen cuttings from about 0.25 to an average of 0.18 by using several different transplanting times and by grading them into different height categories. Transplanting, especially when it is performed several times, demands more work and thus increases the cost of the plants. In addition, the transplanting date affect the growth rhythm of hybrid aspen plants and thus the risk to decreased survival and shoot tip dieback can increase in the late transplanting dates. The field performance of the hybrid aspens planted in summer at the time of plug-to-plug transplanting was good. One method of increasing the number of plants delivered for plantation is that plants will be delivered both in summer and in spring. The tallest plants at the time of plug-to-plug transplanting can be dispatched for planting during summer. The shorter plants at that stage can be transplanted to larger plugs and grown during the rest of the growing season in the nursery, and then dispatched for spring planting following winter-storage. In the case of such approach, it is important to ensure that the shoots cease growth and harden adequately for over-winter storage.

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ВЫРАЩИВАНИЕ РАВНЫХ ПО РАЗМЕРУ РАСТЕНИЙ ГИБРИДНОЙ ОСИНЫ ИЗ КОРНЕВЫХ ЧЕРЕНКОВ: ПЕРЕСАДКА, СОРТИРОВКА ПО ВЫСОТЕ И СРОКИ ПОСАДКИ

Я. Луоранен, Г. Чанг, Х. Смоландер

Резюме

В настоящее время в лесопитомниках Финляндии гибридная осина воспроизводится корневыми черенками путем пересадки взросших черенков в большие контейнеры (размер ячеек 380-400 см^3). Сроки прорастания черенков резко отличаются между группами ростков, что обусловливает выращивание неравномерных растений осины, т.е. большую разницу высоты в одной партии черенков в питомнике и высокую долю низкорослых растений (с минимальной высотой в 40 см.). Для производства партий черенков более равномерной высоты растения были дважды разделены на категории роста: при пересадке в малые короба, а затем при пересадке в крупные короба. Эта процедура позволила снизить вариации конечной длины отсортированных партий по сравнению с партиями, пересаженными непосредственно в контейнеры крупного размера. Однако вариация высоты гибридной осины не превысила вариации эталонной партии березы повислой (*Betula pendula*). Использование короткомерных растений для пересадки из короба в короб изменило ритм роста растений, что привело к остановке роста растений в высоту. Одним из решений существующих проблем стала посадка гибридной осины в летнее время во время пересадки из короба в короб. Рост данных растений увеличился, а суховершинность черенков сократилась по сравнению с растениями, которые выращивались в питомнике более долгие сроки, замораживалисьб и затем высаживались весной или ранним летом следующего года.

Ключевые слова: сортировка, высота, гибридная осина, посадка, *Populus,* корневые черенки

Growth Dynamics of Scots Pine Geographical Provenances in Latvia

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Abstract

Results from geographical provenance trials (totally 40 foreign provenances from Poland, Eastern Germany, Russia, Belarus, and Ukraine) in three test locations in Latvia have been evaluated.

For analysis only superior trees (10% of the highest trees in each provenance) have been chosen.

Results indicate that credible evaluation (observed trend does not change with increasing tree age) of survival for provenance groups from different regions can be done at the age of 6 years, for growth traits – at 15 years, but growth performance of individual provenances vary considerably up to the age of 28 years. Provenance influence on height and diameter growth is highest, exceeding regional influence even three times for height and twice for diameter.

Results of geographical Scots pine trial are site-dependent. Provenances from the same region tested in 3 different test locations in Latvia at the same age demonstrate differences in survival up to 16% and in yield more than double.

Average growth and survival of Eastern German and Polish Scots pine provenances decrease when comparing the areas with mild, maritime climate (Liepāja and to a lesser extent Zvirgzde) and the areas with harsher, more continental climate (Kalsnava). The decrease is sharper for Eastern German provenances.

In Kalsnava, the performance of Polish and East German provenances differs considerably from the general trend, described in the literature. We suggested that the Kalsnava area could be taken as an indicator for a borderline for growth patterns of transferred Scots pine provenances.

Key words: *Pinus sylvestris* L., provenance trial, growth dynamics, quality, provenance influence

Introduction

Evaluation of growth traits for different provenances has been of interest already for more than a century (Giertych 1991b). Choice of the suitable provenance for local conditions is the primary precondition for successful further breeding and useful outcome (Baumanis *et.al*. 2001). To compare provenances plenty of national and international trials have been established. Most known from them are the IUFRO (International Union of Forest Research Organizations) trials established in 1907, 1938, 1939, and 1982 (Giertych 1979, Kohlstock and Schneck 1998) and Ogievskij pre-revolutionary Russian provenance experiment (Giertych and Oleksyn 1981). Recently the results from a comprehensive provenance trial established in all the territory of former USSR in 1974-1976 have become available (Shutyaev and Giertych 2000).

There are considerable difficulties in evaluating the old-time trials: the differences in establishment method particular trial planting places (Giertych and Oleksyn 1981) can cause errors. Some of the trials on each planting site have no replications, so it is hard to distinguish between the soil and provenance effects (Abraitis and Eriksson 1998).

In spite of that the results obtained in these trials are used to delineate general trends of Scots pine growth (e.g. Giertych, 1991b). In some cases the use foreign provenances in forest regeneration have been recommended because of their growth and quality (e.g. Pedersen 1998).

In spite of numerous trials, the results are usually published only from the latest measurements taken at different ages, but there is lack of growth-dynamics analysis. Usually a considerable area or even a country is represented by only one provenance and it is impossible to distinguish between the influence on the growth and quality of the region (or country) and the particular provenance. The aim of the present study was to evaluate the growth and survival dynamics of foreign provenances in three climatically different localities in Latvia.

Materials and methods

In the trial of geographical Scots pine provenances totally 58 provenances are included – 27 from Eastern Germany, 8 from Poland, 1 from Belarus, 3 from Russia and 1 from Ukraine as well as 18 Latvian provenances. Data on the origin of non-Latvian provenances are presented in Table 1.

Table 1. Geographical origin for pine provenances included in experiment

Origin region	Nr.	Provenance	Geographical origin		
			Latitude	Longitude	Altitude, m
Russia *	125	Ангасяк-2	50°	56°	150
	126	Мелекесс	54°	49°	20
	127	Ангасяк-1	50°	56°	80
Ukraine *	128	Киев	50°	30°	20
Byelo-russia *	129	Борисов	54°	28°	20
Poland	130	Rychtal	51° 06'	17° 53'	80
	131	Pokoj	51° 00'	18° 00'	80
	132	Plaska	53° 50'	23° 00'	60
	133	Rospuda	54° 00'	22° 50'	20
	134	Rytel	53° 30'	17° 50'	70
	135	Supras'l	53° 15'	23° 07'	50
	136	Taborz	53° 35'	20° 00'	50
	137	Tarda	53° 45'	20° 00'	15
Eastern Germany	138	Neusterliz	53° 20'	13° 00'	70
	139	Dippoldiswalde	50° 50'	13° 30'	50
	140	Hagenow	50° 30'	11° 15'	50
	141	Konigstein	51° 00'	14° 00'	80
	142	Rathenow	52° 30'	12° 30'	100
	143	Bad Berka	51° 00'	11° 15'	80
	144	Mirow	53° 15'	12° 45'	150
	145	Oranienburg	52° 40'	13° 15'	70
	146	Eibenstock	50° 30'	12° 45'	80
	147	Neubrandenburg	53° 30'	13° 15'	70
	148	Lobau	51° 10'	14° 45'	80
	149	Nedlitz	52° 10'	12° 205'	80
	150	Niesky	51° 20'	15° 00'	60
	151	Rostock	54° 10'	12° 10'	60
	152	Schleitz	50° 35'	11° 40'	80
	153	Perleberg	53° 00'	11° 50'	60
	154	Neuhaus	53° 15'	11° 00'	150
	155	Gransee	53° 00'	13° 15'	80
	156	Kyritz	52° 50'	12° 30'	80
	157	Tharandt	51° 00'	13° 30'	150
	158	Colbitz	52° 20'	11° 30'	50
	159	Gustrow	53° 50'	12° 15'	80
	160	Oelsnitz	50° 25'	12° 15'	60
	161	Potsdam	52° 20'	13° 00'	120
	162	Peitz	51° 50'	14° 30'	150
	164	Jena	51° 00'	11° 30'	150
	165	Kolpin	52° 20'	14° 00'	80

* - just approximate data on latitude and longitude available

According to a popular methodology (Aitken 2004), each provenance sample is made up from the seeds of 20-25 trees. The trial was established in 3 different places in Latvia – Liepâja, Zvirgzde and Kalsnava (Figure 1), using one-year-old seedling. The site quality for pine was above the average (Site index 2). Trial design – two blocks with 6 replications, 7 x 5 plants in a parcel, initial spacing 2 x 1 m.

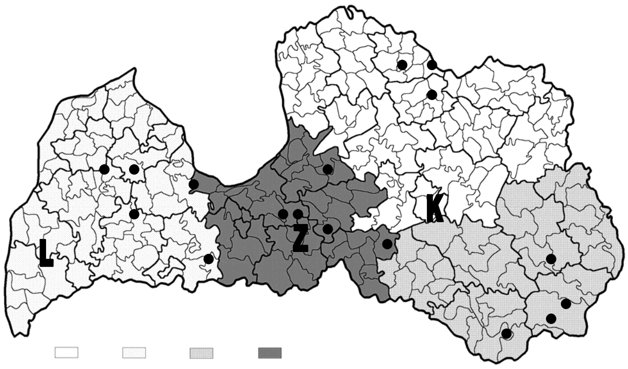

Figure 1. Test locations and native pine sample collection places in Latvia
L-Liepāja, Z – Zvirgzde, K – Kalsnava; black dots – seed collection places; with different colours pine seed zones are labeled

The trees on the trial plot were measured at the age of 5, 10, 11, 15, 21 and 28 years (Birģelis 1983, Baumanis *et al*. 1986, Áàóì àíèñ *et al*. 1990, Birģelis *et al*. 1994, Jansons and Baumanis 2005).

The survival was assessed up to age of 21 year, when the first thinning was made, leaving 1/3 of the initial number of trees

Stem straightness and branchiness at the age of 28 years has been assessed by using 3 grades – where Grade1 – straight stems or thin branches; Grade 3 – crooked stems or thick branches.

The statistical analysis was done by using Microsoft Excel. The following ANOVA model was used:

$$y_{ijkl} = \mu + t_i + r_{j(i)} + o_k + p_{l(k)} + e_{ijkl}, \quad (1)$$

where y_{ijkl} – individual tree height; μ – overall mean; t_i – test site effect; $r_{j(i)}$ – replicate within test site effect; o_k – origin region effect; $p_{l(k)}$ – provenance within origin region effect; e_{ijkl} – error within provenance.

Only three regions (Latvia, Poland and Eastern Germany) were used in the analysis.

For assessment of yield, the stem volume of trees up to 10 cm in diameter has been calculated according to the formula suggested by Gerkis (Ãåð-êèñ 1981):

$$m = 0.019 + 0.01142(d_{1,3} + 2)^{2,61614} \times h^{0,76489}, \quad (2)$$

where m – stem volume, dm^3; $D_{1,3}$ – diameter at breast height (1.3 m), cm; h – tree height, m.

The tree volume for the trees thicker than 10 cm d.b.h. (hereinafter the diameter at breast height – 1.3 m) was assessed according to the formula suggested by Ozoliņš (Ozoliņš 1997):

$$V = \frac{\pi D^2 \cdot H \cdot I}{4 \cdot 10^4 \cdot (P(\frac{1,3}{H}))^2}, \quad (3)$$

where V – stem volume, m^3; H – tree height, m; D – d.b.h., cm; I = 5298,6; P – perturbation coefficient; π = 3,14159.

Degree of influence (η) has been calculated according to the method described by Liepa (1974):

$$\eta_A = SS_A * SS_{Total}^{-1}, \quad (4)$$

where η_A – degree of the influence of evaluated factor (factor A); SS_A – sum of squares for factor A; SS_{Total} – total sum of squares.

The factor, that most strongly affects the measured trait, has the highest value of η.

To compare growth for different provenances and get the most accurate results, it is important to use traits with small variation. The variation coefficient for the stem volume components (height and diameter) is decreasing with time in all the trials. However, the diameter variations invariably exceed height variation (Table 3). That is why the height has been chosen as the major measure for delineating the tree group for further calculations. Height as a measure has been recommended also in the literature – see e.g. the review by Nilsson (1991).

The suppressed trees are not representatives of the population (Abraitis and Eriksson 1996). So it is important to delineate them from the calculations. To ensure equal representatives for each provenance we decided to use 10 % from initially planted trees – 3 highest trees in each replication that makes 18 trees for each trial plot.

If we chose sample group 10% of the highest trees for each provenance (instead of bigger sample group e.g. 20%), the degree of the influence of replication usually decreased, but the degree of the influence for provenance increased compared to the evaluation of all the planted trees. The small group of dominant trees (as 10% highest) makes the influences more visible (Figure 2).

Moreover, 10% from the initial number of trees (e.g. 500 tree/ha) make the amount recommended as optimal for final felling in the particular growth conditions in Latvia (Anonymous 2000).

So we chose the group standing for 10% of the highest trees from initially planted ones for the growth and quality comparison trial.

For the calculations of standing volume and other comparative means at age 28 years (last measurement) in Table 4 sample group of the 20% highest trees were used. It is the approximate amount (1,000 trees per ha) recommended in Latvia to be optimal in certain conditions of growing site for Scots pine stands (Anonymous 2000). Results of each provenance in Table 4 have been compared with the average performance of Latvian provenances with the difference in % (S%) calculated.

In the analysis provenance origin regions are defined correspondingly to country borders. It is done in order to evaluate, what differences are in performance of provenances from one country and what effects are in choosing just one (or very few) provenances to represent country in international provenance trial. Provenances in the group from the former USSR differs a lot in longitude of origin, but can not be separated, because there are too few provenances representing particular country. For that reason these groups are not much used in the analysis, but still left in dataset in order to show observed performance of particular provenances.

Results

The growth and survival are obviously two related factors, describing the final stand volume and quality –the authors, who study Scots pine provenances in Europe, conclude that the major source of observed variations among the wood volume production is related to dissimilarities in the growth rate and survival (e.g. Oleksyn *et al*. 1999).

Survival. Table 2 shows survival rates for provenances from different regions planted in 3 different test locations in different parts of Latvia. In all three test locations the Latvian provenances showed the best survival. The Polish provenances demonstrated average survival, slightly better than that for Eastern German provenances. For distant populations from the former USSR the survival was exceptionally low.

Table 2. Survival rates (% from initially planted) for provenances from different regions

Liepāja					
Provenience origin	**Age, years**				
	6	**10**	**11**	**15**	**21**
Former USSR	17	17	17	16	15
Poland	52	52	52	51	44
Estern Germany	52	52	51	50	43
Latvia	58	58	57	56	47
Zvirgzde					
Provenience origin	**Age, years**				
	6	**10**	**11**	**15**	**21**
Former USSR	20	20	16	16	16
Poland	50	50	44	43	39
Estern Germany	45	45	39	37	35
Latvia	52	52	45	43	39
Kalsnava					
Provenience origin	**Age, years**				
	6	**10**	**11**	**15**	**21**
Former USSR	19	19	18	16	15
Poland	45	45	44	40	35
Estern Germany	35	35	35	32	29
Latvia	65	65	63	57	46

Most of the differences in survival appeared during the juvenile growth (first 6 years). Afterwards the survival decreased only slightly and quite equally for all the provenance groups in Zvirgzde. In Liepāja and Kalsnava the survival decreases somewhat faster for the Latvian provenances than for introduced ones.

The provenances from the former USSR have equally low survival in all test locations. The Polish provenances showed the highest survival in Liepāja. If survival in Liepāja is presumed as 100%, survival in Zvirgzde is 96% and in Kalsnava 91%. The same trend was observed for the Eastern German provenances (decrease in survival compare to Liepāja 8% and 16%, respectively) (see Table 2). The lowest survival for Latvian provenances are in Zvirgzde. There the difference between the Latvian and Polish provenances in survival is negligible too. The highest survival for local populations of the age up to 15 years is in Kalsnava, but for the age of 21 years the survival in Kalsnava and Liepāja is almost equal.

Survivals of individual provenances differ from the mean values of the region, but differences seldom exceed 10%. The results of survival for individual provenances in Kalsnava are presented in Table 5.

Growth. Provenance has the highest influence on height growth in every tree age and provenance group has the second highest influence (Figure 2, Table 3).

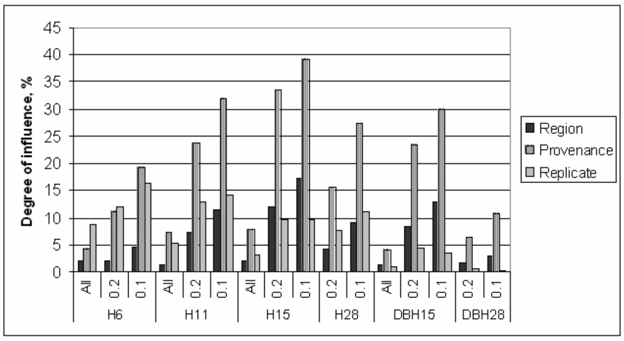

Figure 2. Degree of influence of region, provenance and replicate on height and diameter of trees
H– height, DBH – diameter at breast height, adjacent numbers indicate experiment age, when measurements have been taken (e.g. H6 – height at age 6 years). All – all trees considered, 0.1 (0.2) – sample group of 10% (20%) of the highest trees considered

In determining the average diameter for 10% of the highest trees provenance plays the major role in every tree age group. The region and the replication are of minor importance. The influence of provenance and region starts to decrease at the age of 15 years in Liepāja and Kalsnava, but in Zvirgzde it continuously decreases throughout the entire observation period.

Table 3. Results of the statistical analysis

Trait	Variation coefficient			Degree of influence (η) % and its significance									
				Test location	Liepāja			Zvirgzde			Kalsnava		
	Liepāja	Zvirgzde	Kalsnava		Reg.	Prov.	Repl.	Reg.	Prov.	Repl.	Reg.	Prov.	Repl.
H6	21	14	15	8 ***	5 ***	19 ***	16 ***	4 ***	20 ***	3 ***	5 ***	14 ***	24 ***
H10	20	15	14	7 ***	10 ***	29 ***	12 ***	10 ***	33 ***	2 *	9 ***	33 ***	3 ***
H11	20	15	14	3 ***	11 ***	32 ***	14 ***	8 ***	32 ***	2 ***	10 ***	34 ***	3 ***
H15	15	14	15	8 ***	17 ***	39 ***	10 ***	9 ***	34 ***	2 *	12 ***	38 ***	5 ***
H21	10	10	14	33 ***	22 ***	47 ***	4 ***	12 ***	32 ***	6 ***	15 ***	43 ***	7 ***
H28	10	10	12	25 ***	9 ***	27 ***	11 ***	4 ***	21 ***	10 ***	9 ***	30 ***	12 ***
DBH10	33	26	23	7 ***	6 ***	22 ***	11 ***	8 ***	26 ***	2 ***	4 ***	20 ***	3 ***
DBH11	29	23	22	3 ***	10 ***	27 ***	12 ***	8 ***	24 ***	2 *	5 ***	22 ***	2 ***
DBH15	23	20	21	15 ***	13 ***	30 ***	3 ***	5 ***	20 ***	1 *	5 ***	22 ***	5 ***
DBH21	21	19	21	30 ***	8 ***	22 ***	2 ***	5 ***	17 ***	2 *	7 ***	21 ***	4 ***
DBH28	21	20	20	16 ***	3 ***	11 ***	0	2 ***	14 ***	1 *	3 ***	15 ***	7 ***
Stem 28	43	45	46	1 ***	11 ***	18 ***	2 *	10 ***	16 ***	4 ***	12 ***	20 ***	2 *
Branch 28	26	30	27	0 *	2 ***	8 *	2 *	2 ***	13 ***	0	3 ***	11 ***	2 *

Trait: H – height, DBH – diameter at breast height, Stem – stem straightness, Branch – branchiness. Adjacent numbers indicate experiment age, when measurements have been taken (e.g. H6 – height in age 6 years). Significance level of calculations: * - α=0.05, ** - α=0.01, *** - α=0.001

In each test location the influence of provenance increases up to the age of 21 years, then decreases slightly. The same trend is observed for the influence of the region. Replications are quite important in the juvenile growth (up to the age below10 years) and again at the age close to 28 years, when these influences can be equally important or even slightly exceed the influence of the region.

The variation coefficient for stem straightness is twice as high as for the diameter. The relation between branchiness and height variation coefficients is the same (Table 3). The stem quality as an integrated volume from branchiness and stem straightness are most strongly influenced by the provenance, to a lesser extent by the region and negligibly (not exceeding 4%) – by the replication.

The test location has an increasing influence with the older trials reaching maximum values at the age of 21 year, – 33 for the height, and 30 for the diameter. The planting sites influence the stem quality negligibly – less than by 1% (Table 3).

The next step is to understand, whether all the foreign proveniences grow equally well in all the test locations. As revealed by the correlation analysis, the height for a particular provenance at the same age correlated strongly and was significant between Liepāja and Zvirgzde (Figure 3). The weakest correlation on average is between the tree height in Kalsnava and Liepāja.

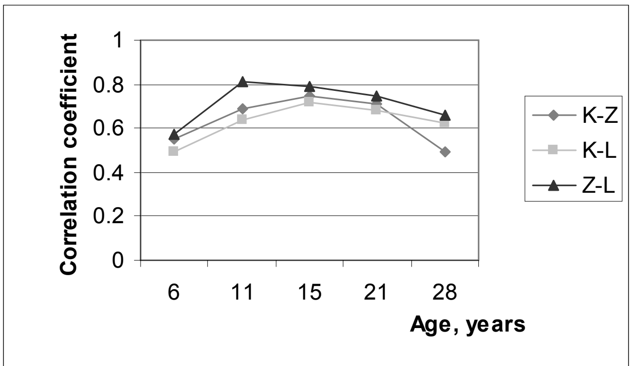

Figure 3. Correlation between tree height in different test locations; K-Kalsnava, Z- Zvirgzde, L- Liepāja, K-Z –correlation between tree height in Kalsnava and Zvirgzde

In order to evaluate the time, when the correct assessment of the results of the experiment can be stated we calculate the correlations between the height at provenance level at the age of 28 years and other ages. There were almost no differences between the average correlation value for the height between the ages of 28 and 21 year as well as between 28 and 15 years. In two cases (Kalsnava and Zvirgzde) the correlation 28-15 was even stronger (Table 4). That is in agreement with the average tree height for the provenances from different regions – the trend is the same as for the age group of 15 and 28 years. A sharp decrease (more than 10 %) in correlation tightness was observed between the correlations 28-11 and 28-6.

Correlation tightness for d.b.h. for 10% of the highest trees at the age of 28 years and other ages increased, as older the measurement was (Table 4).

In general, the correlation was the strongest between the average height for 10% of the highest trees in the same test location between two nearest measurements in time (e.g. Kalsnava at the age of 15 and 11 years r=0.98) (data not shown). The average index for these correlations was 0.91 and highly significant (α=0.001). The correlations in this line were weakest between the heights at 6 and 11 years, in all other cases exceeding r=0.90.

Table 4. Correlation between height and diameter at age 28 years and other ages in different test locations

Trait	Test location	Age, years			
		6	11	15	21
Height at age 28 years	Kalsnava	0.77	0.89	0.93	0.91
	Zvirgzde	0.56	0.80	0.82	0.81
	Liep• ja	0.77	0.88	0.90	0.93
DBH at age 28 years	Kalsnava		0.77	0.87	0.91
	Zvirgzde		0.57	0.63	0.8
	Liep• ja		0.74	0.79	0.84

Correlations calculated at provenance level
All correlations are significant at confidence level α=0.001

The provenances at each measured age are ranked according to the average height of 10% of the highest trees from 1 (highest) to 58 (lowest) (Table 5). The correlations for the ranking demonstrate the same trends as described above. The pattern for regional differences demonstrates quite the same as for the age starting from 15 years. But the variations in ranking for individual provenances can be considerable (e.g. provenance Niesky in Liepāja at the age of 15 years is ranked 26, but at the age of 28 years – 3).

The correlation between the height rank and the yield (m^3/ha) at the age of 28 years is high (Liepāja r=-0.73; Zvirgzde r=-0.81 and Kalsnava r=-0.85) and significant (α=0.001). For Liepāja and Zvirgzde, better correlation can be obtained between the average height rank and the yield at the age of 28 years (r=-0.77 and r=-0.86 respectively).

The Eastern Germany provenances show higher yield in Liepāja (+17% compared to the average of Latvian provenances), lower - in Zvirgzde (+3%) and Kalsnava (-19%) For survival the trend is the same. The stems of the Eastern Germany provenances show considerably higher crookedness (31-41%) than the Latvian provenances and also the branchiness is more considerable (7-9%). The Polish provenances show a higher yield in Liepāja (+19%) and also in Zvirgzde (+23%) (regardless of slightly lower survival), while in Kalsnava the yield (+4%) is approximately the same as for the indigenous provenances. For Polish provenances the stem straightness (12-25%) is worse than for the Latvian ones, but better than for the Eastern German provenances. The branchiness (6-15%) is even poorer than for the Eastern German provenances.

Table 5. Main growth, survival and quality parameters for Scots pine provenances in Kalsnava.
Height rank is given for all provenances (including Latvian), but data on Latvian pine growth are not shown. Rank 1 – highest provenance, rank 58 – lowest; x – average; S% – difference (%) from the average result of Latvian provenances, Survival – % from initially planted trees

Origin region	Nr.	Provenance	Height rank in 6 years	11	15	21	28	Survival in age 21 year, %	Yield, m^3/ha $\bar{x}$	S %	Stem straightness $\bar{x}$	S %	Branchiness $\bar{x}$	S %
Russia	125	Ангасяк-2	57	58	58	58	58	6	9	-89	1.5	9	1.6	-14
	126	Мелекесс	55	55	56	55	54	9	17	-79	1.8	31	1.8	-5
	127	Ангасяк-1	56	57	57	56	57	6	13	-84	1.4	2	1.6	-16
	$\bar{x}$							**7**	**13**	**-84**	**1.6**	**15**	**1.7**	**-11**
Ukraine	128	Киев	58	56	55	57	56	**5**	**20**	**-75**	**2.0**	**46**	**2.0**	**5**
Belorus	129	Борисов	5	3	6	10	10	**49**	**101**	**24**	**1.5**	**8**	**2.0**	**5**
Poland	130	Rychtal	12	28	38	39	45	23	66	-20	2.2	59	2.3	22
	131	Pokoj	46	48	50	52	49	21	55	-33	1.9	41	2.2	15
	132	Plaska	27	24	26	32	14	41	104	27	1.5	11	2.1	8
	133	Rospuda	31	41	31	25	8	30	91	11	1.4	1	2.0	7
	134	Rytel	3	2	1	6	1	50	112	37	1.6	15	2.4	25
	135	Supras'l	7	18	17	17	12	33	82	0	1.7	22	2.1	11
	136	Taborz	13	10	4	1	2	47	99	21	1.9	35	1.8	-4
	137	Tarda	4	15	14	14	15	35	85	4	1.7	21	2.2	15
	$\bar{x}$							**35**	**87**	**6**	**1.7**	**24**	**2.1**	**12**
Eastern Germany	138	Neusterliz	42	40	43	24	40	31	62	-24	2.1	53	2.0	5
	139	Dippoldiswalde	19	50	52	53	55	20	30	-63	1.4	-2	1.5	-20
	140	Hagenow	47	34	33	29	31	32	86	5	2.0	46	2.2	17
	141	Konigstein	29	31	37	38	37	30	63	-23	1.8	33	1.7	-11
	142	Rathenow	33	53	53	50	51	23	48	-41	2.0	46	1.8	-7
	143	Bad Berka	44	44	44	19	24	29	59	-28	2.0	46	2.1	9
	144	Mirow	35	29	28	15	16	36	93	14	2.0	42	2.2	15
	145	Oranienburg	36	33	30	22	18	28	81	-1	2.1	56	2.1	10
	146	Eibenstock	18	37	36	28	47	46	63	-24	1.8	29	1.8	-8
	147	Neubrandenburg	9	1	7	4	5	36	106	30	1.9	35	2.2	16
	148	Lobau	22	22	22	16	27	33	72	-11	1.9	36	1.9	1
	149	Nedlitz	53	51	48	51	46	24	64	-22	1.9	35	2.1	12
	150	Niesky	26	36	34	49	22	25	60	-27	2.0	43	2.0	7
	151	Rostock	30	19	21	33	28	39	89	9	1.7	25	2.2	17
	152	Schleitz	48	46	47	47	50	26	53	-35	2.0	46	1.9	0
	153	Perleberg	50	45	46	48	48	19	44	-47	1.9	35	2.1	11
	154	Neuhaus	49	47	45	44	43	24	70	-15	2.0	44	2.2	14
	155	Gransee	45	43	40	36	26	27	65	-21	2.1	51	2.2	13
	156	Kyritz	21	21	20	30	25	31	78	-5	2.0	44	2.2	16
	157	Tharandt	52	49	49	46	44	31	59	-28	2.0	46	2.0	5
	158	Colbitz	43	42	42	41	39	22	69	-16	2.2	57	2.0	4
	159	Gustrow	34	14	12	8	20	40	86	6	1.8	28	1.9	-2
	160	Oelsnitz	16	16	25	20	35	33	68	-17	1.9	38	2.0	5
	161	Potsdam	40	17	23	23	42	31	68	-17	1.9	42	2.1	12
	162	Peitz	54	54	54	54	53	19	42	–-48	2.1	49	2.2	15
	164	Jena	15	5	9	11	23	38	77	-6	1.9	40	2.1	8
	165	Kolpin	51	52	51	43	52	16	40	-51	2.3	70	2.1	8
	$\bar{x}$							**29**	**67**	**-19**	**1.9**	**41**	**2.0**	**7**

Discussion

Survival. Good survival of seedlings in the local conditions is the first prerequisite to recommend their use in forest regeneration.

Oleksyn et al. (2000) as a result of experimenting with geographically diverse Scots pines concluded, that most of the difference in standing volume was because of differences in survival (number of standing trees per ha) rather than the average volume of individual trees within the provenance. Introduced provenances often show lower resistance to the local pests and diseases. Stephan (1991) concluded that transfer of populations from south to north increased susceptibility to the needle cast. It has been true also in the Latvian trial – the foreign provenances suffer from the needle cast (Бауманис *et al.* 1989). In analyzing native populations in juvenile age (3-5 years) Birģelis (1983) concluded, that the meteorological factors could have a dominant role of growth determination. It can be true also for early survival. In Kalsnava the climate is far more continental – e.g. the period without frost in Kalsnava is 120 days per year, but in Liepāja – 150 days (Fomina *et al*. 1992). Also the Latvian populations from western ad central part of the country where the climate is more maritime and milder – (Liepāja and Zvirgzde) are not recommended for use in forest regeneration in the eastern part of Latvia because of poorer growth and survival (Baumanis *et al.* 2001).

Decrease in the number of trees at later development stages (after 6 years) can be related mostly to tree competition for light and nutrient resources. That explains also a sharper decrease in survival for the Latvian provenances caused by higher initial competition for survival among trees starting earlier and being more intense.

Growth. Influence of replications on juvenile growth can be explained by slight differences in soil preparation, since stumps had to be removed. These differences are partly related to the intensity of pine weevil attacks (Baumanis *et al*. 1986). Besides, browsing damages occur unevenly all over the area (unpublished data).

Region characterizes the conditions for particular provenance growth. These conditions are partly due to genetic adaptation in the evolution process (Eriksson 1998) and serve as the basis for regular growth and quality pattern for pines from one region (Oleksyn *et al.* 2000, Shutyaev and Giertych 2000).

In the analysis provenance origin regions are defined correspondingly to country borders. Poland and Germany exceed Latvia more than twice by latitude. It means, that also heterogeneity of growth conditions will be higher and a comparison between the regions in the analysis less reliable. However, in most of the international province trials one or few provenances usually represent the country. By choosing regions in the same way we reveal what consequences this method has.

Our results demonstrate that the provenance influence on the height and diameter growth is even three times as high as the region influence.

Stem straightness at the age of 28 years is accordingly more influenced by the provenance, than the region, but the difference in these influences is not so high (no higher than twice). Besides, a negligible influence of the replication can indicate that stem straightness is strongly determined genetically. It is in agreement with the previous studies (e.g. Prescher and Ståhl 1985, Giertych 1991a). The same pattern of influences has been observed for branchiness. All evaluated influences were lower than those for stem straightness. It can be determined by the influence of different spacing (because of different early survival). It is also in agreement with the results of the geographical provenance trials in Germany, where significant differences have been found for branchiness of different provenances as well as for branchiness for the same provenance in different spacing patterns. Also the dependence between the provenance and spacing in relation to branch diameter was significant (Kohlstock and Schneck 1998). Significant population differences for most of the quality traits have been found also in Sweden (Eriksson *et al.* 1987).

According to our results we argue, that country or region with similar size cannot be objectively represented with only one or few provenances.

Test location at the age of 21 and 28 years has almost the same influence on the height and diameter growth as the provenance. It means, that the performance of introduced Scots pine provenances will be different in different places of Latvia. General conclusion: the results of geographical trial for Scots pine are site-dependent. The above-mentioned differences in survival for provenance groups in test locations also support this conclusion. The correlation analyses for height growth reveal similarities between Liepāja and Zvirgzde (on average r=0.71, α=0.001) and lower between the above-mentioned locations and Kalsnava (average r=0.63), where the climatic conditions are harsher.

It agrees with the suggestions of Pedersen (1998) from provenance trials in Denmark, but disagrees with the idea about "general trends" (Giertych 1991b, Aitken 2004), suggesting the same performance of a particular provenance over all the territory of such a globally small area as Latvia. The weakest point for our conclusion is the heavy incidence of root rot around the age of 21 years (when the peak of the influence of the test location observed). This disease was most harmful in Zvirgzde, less in Kalsnava and almost absent in Liepāja (data not published). It can lead to an overestimation of the importance of test location.

The results of correlation analysis suggested that the conclusions about the average performance of provenance group from one region could be drawn already at the age of 15 years. But the growth performance of a particular provenance varies considerably up to the age of 28 years and recommendations of their use cannot be made before that age. The exception is 10-12 inferior provenances and 5-7 best ones that can be recommended already at the age of 15 years.

The general results of the growth, quality and survival for Russian and Belarus provenances are in agreement with the trends suggested by Shutyaev and Giertych (2000). According to these conclusion as well as the results of geographical Scots pine provenance trial in Lithuania (Abraitis and Eriksson 1996) the provenance from Ukraine (Kiev) should not show so inferior growth performance. But it can be explained by the fact already mentioned, that a single provenance cannot represent the whole region.

The average performance for the growth and quality of the Eastern German and Polish Scots pine provenances in Liepāja and Zvirgzde is in agreement with the trend observed in previous provenance studies in Europe (review by Giertych 1991b, Matras 1998). Performance in Kalsnava is quite different.

For example – German provenances are reported as superior in growth up to 60^0N latitude and are found to be superior in Liepāja and Zvirgzde. At the same time only one from tested Eastern German provenances is among the 15 best in height growth in Kalsnava (Table 5). Also survival for these provenances is considerably reduced as compared to Liepāja (Table 2).

We suggest, that it can indicate a borderline for growth patterns (transferring effects) of geographical provenances.

Conclusions

1. Survival trend for provenances tends to stabilize already at age 6 years, in contrary to growth trend that is variable in the whole period of the experiment. It underlines once more the necessity for a considerable time span until the results in geographical provenance experiments can be obtained.

2. Provenance influence on the height growth is even three times as high as the region influence, to the diameter growth - twice as high as region influence. It means, that observed trend in international provenance trials will be notably influenced by choosing of provenance that represents a particular country or region.

3. Provenances from one region in 3 different test locations in Latvia demonstrate differences in survival at the same age up to 16% and in yield more than twice. The results of Scots pine trials (even in regions with moderate climate gradient) are site-dependent and test location will have notable influence on observed growth trends.

4. Average growth performance of Eastern German and Polish Scots pine provenances in Liepāja and

Zvirgzde is in agreement with the trends deduced in the previous provenance studies in Europe. Performance in Kalsnava differs considerably and can indicate a borderline for growth patterns of geographical provenances.

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ХОД РОСТА ГЕОГРАФИчЕСКИХ ПРОВЕНЕНЦИЙ СОСНЫ ОБЫКНОВЕННОЙ В ЛАТВИИ

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Резюме

Проведена оценка хода роста 40 сосновых провененций в трех географических регионах Латвии. Анализированы только самые высокие по росту деревья (10%). Определено, что наиболее достоверное сравнение показателей сохранности провениенции с разных регионов происхождения возможно в 6-ти летнем, а показателей роста – в 15-ти летнем возрасте, хотя показатели индивидуального роста каждой провененции имеют различия даже до 28-летнего возраста. Особое значение имеет влияние конкретной провененции на величину прироста в высоту и толщину деревьев – оно в два раза по высоте и в три – по толщине – превышает влияние региона происхождения данной провененции. Определены существенные различия по росту и диаметру деревьев между опытными объектами, заложенными в разных климатических зонах Латвии.

Наилучшие показатели по росту и сохранности проявили провененции сосны обыкновенной восточногерманского и польского происхождений в регионе с наиболее мягким (приморским) климатом в Лиепае, а самые низкие – в местах произрастания в континентальном климате.

Ключевые слова: сосна обыкновенная, географическая провененция, высота, диаметр, сохранность, ход роста.

The Theoretical Fundamentals of Forming of the most Productive Stands

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Abstract

The paper deals with the development of the theory of the most productive *Picea abies* Karst., *Pinus sylvestris* L., *Quercus robus* L., *Fraxinus excelsior* L., *Betula pendula* L., pure and mixed stands, the utilization of solar energy by trees and storeys, the interaction between trees, their productivity, optimal stand density, the influence of intermediate fellings on the increment of trees and stands. Also the construction of the models of the most productive stands and the development of the standards of intermediate fellings are analysed. For this the data gleaned over 30 years in more than 500 permanent experimental plots have been used.

The revealed new phenomenon of the stress effect of trees while forming ecosystem enabled the density of forming young stands to be optimized according to the critical limit of crowns approach while the density of stands according to the maximally possible projection area of a storey and an optimal degree of crown overlapping. It ensures the largest increment of the most valuable wood in ontogenesis of ecosystem.

It has been determined that the more the surface of a storey resembles the stairs, the more the solar energy penetrates into the stand. The most productive trees (class A) use the solar energy most effectively for the increment of wood. The most significant productivity of stands is achieved in case the stocking of a storey is maximal, the trees in the storey are maximally productive and the distance between them (crown overlapping) is optimal.

In the paper tree prototype – models of the most productive stands and the standards of their forming by intermediate fellings are presented. It has been ascertained that at a certain interval of stand age and thinning intensities the increment of thinned stands exceeds that of stands where thinnings have not been applied. With increasing age of stands the feasibility to enlarge stand increment by regulating density is more seldom noted because stocking augments, up to which it is feasible to thin stands without diminishing their increment, in comparison to the increment of stands where thinnings have not been applied.

Key words: critical limit of crown approach, the effect of stress, maximal stand productivity, use of solar energy, optimal stand density, intermediate fellings, thinning intensity.

Introduction

The increasing of forest productivity and sustainability is one of the most important tasks in forest management. It has been determined that naturally growing stands are not most productive since, along with productive trees using solar energy and space best, there is 40–60% of trees of average and low productivity (Kairiūkštis 1973). In most cases stand structure and density are not optimal nor do they ensure the largest volume increment of stands and their highest total productivity.

In the given soil and climatic conditions it is feasible to form most productive stands in natural forests and in sufficiently dense plantations by systematic and qualitative regulating quantity, quality and spacing of trees for example by thinning and intermediate fellings carried out in time. This is of paramount importance particularly in the last decade when the requirements of wood quality for industry have increased and acceleration of wood use for energy purposes is increased and their effect by many ecological and socio–economic aspects have enlarged (Kairiukstis *et al.* 2001, 2003, 2005). Foresters of the whole world have done much in developing theoretical assumptions of intermediate fellings and practical ways of carrying out them (Becking 1954, Mitcherlich 1957, Георгиевский 1957, Assmann 1961, Давидов 1971, Казимиров 1972, Кожевников 1971, Marquis *et al.* 1991). They are done from time to time as a means of forest management, which decrease too high density of stands. However intermediate fellings did not become an expedient system of forming stands from the most productive trees of desirable species composition. Moreover, in some countries particularly where conifer forests prevail, for the sake of short–term benefit, intermediate fellings are simplified. Forest is thinned without special selection of trees and intermediate fellings are divided only into precommercial and commercial. The main qualitative criterion of such intermediate fellings remains thinning intensity. The investigations (Kairiūkštis 1964, Kairiūkštis, Juodvalkis 1985) have shown that stand productivity largely depends upon the quantity of solar energy received in the stand effectiveness of their utilization by trees and storey, quality, number and distribution (spacing) of trees left for growing.

In order to achieve more significant effect of intermediate fellings the authors of the paper had the following tasks: 1) to investigate thoroughly intra– and interspecific regularities of the interaction between trees in the process of creation of ecosystem and formation of natural stands or plantations; 2) to perceive the factors crucially affecting penetration and utilization of solar energy in storey, differentiation of trees, their increment and stand productivity; 3) to create a common theory of forming of the most productive forest and on this basis to prepare the standards for thinning and intermediate fellings in stands of the main tree species and their combination. Application of such standards would ensure maximally possible increment of wood of the best quality and significant sustainability in the whole ontogenesis of a stand.

Methods and the scope of research

For determination of intra– and interspecific regularities of the interaction between trees more than 500 stationary experimental plots have been set up by the authors and followed up from 5 to 25 years. In the plots all trees have been numbered and their biometric and actinometric measurements have been repeated 2–5 times. For spruce, birch, pine and asp some physiological investigations of leaves and needles have been conducted. In more than 300 experimental plots intermediate fellings of different intensity have been carried out 2–5 times. Besides, the data on many other experimental plots have been used. The plots have been delineated in stands of different species composition, structure and age, where different soils prevail. The investigations have been conducted along the following directions:

1. The influence of solar energy use in storeys of stands on productivity has been analysed. The investigations have been conducted experimentally on how to decrease the quantity of solar energy reflected from the stand and increase that getting into the stand. The effectiveness of solar energy use by trees of different classes has been studied.

2. Analysis has been conducted on the spatial structure of pure and mixed spruce, pine, oak, birch and aspen stands. The regularities of stocking of stand with increasing age, the parameters of crowns of trees of different classes, the use of occupied space have been determined. Also the most productive area of horizontal projection of crowns in stands of different age has been searched. Interspecific relations between the crown horizontal projection area, stem diameter and age, optimal crown structure and its change with age have been ascertained. For this purpose for 116 experimental plots the plans of tree distribution and crown horizontal projection have been drawn. Crown horizontal projection area for more than 41 thousand trees, stem diameter and its current increment have been determined.

3. The investigation has been conducted on the rate of tree growth, the peculiarities of crown forming, the productivity if the space occupied by trees as well as on their volume. Inter– and intraspecific relations of trees in the process of crown approach in stands of different density have been analysed. Also such investigations have been carried out annually in specially (identical spacing) established spruce and pine plantations covering density variants 100, 50, 25, 12.5, 6, 3, 1.5 and 0.86 thousand trees per hectare.

4. Analysis has been conducted on the peculiarities of mixed stand growth, on the regularities of formation of their composition and structure. For this the data on 47 permanent experimental plots have been applied.

5. Ecological and phytocoenotic conditions of the growth of oaks, ashes and spruces in mixed stands have been determined. The investigation has been conducted on the changes in daylight illumination of crowns and under them by allowing for the growing stock of a storey. The dependence of the growth in height of oaks, ashes and spruces on daylight intensity, the position of a tree in stand and on the growing stock of the storey of broad–leaved species has been investigated. For this purpose more than 29 thousand measurements of daylight have been made and the height increment of more than 3.700 model oaks, ashes and spruces has been measured.

6. The influence of thinnings and intermediate fellings on the growth of different trees and on the productivity of the whole stand has been investigated. Also the reaction of trees of different classes to the thinning of stands has been clarified. The dependence of volume and the current increment on intermediate felling intensity, growing stock, class structure of trees left after fellings has been determined. Optimal and critical stand thinning and optimal regime

of intermediate fellings in stands of different species composition, structure and age has been ascertained. In order to resolve this issue the data on 309 experimental plots have been used in which recurrent measurements every 5 years have been made from 2 to 5 times and intermediate fellings of different intensity have been carried out also from 2 to 5 times.

The methods used for the whole scale of investigation have been described in detail (Kairiukstis 1961, 1968, 1969, 1972, 1973, Kairiukstis, Juodvalkis 1975, 1976, 1980, 1985, 1986).

Results and discussion

With the aid of investigations it has been determined that the productivity of stand of investigated tree species (*Picea abies* Karst., *Pinus sylvestris* L., *Quercus robur* L., *Fraxinus excelsior* L., *Betula pendula* L., *Populus tremula* L.) in given soil capacity is conditioned by the quantity of solar energy getting into the stand, the effectiveness of its use in trees and storeys, by the quality (class) and productivity of trees forming the stand, by its optimal number and their distribution on an area unit.

While investigating the use of solar energy in storeys (Kairiūkštis 1967, 1968) it has been established that the quantity of the solar energy reflected from the stand (albedo) directly depends upon the inequality (depth) of crown surface: the more the storey surface resembles the stairs, the less the solar energy is reflected and the more of it gets into the stand, at the same time more solar energy is used for creating wood. In case the extent of depth of crowns resembling stairs increases from 1–2 to 7–8 metres albedo diminishes from 16 to 8%. Thus additionally nearly 8% of solar energy penetrates into the stand.

While investigating the effectiveness of the use of solar energy it has been found that the use of solar energy by trees of different classes*) is different (Kairiūkštis 1972). The more productive the assimilation part of trees is, the more wood is produced per unit of absorbed energy. In case the coefficient of sum radiation and beneficial energy use of FAR is equal to 1.0 for trees developing well (class A), for trees weak developing (class B) it is equal 0.8–0.7 while for suppressed trees (class C) 0.7–0.5 (Figure 1). Therefore with the aid of intermediate fellings vigorously developed trees (class AI) that use the solar energy nonproductively, suppressed and weak developed trees (C and B) must be eliminated. By forming the stand from trees of A class it is feasible more economically to use solar energy for producing wood increment. Then less solar energy is used for the upper storey and more favourable lighting conditions are created for the second storey and underwood (Kairiūkštis 1973).

In resolving the issues of forming the most productive forest one of the main problems was to find the method of determining the optimal number of trees or stand density. Under identical conditions stands can attain the highest productivity only at optimal density (Kairiūkštis 1972).

A great deal of different methods optimizing density and the growing stock have been suggested in the special forestry literature. In old times stand density was determined on the bases of investigations (Тимофеев 1957, 1959, Кондратьев 1959, Wiksten 1965, Дитикин 1967, Kazimirov 1972 *et al.*) conducted on the regularities of the growth and forming of plantations established at different density as well as on these of self regenerated stands of different density. Other researchers made an attempt to ascertain stand density on the basis of the correlation between the number of trees, spacing between trees, the area of nutrition different inventory indexes of trees, such as stem diameter, height of a tree, crown diameter etc. (Kohler 1929, Reinecke 1933, Шустов 1933, Beck-

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*) A[1] *Vigorously developed trees which are relatively stable*; grow under excessive environmental conditions always of the upper story, fully lighted, having the thickest stems, gnarled, strongly tapered, not of high technical quality; broad, deep crowns with round-tops, the assimilative mass covering area of the crown is high, the foliage of the type grown in full light and low humidity; medium productivity, with a comparatively high coefficient of profitable utilization of solar energy (CPUSE).

A. Well-developed trees, medium stability; grow under optimal environmental conditions deciduous trees of the 1st (upper) storey, spruce of the 1st-2nd storeys; the upper part of the crowns is lighted; medium and thick stems, with normal taper, of high technical quality; compact crowns with pointed tops; the assimilative mass covering area of the crown is the highest one; foliage of the type grown in shade and medium humidity; high productivity, the highest CPUSE: fast growth in the growing season, and long period of the growth.

B. Weakly developed trees, very unstable; grow under minimum environmental conditions deciduous trees of the 1st-2nd, spruce of the 2nd-3rd storeys, moderately shaded; stems of medium thickness; with little taper and of satisfactory technical quality; crowns of medium length, the assimilative mass covering area of the crown is decreased; foliage of the type grown in shade and high humidity; reduced productivity, low CPUSE; the trees have a medium rate of the growth.

C. Suppressed trees, unstable; grow under insufficient environmental conditions, always in the lower part of the stand, strongly shaded; thin stems, with very little taper, of inferior technical quality; short crowns that are comparatively broad, round-tops; the assimilative mass covering area of the crown is the lowest one; foliage of the type grown in deep shade and very high humidity; low productivity and very low CPUSE; poor rate of the growth in a growing season and short period of the growth.

ing 1954, 1972, 1995 *et al.*). Attempts were made to determine density by allowing for the dependence of the current increment of stand volume on nutrition area of a tree (Томазиус 1978 *et al.*).

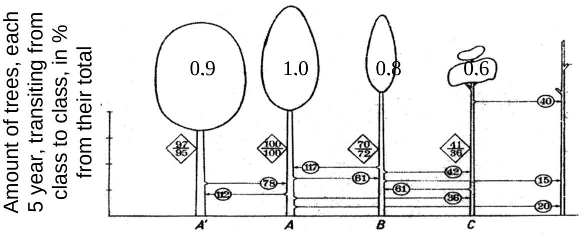

Figure 1. Trees transiting from class to class, their comparative productivity in % from the trees of A class productivity in thinned stands

Indices: in crowns – Coefficient of Profitable Utilization of Solar Energy (CPUSE);
in rhomb: in the numerator comparative productivity of stable trees;
in the denominator comparative productivity of all trees during 5 years, which at the beginning belonged to this class including the productivity of the trees which had transited to other classes over the same period;
in circulars the productivity of trees which have transited from one class to another is shown in the indicated direction. The vertical position of the directional marker indicates the % of trees having transited from one class to another during 5 years

The analysis of the available methods of determining optimal stand density has shown that most of the suggested methods are of theoretical nature. With the aid of them an attempt is made to optimize different constituent parts of a stand while the structure of tree distribution in classes in the stand and its productivity are not taken into consideration. On the other hand, the investigation conducted on a full cycle of ontogenesis (from stand creation process till its maturity) have indicated that density indexes in terms of stand productivity are not univocal. The investigation has been conducted on the growth of plantations established at different initial density as well as on crown approach in the process of coenosis forming. It resulted in revealing a new biological law which we called stress effect of trees in the process of coenosis forming (Kairiūkštis, Juodvalkis 1975). The law enabled us to look newly at density optimization of stands at different stages of their growth and development. It has been clarified that significant changes occur in the mutual relations of trees during the formation of one kind of coenosis. It appeared that the critical limit of crown approach exists. Depending upon generative maturity of given tree species and the height of a tree this limit approximately ranges from 10 to 70 cm. For instance, for spruce it is calculated according to the formula:

$$y = 73{,}2 - \frac{24{,}8}{x}; \quad (\eta=0{,}979)$$

here y – distance between crowns, cm;
x – height of a tree (from 0.5 to 5.0), m.

In case the limit is exceeded the trees are submitted to stress of mutual interaction. Then intensive mutual suppression starts, which reveals itself by a decrease in the increment in all points of the growth (Figure 2). The younger the trees overstep this critical limit of crown approach, the more significant mutual suppression is. Later, when the crowns of trees start closing mutual suppression weakens and the increment of trees again conditionally starts increasing (trees differentiate). It implies that trees already make up coenosis which from the sum of former individuals forms unified homeostatic sustainability of the system.

Such a change in the mutual relations of trees during the creation of coenosis enabled us to infer that it is infeasible to guide by univocal perception of optimal stand density at different stages of stand forming. It appeared that during the creation of young stand optimal density is such when trees do not approach up to the critical limit and there is no negative interaction between individuals, the height and diameter increments of most of the saplings are largest. It poses an assumption to attain the culmination of stand productivity at pole stand age. Thus, optimal young stand density is such when maximal diameter and height increment are ensured for a possibly larger number of individuals. It is calculated according to the formula:

$$N_{opt} = \frac{Q}{S};$$

here Q – the most significant stocking of a storey during crown closing, m^2/ha, S – nutrition area (m^2) per one tree when there is critical distance between crowns.

After finding the law of stress effect in the process of crown approach and after optimizing density of trees in the phase of young stand forming the onset of forest (as coenosis or an ecosystem) functioning has been determined (Kairiūkštis 1992). It appeared that prior to the critical crown approach trees do not affect each other nor do they make up coenosis (ecosystem) or forest.

There was a possibility to prepare a method of determining stand density for already established stands which enables all the constituent parts of stand to be optimized in the rest ontogenesis of forest. The method was created relying on the spatial parameters of tree crowns and on optimal space norm conditioning optimal increment of trees and maximal increment of the whole stand. Crown of trees was taken as the basis of stand density optimization because it is the most informative index. Crown indicates the degree (class) of the development of a tree, its productivity and position in the stand. On the other hand, our investigations have shown that the correlation between the current increment of tree volume and the area of crown horizontal projection is closer (r=0.75) than the area of tree nutrition (r=0.47) or the average distance between trees (r=0.26), i.e. the indexes which for a comparison have been also applied for determining optimal stand density.

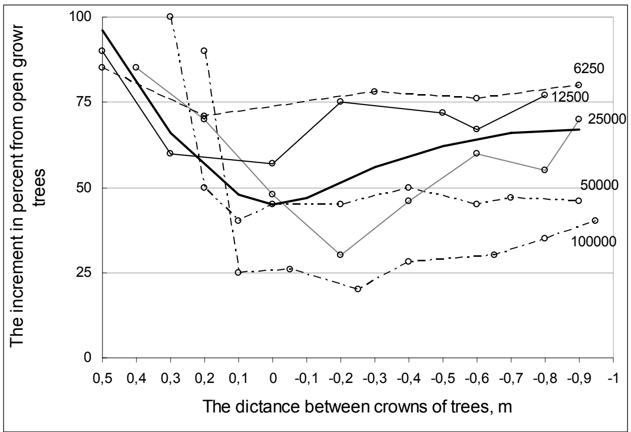

Figure 2. A change in the growth in height of spruces in different phases of crown closing 6250, 2500 etc. tree density, trees/ha

Having investigated the laws of changes in stocking with increasing age of stands (Kairiūkštis, Juodvalkis 1973, 1985) we have ascertained that self–forming stands attain neither maximally possible stocking nor productivity. In stands there are always larger or smaller openings that are not occupied by tree crowns. A part of these openings consists of the areas where trees might grow. However, for some reasons they are absent there another part of these gaps consists of so called inevitable clear spaces which depending upon the species and age comprise from 9 to 30% of the stand area. Thus, in case we deny inevitable clear spaces and artificially insert trees in larger spaces it is possible to calculate maximal storey area and maximally possible crown projection sum (Figure 3) of trees. It has been determined that depending upon species and age maximal storey area makes up from 6.8 to 9.1 thousand m¸/ha while maximal projection sum from 7.4 to 14.2 thousand m¸/ha. Of course, the largest storey area and crown projection sum has been found in spruce stands and the least in aspen and birch stands.

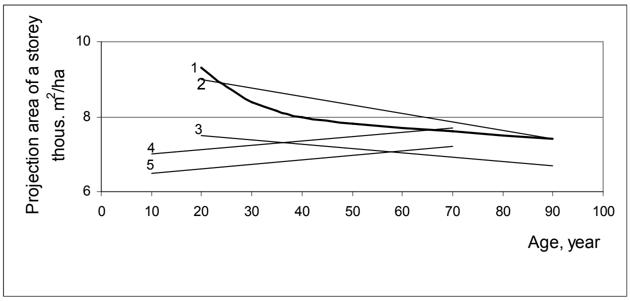

Figure 3. A change in the projection area of a storey according to age in closed natural oak (1), spruce (2), ash (3), aspen (4) and birch (5) stands

While constructing the theoretical model of the most productive forest we have established experimentally the classes of trees and their crown parameters that must occupy maximally possible crown area of a storey in order the stand could give maximal increment. Every stand consists of trees differing in not only in crown parameters but in their productivity. While measuring trees in long–term stationaries over several decades it has been found (Kairiūkštis, Juodvalkis 1980) that within every stand by going from suppressed and weakly developed trees up to well and vigorously developing trees relative crown productivity increases. At a certain size of crown its productivity attains maximum and with further enlargement of crown the productivity starts diminishing (Figure 4). Hence, at a certain age in a stand of every species there is an optimal area of horizontal crown projection. It has been clarified that the parameters of an optimal crown are very similar to the average crown parameters of trees of class A of that stand. It means that in order to achieve maximal stand productivity it is imperative that maximally possible area of a storey be occupied only by crowns of trees of class A.

After determining maximally possible stocking of a storey and optimal parameters of the most productive crowns of trees it was necessary to clarify the spacing between trees, at which the most productive ones should grow, in order maximal stand productivity might be ensured. The investigations conducted on the optimal spacing between trees showed that it was expressed best by crown overlapping. It appeared that with increasing degree of crown overlapping the increment of an individual tree gradually diminishes while that of a stand increases till reaches maximum at a certain degree of crown overlapping. After that stand increment starts diminishing (Figure 5). It means that in every stand there exists a certain degree of overlapping at which maximal stand productivity is attained. Depending upon the species and age it ranges from 4 to 25%. It appeared that optimal degree of crown overlapping is rather similar to the average degree of crown overlapping of trees of class A.

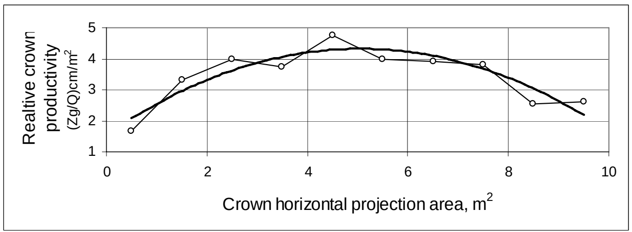

Figure 4. The dependence of relative crown productivity on its size in the stand aged 22 years

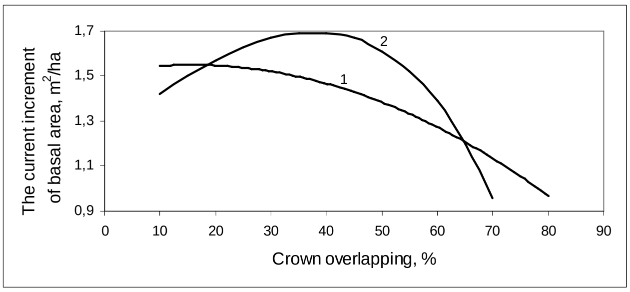

Figure 5. The dependence of the current increment of a tree (1) and stand (2) on percent of crown overlapping in oak stands (*Aegopodio Quercetum*) aged 30 years

$$N_{opt.} = \frac{Q_{max}}{S_{opt}\left(1 - \frac{P_{opt}}{100}\right)};$$

here Q_{max} – refers to the maximal stocking of a storey, m²/ha, S_{opt} – optimal area (m²) of crown horizontal projection of a tree, P_{opt} – optimal crown overlapping, %.

Optimal density determined according to this formula at the given moment allows maximal volume increment and maximal stand productivity also comparative hight but not highest stand stability to be achieved.

On the basis of the determined regularities of the growth of stands and their spatial structure forming the prototypes (models) of the most productive stands were constructed for the main tree species growing in the Baltic sea region according to the prevailing site types and species composition as, for example, shown in Table 1. For practical use optimal number of trees are expressed not from stand age but from the mean height of well developed trees (class A). This enabled to reduce the influence of soil–ecological conditions on the change in inventory indexes and use one model for forest site types similar according to productivity. It allowed us to simplify practical use of standard tables (optimal number of trees) as shown in Table 2.

Table 1. The model of the most productive *myrtillus* spruce stands

Stand age	Stem diameter, cm	Height, m	Crown horizontal projection area of a tree, m²	Sum of crown projection areas, m²/ha	Optimal inventory indexes			
					Number of trees, trees/ha	Sum basal area, m²/ha	Volume, m³/ha	The average distance between trees, m
10	2.0	2.6	1.4	4360	3113	.0	3	1.9
15	4.5	5.1	1.9	4590	2416	3.9	10	2.2
20	6.9	7.5	2.5	5320	2130	8.1	34	2.3
25	9.1	9.5	3.2	6530	2040	13.3	69	2.4
30	11.2	11.3	3.9	7610	1950	19.3	118	2.4
35	13.2	13.0	4.7	8790	1870	25.6	178	2.5
40	15.2	14.5	5.6	9490	1702	30.8	240	2.6
45	17.0	15.8	6.3	9360	1486	33.7	278	2.8
50	18.8	17.1	7.1	9230	1300	36.1	318	3.0
55	20.5	18.3	7.9	9110	1153	38.0	356	3.2
60	22.1	19.3	8.7	8990	1033	39.7	390	3.3
65	23.7	20.3	9.5	8870	934	41.2	420	3.5
70	25.1	21.1	10.3	8760	850	42.1	445	3.7
75	26.4	21.8	11.1	8660	780	42.7	464	3.8
80	27.7	22.5	11.9	8540	718	43.3	480	4.0

Table 2. An optimal number of trees in birch stands of different site types

Height, m	Forest type				
	Myrtillus	Myrtillum–oxalis	Oxalis	Aegopodium oxalido nemorosa	On average all forest types
6	6000	6470	6840	7530	6750
7	5410	5810	6160	6680	6010
8	4880	5220	5540	5920	5350
9	4390	4680	4980	5240	4760
10	3940	4190	4460	4640	4230
11	3540	3750	4000	4110	3760
12	3170	3350	3580	3640	3340
13	2830	2990	3200	3220	2960
14	2530	2660	2860	2850	2630
15	2250	2370	2540	2520	2330
16	1990	2100	2260	2230	2060
17	1760	1860	2000	1970	1820
18	1550	1640	1770	1740	1600
19	1360	1440	560	1530	1410
20	1180	1260	1360	1350	1240
21	1020	1100	1190	1190	1090
22	880	950	1030	1050	950
23	740	820	890	920	830
24	620	700	760	810	720
25	510	590	640	710	620
26		490	530	620	530
27			430	540	450
28				470	380
29				410	320

As illustrated in Table 2, for instance, for all forest sites of birch stands it is feasible to use the average standard (for instance, *Oxalis* type) of an optimal number of trees or three standards (*myrtillus*, *myrtillum Oxalis* and *Oxalis*) at the most because *Aegopodium–oxalido nemorosus* was assigned to *Oxalis* site type.

The peculiarities of mixed stand forming, the dependence of the growth in height of the main tree species on lighting have been investigated. Also the intensity of lighting in different parts of a storey of soft broadleaved stands has been determined. It resulted in constructing the models of the most productive mixed stands (Kairiūkštis, Juodvalkis 1981, 1985). While designing the models the stocking of stands has been allowed for. The optimizing of the structure of trees in mixed forest has been based on the factor of light, namely, that for the main tree species optimal conditions of lighting might be created without reducing the total stand productivity. The models have been constructed for different composition groups of mixed stands.

In all the models (50) optimal inventory indexes of stands are indicated at different stages of their growth and development. However, the optimum is a dynamic concept. What is found to be optimal at the given moment will not be optimal after some time. Therefore in a natural forest practically it is difficult to find a stand in which composition, structure and density might be optimal at the given moment. The most productive stands can be formed by systematically regulating the number of trees. The long term experience of thinnings shows that in terms of stand productivity the regulation of the number of trees has the greatest effect in case thinnings recur optimally and the trees for felling are selected correctly.

After investigating the regularities of the growth and formation of stands thinned by removing trees of different classes and different growth intensity the possibilities were found to increase stand increment by intermediate fellings (Kairiūkštis 1969, Kairiūkštis, Juodvalkis 1986). While analysing a response of trees to different thinning intensities it was noticed that the duration of response of trees left after fellings and additional increment depended on stand age, the extent of thinning and on the stocking of the stand prior to thinning. **The younger the stand, the more intensive the thinning and the more dense the initial growing stock, the more considerable response of trees to thinning and the increment of fostered trees for a longer time exceeds** that a trees growing in stands which were not thinned (Figure 6).

A response of trees to better conditions of the growth is not proportional to the enlargement of the area of the growth nor to a decrease in the stocking of stands. Depending upon tree species and age the diameter increment of trees increases when the stocking of stands decreases only up to 0.6–0.3 (Figure 7). **The stocking below which trees no larger respond to thinning is called minimal stocking phytocoenosis, beyond which the functioning of forest as coenosis or ecosystem as well as the effect of its homeostatic forces cease.** Minimal stocking in young stands is 0.3–0.4, in middle–aged 0.4–0.5 whilst in maturing stands 0.5–0.6. The reducing of the stocking below this limit is not expedient neither from the stand point of biology nor forest management.

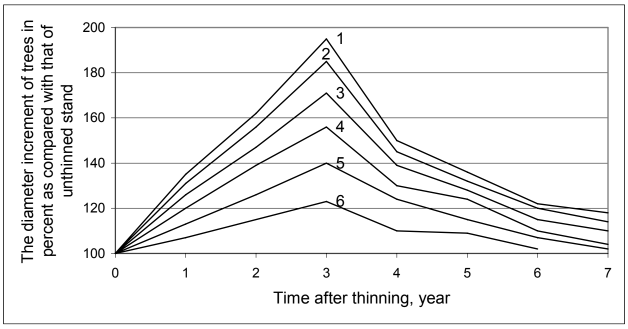

Figure 6. The diameter increment of well developed trees in the thinned 22–year–old oak stand depending upon thinning intensity and the time spare after thinning. Stand volume felled comprised: (1)–60%, (2)–50%, (3)–40%, (4)–30%, (5)–20%, (6)–10%

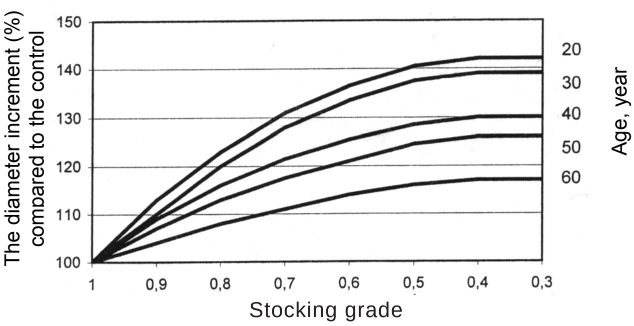

Figure 7. The influence of thinning intensities on the diameter increment of stands aged between 20–60 years

Having determined a response of trees to thinning and to an increase in their increment we investigated: (1) kinds of current increment after thinning and (2) whether the increased increment of trees left after felling can compensate loss of the increment, which the stand incurs after eliminating a part of trees that are increment producers. It has been found that in case stand basal area or their stocking before thinning are identical the increment of thinned stands consisting of soil–lighting and pure additional increment, which result from fellings, will be always larger than the increment of stands where thinnings have not been applied (Figure 8). Depending upon the species and age this difference constitutes from 10 to 85%.

The essence of pure additional increment lies in the fact that the magnitude of the increment of thinned stands depends upon correct selection of trees for felling. In case first nonproductive trees (class C, B, A[1]) are eliminated (felled) stand productivity after felling may be up to 12% larger than the productivity of stand from which at the same thinning intensities proportionally to class structure will be eliminated trees (Figure 9) of all classes. Vici versa, if productive trees (class A) are felled first the stand increment by the same thinning intensity may be reduced up to 20% (Kairiūkštis 1969).

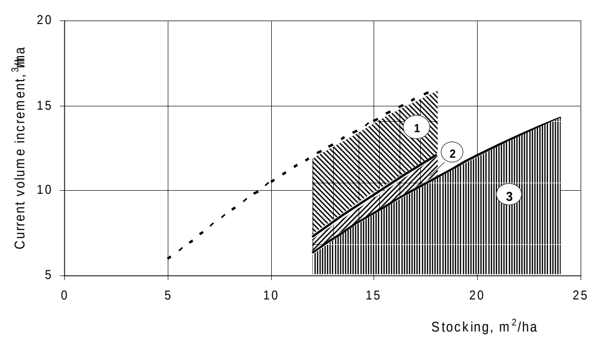

Figure 8. Increment induced by soil–lighting (1), pure additional increment (2) and (3) increment of self–forming stands

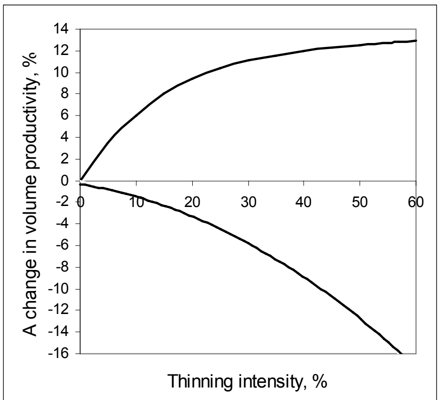

Figure 9. The limits of an increase or a decrease in the current productivity of a storey depending upon the selection of trees for felling

It has been ascertained that if the selection of trees for felling is correct in most cases the increments (pure additional and soil–lighting increment) of thinned stands (even if the stocking of these stands is less than that in self–forming stands) are larger than the increment of stands where thinnings have not been applied (Figure 10).

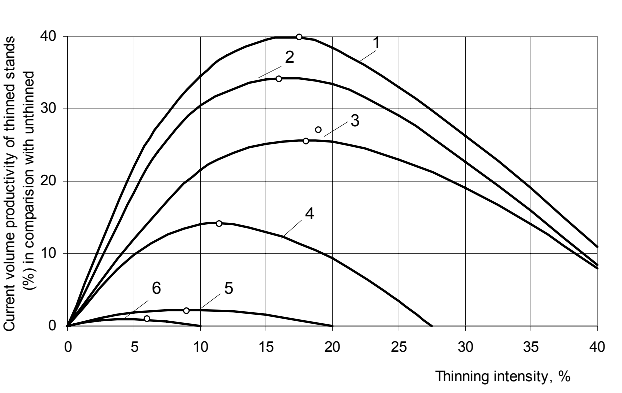

Figure 10. A change in the volume increment (%) of Oxalis spruce stands thinned at different intensities in comparison to that of self–forming (unthinned) stands, 1 – stand aged 24 years; 2 – 27 years; 3 – 25 years; 4 – 36 years; 5 – 56 years; 6 – 58 years; 0 – optimal thinning intensity

It has been determined that under similar other conditions the magnitude of additional increment largely depends upon stand age and thinning intensities. In every age category there exists optimal thinning intensity at which maximal fostering effect is attained (Kairiūkštis, Juodvalkis 1985). With increasing age optimal thinning intensity diminishes (Figure 11). Also the effect of intermediate fellings lessens (Figure 12). In stands older than 60–70 years intermediate fellings are no longer effective. Therefore, any thinning of stands older than 60–70 years reduces their increment, in comparison to that of self–forming – unthinned stands. With increasing stand age not only optimal thinning intensity and the effect of intermediate fellings diminish but also the stocking increases, up to which thinning of stands is feasible without decreasing their increment compared to that of stands which are not thinned. Consequently, in stands older than 60–70 years any regulation of the number of trees for maintaining the largest increment is senseless.

Based on the results of long–term stationary investigations the theory of the most productive forest has been developed. According to the theory also the programmes of forming maximum productive: *Picea abies* Karsten, *Pinus sylvestris* L., *Quercus robur* L., *Fraxinus excelsior* L., *Betula pendula* Roth., *Populus tremula* L. pure and mixed stands according to the prevailing sites in the Baltic region have been created. For practical thinning perposes special tables for each above mentioned species have been established. As one example (Table 3) shows the number of most productive (class A) trees, the distance between them, the basal area and volume of stand to be left after thinning in each table are given. Such tables adopted by the government currently are widely used in Lithuania. They served also for objective quality control of thinnings and intermediate cuttings.

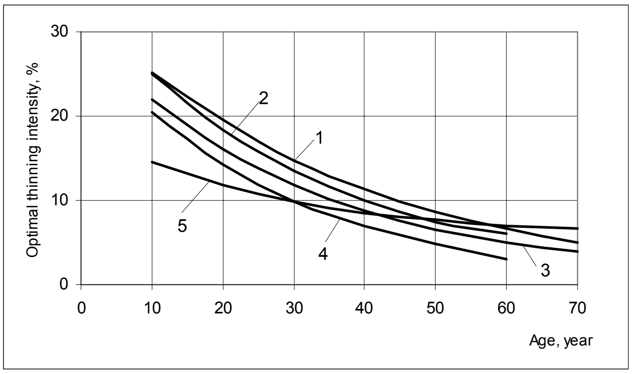

Figure 11. The dependence of optimal thinning intensity on age of different tree species: 1 – spruce stands, 2 – aspen stands, 3 – ash stands, 4 – birch stands, 5 – oak stands

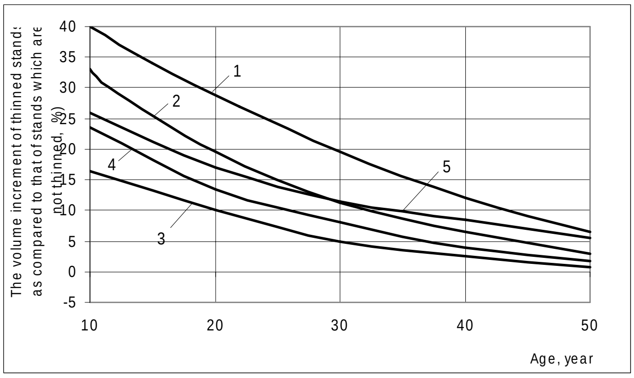

Figure 12. Maximal positive effect of intermediate fellings in different stands. 1 – spruce stands, 2 – aspen stands, 3 – ash stands, 4 – birch stands, 5 – oak stands

General conclusions

The theory of the most productive forest is based on the following determined regularities:

1. In any period of time the largest productivity (the stem increment) of forest (where this or that species grows) depends upon the largest quantity of the energy (least albedo) getting into the stand, the effectiveness of energy consumption in trees and storeys, upon the conformity of tree species for the type of site conditions, upon the quality of trees (classes of tree development) forming the stand, upon their productivity and optimal number of trees properly distributed in the area.

2. The quantity of solar energy reflected from the forest directly depends on the depth of crown surface of a storey: the more stepped the surface of a storey is, the less albedo and the more energy gets into the stand and the more of it is used for producing wood. Trees of different classes use the solar energy differently for creating production. The more productive is the assimilation part of trees (a larger part of light needles and leaves), the larger the increment per volume unit of a stem of a growing tree, the more wood is produced per absorbed energy unit (well developed trees – class A 100%, vigorously developing trees – class A′ 95–97%, weakly developing trees – class B 70–72%, suppressed trees – class C 36–41%). In case the relative coefficient of useful energy use for well developing trees (class A) is equal to 1.0, that for weakly developing trees (class B) is equal to 0.8–0.7 while the relative coefficient of trees of suppressed development (class C) is 0.7–0.5.

Table 3. The number (N) of trees left after felling, the distance between them (1), Basal area (Σg) and the volume in spruce stands when thinnings are repeated every 5 years while intermediate cuttings every 10 years

The height of well developed trees, m	Groups of site types							
	Myrtillus, oxalido–nemorosus, aegopodius				Oxalis–myrtillus, oxalis–hepaticus, Oxalis			
	N, tree/ha	l, m	Σg, m³/ha	V, m³/ha	N, tree/ha	l, m	Σg, m²/ha	V, m³/ha
2	2320	2,2	0,3	3	2410	2,2	0,2	2
3	2310	2,2	0,9	5	2400	2,2	0,7	3
4	2290	2,2	2,0	6	2390	2,2	1,5	4
5	2250	2,3	3,2	9	2370	2,2	2,6	7
6	2200	2,3	4,8	15	2320	2,2	4,1	14
7	2140	2,3	6,6	25	2270	2,3	5,9	24
8	2080	2,4	8,8	40	2210	2,3	7,9	35
9	2000	2,4	11,4	59	2140	2,3	10,0	51
10	1920	2,5	13,9	78	2070	2,4	12,4	68
11	1830	2,5	16,5	101	1980	2,4	14,6	89
12	1740	2,6	19,2	128	1890	2,5	17,1	112
13	1640	2,7	22,1	158	1800	2,5	20,0	139
14	1540	2,7	24,9	188	1700	2,6	22,6	165
15	1430	2,8	27,7	222	1590	2,7	25,1	196
16	1330	2,9	30,0	255	1490	2,8	27,2	228
17	1220	3,1	32,4	287	1380	2,9	29,5	256
18	1120	3,2	34,5	321	1280	3,0	31,3	289
19	1020	3,4	36,3	352	1180	3,1	33,5	320
20	920	3,5	37,9	384	1080	3,3	34,7	352
21	830	3,7	39,2	415	980	3,4	35,9	380
22	740	4,0	40,3	443	890	3,6	37,4	410
23	650	4,2	41,1	470	800	3,8	38,3	435
24	580	4,5	42,0	493	720	4,0	39,3	458
25	510	4,8	42,8	517	650	4,2	40,2	485
26	450	5,1	43,6	540	590	4,4	41,0	510
27					540	4,6	41,7	534

3. During intermediate fellings due to elimination of trees using the solar energy non–productively and by forming the stand from the most productive trees of class A energy capacity of a storey is enlarged and the effectiveness of energy use increased. Energy economy (up to 8% from complete lighting of an open place) results in additional (lighting) increment of the remaining trees and creates more favourable conditions for lower storeys and for the growth of underwood.

4. The critical limit of crown approach has been found in the process of forest (ecosystem) forming. Crowns overstepping this limit induce too early the effect of stress on trees (response, suppression, tolerance) during mutual interaction. In case in young age (the phase of vegetative growth) the overstepping of the critical limit of crown approach is not allowed the density of forest ecosystem (young stand) being formed is optimized. It ensures maximal growth in height and diameter for a maximal number of individuals that can grow on the given area (Invention No. 409677).

5. In self–formed or regenerated stands the largest increment of stems is attained in case the stocking of a storey is maximal (depending upon tree species 68–91% of the stand area) and in case maximally productive (class A) trees grow in the storey at an optimal distance from each other. Optimal stand density is determined according to the spatial parameters of the crowns of well developed trees (class A), according to the maximally possible area of storey projection for the given species, optimal crown overlapping degree and according to the space standards indispensable for trees left till the next thinning, which condition optimal volume increment of trees and maximal volume increment of the whole stand.

6. Having optimized the process of forest ecosystem forming (young stand) as well as the density of closed stands (spatial structure, number of trees, quality, distribution) we designed the prototypes (models) of the most productive stands for pure stands of the prevailing tree species growing in the Baltic region. The site types were allowed for. The models of the most productive stands for mixed forests had been constructed according to the principle that it was indispensable to create optimal (or close to the optimum) daylight illumination conditions for the main tree species without reducing the total stand productivity. For this, the dependence of the growth in height of the main species of trees on daylight illumination in mixed stands and lighting intensity in different parts of a storey of mixed stand was determined taking into consideration the stocking of stand. The models were designed for different groups of mixture of stand composition. All the models incorporate optimal stand inventory indexes when the volume increment is largest at this stage of stand growth and development.

7. In a self–regenerated or planted forest practically it is difficult to find a stand which at the given moment completely would meet the requirements of the most productive forest – standard (optimal density, class structure of trees, distribution) since in the growing forest the optimum of indexes is only for a short time. Optimal parameters (assumption of the largest increment) in stand can be maintained by systematical regulation (partial regeneration, intermediate fellings) of them.

8. Due to a positive change in class structure (leaving trees of class A), which results from thinnings and intermediate fellings, pure additional increment is noted. Its maximal magnitude attains 12%, as compared with that when fellings of the same intensity are carried out without changing class structure of trees. Depending upon stand age and stocking positive magnitude of soil–lighting induced increment after thinnings is found to be 40% of the base increment. Depending upon the sum of these increments the increment of thinned stands is usually larger than that of stands where the stocking is less and the thinnings have not been done.

9. In every age and height category there is an optimal thinning intensity at which the sum increment and fostering effect are most significant. With increasing age optimal thinning intensity and the effect of intermediate fellings lessen. In stands older than 60–70 years any regulation of stand density and structure does not result in enlargement of the increment. With increasing age the stocking augments up to which thinning of stands is feasible without diminishing their increment, as compared with that of stands where thinnings have not been done.

The revealed regularities of pure and mixed stand formation (natural and artificial) make up the theory of the most productive forest forming. It defines the conditions necessary to enlarge the increment and total productivity of forests. On the basis of this theory the models (standards) of the most productive forest were designed and the programmes of constructing such models for pure and mixed stands in forests were developed. In accordance with it (a) the beginning of stand density regulation is the onset of ecosystem (coenosis) forming; (b) after stand closing the most productive (class A) trees are left; (c) for limited intervals of time intermediate felling intensity is optimized by diminishing it with increasing age.

The theory of the most productive forest and clarified regularities provided the foundation for developing the programmes and normatives of thinning and intermediate fellings. The normatives are applied in Lithuania and positively affect the forest productivity and sustainability of stands. These normatives are applicable for forests of North East Europe in carrying out thinnings and intermediate fellings.

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ТЕОРЕТИЧЕСКИЕ ОСНОВЫ ФОРМИРОВАНИЯ МАКСИМАЛЬНО ПРОДУКТИВНОГО НАСАЖДЕНИЯ

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Резюме

В статье рассматривается развитие теории максимально прлдуктивного леса и ее применение в практике лесного хозяйства применительно к чистым древостоям: ели, сосны, дуба, ясеня, березы а также применительно к различным типам их смешения. В основу теории положены долговременные (30–50 лет) исследования естественного и искуственного формирования чистых и смешаных насаждений различной первоначальной густоты (100–0,8 тыс. деревьев на 1 га), растущих на более чем 500 постоянных пробных площадях (с нумерированными деревьями, на многих и с зарисовкой планов площадей проекции крон) на которых переучет проводился каждые 5 лет.

В исследованиях открыто новое явление – эффект стресса деревьев наступающий по мере сближения их крон и образования древесного ценоза (экосистемы). Установлена критическая граница сближения крон, по которой оптимизируется первоначальная густота образующегося леса, тогда как оптимальная густота древостоя (возникшего леса) определяется по максимально возможной для данной породы площади яруса состоявшего из хорошо развитых деревьев и оптимальному проценту перекрытия крон.

Установлено что чем большая ступинчатость древесного полога тем меньше альбедо и тем больше солнечной энергии поступает в экосистему. Постоянный переход деревьев из класса в класс определяет различную степень их развития, различную продолжительность их роста в течении вегетационного периода и различную эффективность использования солнечной энергии на образования единицы (1 куб. м) древесины. Максимальная продуктивность древостоя достигается при условии, когда площадь яруса является максимальной, а ярус состоит из равномерно распределенных по площади деревьев с оптимальным перекрытием их крон в данный момент отличающихся максимальной продуктивностью. В чистых насаждениях это деревья класса II по Крафту, в смешанных – класса A по Кайрюкштису, включая деревья переходящих в указанные классы из менее развитых.

Посредством рубок ухода и другими несплошными рубками регулирование оптимальной густоты, качества деревьев и перекрытия их крон при максимально равномерном их распределении на площади, обеспечивает максимальный прирост древесины лучшего качества по всему циклу онтогенеза чистого леса. При этом также достигается высокая, но не максимальная устойчивость насаждения. В смешанных насаждениях при этом учитывается световое довольствие главной породы и разница высот между ней и второстепенными породами.

В статье приводится основные закономерности формирования чистых и смешанных древостоев, даны некоторые прототипы – модели максимального продуктивных древостоев и програмы рубок ухода, которые обеспечивают максимальный прирост. Установлено, что на определенном возрастном интервале древостоя регулирование рубками ухода густоты и качества древостоя позволяет за счет почвено–светового и чистого дополнительного прироста значительно повысить текущую продуктивность древостоя по сравнении с контрольным насаждением (без ухода). По мере старения древостоя возможность повышения прироста посредством регулирования густоты и качества деревьев резко снижается, так как критическая полнота до которой можно разредить древостой, получая дополнительный прирост, резко повышается.

Ключевые слова: эффект стресса, образование ценоза, оптимизация густоты, продуктивность класса дерева, прирост, рубки ухода.

First Commercial Thinnings in Peatland Pine Stands: Effect of Timing on Fellings and Removals

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Abstract

The aim of this study was to examine the fellings and removals and their dimension distributions in first commercial thinnings in Scots pine (*Pinus sylvestris* L.) stands growing on drained peatlands, when the cuttings are carried out at different stages of thinning maturity. The reference for standard thinning maturity was defined as in the present guidelines for silviculture on upland sites in non-industrial, privately owned pine forests in Finland. Experimental and/or simulated thinnings were applied in altogether fifteen stands representing a wide range in site productivity, climate, and time elapsed since first ditching, and premature (7 cases), mature (11), and over-mature (15) stages for thinning. The average stemwood volumes of fellings were 51, 69, and 92 m^3ha^{-1} and those of harvest removals 36, 59, and 84 m^3ha^{-1} for premature, mature, and over-mature cases, respectively. The removals from stands mature and over-mature for thinning were large enough to enable a commercially profitable harvesting operation in most cases, unlike those from the premature stands where the fellings were barely harvestable and consisted of clearly smaller stems. Considering the obvious trends of increasing supply and simultaneously decreasing price competitiveness of pine pulpwood, our results do not support early thinning unless absolutely necessary from the silvicultural point-of-view. Retarding the thinning until the stage when thinning maturity criteria are actually met, i.e. till stand dominant height of ca. 15 m or even further, would result in markedly better harvesting profitability and hence enhance the implementation of thinnings as a part of the best management practices of peatland stands.

Key words: *Pinus sylvestris*, peatland forestry, silviculture, first thinning, intermediate cuttings, drainage

Introduction

In the boreal forests around the Baltic Sea, peatlands drained for forestry comprise a considerable land base: 4.7 million hectares in Finland (Hökkä *et al.* 2002), 1.6 Mha in the Baltic countries (Zalitis 1990, Kaunisto *et al.* 1991, Ruseckas 1991; cited by Paavilainen and Päivänen 1995), and 1.5 Mha in Sweden (Hånell 1990). Remarkable peatland areas have been drained for forestry also in North-West Russia (Medvedeva and Ionin 1983, Stolyarov *et al.* 1983, Vompersky 1991). Most of the peatland forest area consists of pine peatlands, i.e. sites fairly poor in nutrients (Westman and Laiho 2003) and typically dominated by Scots pine (*Pinus sylvestris* L.) with various admixtures of other tree species, mostly pubescent birch (*Betula pubescens* Ehrh.). As the bulk of these sites were drained during the 1950s to 1970’s, they presently form a large potential supply of roundwood for forest industry. Furthermore, appropriate management of this resource for a sustainable supply of timber in the long-term may demand silvicultural operations on large areas in the very near future. In Finland alone, according to scenarios based on data from the 8th Finnish National Forest Inventory, the potential for annual cuttings in peatland forests may increase up to 15 - 20 million cubic meters in 20 years (Nuutinen *et al*. 2000). Particularly, thinnings in young peatland pine stands and, hence, the supply of pine pulpwood have a potential to increase markedly.

Apart from the silvicultural needs the implementation of the cuttings as well as the demand and the supply of roundwood depend on market conditions. Until recent times, the Finnish and Swedish pulp industries have largely utilized domestic pulpwood supplies, but recently expanded their wood-procurement also to Russia and the Baltic countries (Toppinen and Toropainen 2004). The demand for pine sawlogs is increasing, being higher than supply, in all the Baltic Sea countries, whereas the supply of pulpwood is abundant (Toppinen and Toropainen 2004). This may result in a more or less permanent decrease in the stumpage price of pine pulpwood, especially in relation to good quality saw logs, possibly leading to the situation where thinnings are neglected. Thus, the management applications that would enable profitable thinning harvests and simultaneously enhance the quality and value of the retained crop trees should draw the interest of forest owners in the Baltic region.

In the management of Scots pine, thinnings are widely used to control inter tree competition and to concentrate growth on fewer final crop trees of potentially high value as sawlogs. The basic concept for the present silviculture consists of early non-commercial thinnings in sapling stands followed by one or a few thinnings in more advanced stands with a potential for commercially profitable harvesting removals. Peatland pine stands, which are still mostly derived from naturally regenerated pre-drainage stands, generally differ from those on upland sites by their heterogeneous age and size structure and often clustered spatial distribution of trees (Hökkä and Laine 1988, Penner *et al*. 1995, Sarkkola *et al*. 2004). In such stands, the application of thinning operations and even the determination of thinning maturity is often more problematic than in homogenous stands. Despite the fairly intensive research and development of harvesting technology, the problematic harvesting conditions on peatlands, due to low bearing capacity of the ground and structural unevenness of the stands, often remain as unavoidable constraints to the harvesting operations (Sirén 2004, Väätäinen *et al*. 2004). Even though the structural differences between peatland and upland forests are widely recognized, there are very few studies on the applicability of different thinning regimes in peatland stands.

The profitability of thinning harvesting is known to markedly improve with increased harvesting removals and/or increased average stem size of the harvested trees (Ylimartimo 2001, Sirén and Aaltio 2003). Whole-tree harvesting has sometimes been used as a means of increasing thinning removals but, as this method removes considerably more nutrients from the site than conventional stem wood harvesting (Finér and Kaunisto 2000, Jacobson *et al*. 2000), it may not be a sustainable method on pine peatland sites. Silvicultural thinning guidelines or comparable regulations usually set a minimum limit to the stocking of the retained stand and thus inherently constrain the thinning removal. The timing of the thinning operation in relation to stand stocking or thinning maturity, remains, however, a potential but not much investigated tool in adjusting the harvestable removal. It should be noted that the growth losses and, ultimately, natural mortality potentially caused by delayed thinning may also be different in peatland vs. upland stands because of the differences in stand structure and inter-tree competition.

The aim of this study was to examine the fellings and removals and their dimension distributions in first commercial thinnings of peatland pine stands when the cuttings are carried out at different stages of thinning maturity. This study was part of the project “Quality and yield of pulpwood in drained peatland forests” within the Finnish forest cluster research program Wood Wisdom. Other parts of this project have focused on the variation in wood and fiber properties among peatland pine trees (Rissanen 2003), variation in pulpwood properties of the thinning removals among peatland pine stands (Varhimo *et al*. 2003), and the impacts of different thinning regimes on the post-thinning yields of the retained stands (Kojola *et al*. 2004). We used a set of experimental stands selected to represent a wide variation of drained pine peatland sites in Finland. In addition to experimental thinnings, we used a stand simulator to provide a wider selection of alternative thinning situations in some stands.

Material and methods

The study sites were selected from a set of stands initially meant to be treated with commercial thinnings by the forest owners (i.e. the Finnish Forest Research Institute [Metla], the Finnish Forest and Park Service, Stora Enso, and non-industrial private owners) and where Metla had earlier set up thinning experiments. Thus, the site and stand properties and their management histories (time and manner of stand establishment, timing of first and complementary ditching, pre-commercial thinnings, *etc.*) were well documented and could be used as a basis for site selection.

We selected Scots pine dominated stands that had been managed with pre-commercial thinning at an earlier stage of stand development. The stands represented i) a range as wide as possible of the potential variability in site productivity, climate, and the time elapsed since the first ditching (Table 1), and ii) a premature (dominant height 10-13 m), mature (13-16 m), or over-mature (16-19 m) stage of thinning maturity. Thinning maturity was defined according to the present guidelines for the first commercial thinnings in the forests of non-industrial private owners in Finland (Hyvän metsänhoidon... 2001) and as illustrated in Figure 1. Stand dominant height (H_{DOM}) was used as the primary criterion for thinning maturity but also the level of basal area was used for fine tuning the judgment. Consequently, one site (no 7164) was considered premature due to its low level of basal area despite the dominant height of 15.5 m.

The selected fifteen sites represented the range of peatland forest site types generally managed for pine and they were located on areas drained for forestry

Table 1. Study site properties

Stand id	Municipality	Location N	E	Temp. sum, dd[a]	Site type[b]	Peat depth, m	First ditched	V^c, $m^3 ha^{-1}$	SB-mix[d], %
5770	Kannus	63 60’	23 51’	1068	VT1	0.2	1954	205	35
5916	Viitasaari	63 16’	25 59’	1050	DsT	0.2-0.8	1958	163	1
5922	Pelkosenniemi	67 17’	27 44’	769	MT2	>1	1969	143	2
5923	Pelkosenniemi	67 17’	27 42’	761	MT2	>1	1969	147	5
5932	Rovaniemi	66 21’	26 38’	862	VT2	0.4	1934	100	0
5944	Simo	65 47’	25 19’	962	MT2	0.2	1961	143	40
5945	Kuivaniemi	65 34’	25 28’	982	VT2	0.2-0.5	1957	151	25
5949	Kittilä	67 22’	24 39’	776	MT2	0.9	1971	97	7
5953	Pudasjärvi	65 41’	27 19’	905	MT2	0.7-1.0	1937	153	19
5954	Yli-Ii	65 21’	25 51’	1020	VT2	0.3	1939	219	41
5955	Kuhmo	64 04’	29 20’	967	VT1	0.1	1963	181	34
5956	Puolanka	64 49’	27 22’	939	MT2	0.4-1.0	1967	176	2
5958	Pyhäjärvi	63 38’	25 42’	1039	VT2	0.6-1.0	1973	159	25
5960	Yli-Ii	65 25’	25 41’	1000	MT2	>1	1939	253	20
7164	Ruovesi	61 51’	24 16’	1127	DsT	>1	1967	130	3

[a] Cumulative annual temperature sum with +5˚C threshold value
[b] Peatland forest site types according to Laine (1989):
MT2 = *Vaccinium myrtillus* type 2 [Mtkg(II) in the Finnish nomenclature]
VT1 = *Vaccinium vitis-idaea* type 1 [Ptkg(I)]
VT2 = *Vaccinium vitis-idaea* type 2 [Ptkg(II)]
DsT = Dwarf-shrub type [Vatkg].
[c] Total stand volume before thinning
[d] Combined proportion of spruce and birch of stand volume before thinning

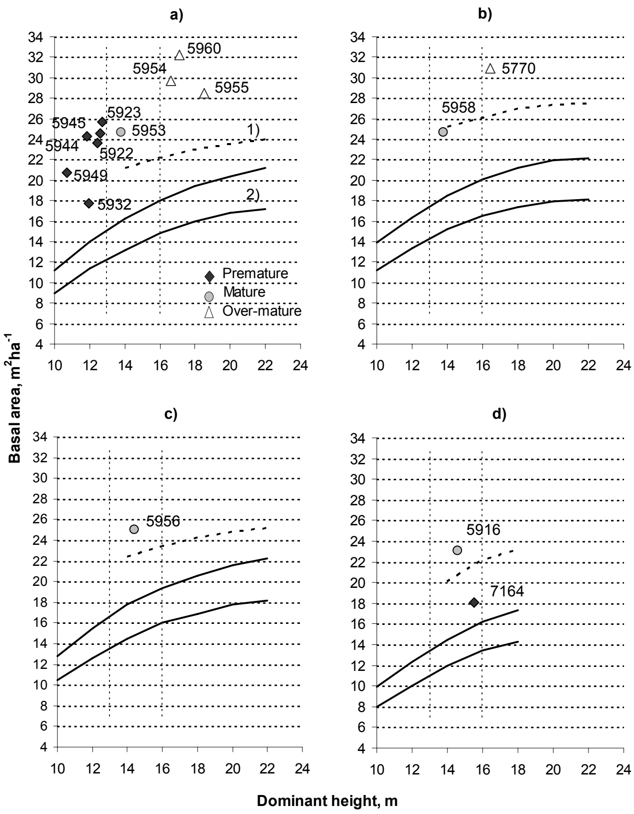

Figure 1. Dominant height and basal area of the stands before thinning, as related to the lines indicating 1) thinning maturity and 2) level of growing stock to be retained after thinning (basal area, minimum-maximum), on different site types (see Table 1) according to the present management guidelines in the forests of non-industrial private owners in Finland (Hyvän metsänhoidon... 2001):
a) VT2 and MT2, North Finland.
b) VT1 and VT2, South Finland
c) MT2, North Finland
d) DsT, South Finland.
Symbols depict thinning maturity; stand numbers refer to Table 1.

between 1934 and 1973 in different climatic regions from south boreal to mid boreal. The dominant height of the stands varied from 10.7 m to 18.5 m (Fig. 1), and total stand volume from ca. 95 up to 250 m^3ha^{-1} (Table 1). The stands contained varying proportions of birch and in some cases also spruce (*Picea abies* (L.) Karst.), mainly as understory mixtures (Table 1). The proportion of standing dead wood varied from 0.1 to 4.5 percent of the total stand volume.

The recently assessed (mapping of individual trees and measurement of tree DBH [diameter at 1.3 m]) control plots of the thinning experiments on the selected sites provided the tree stand framework for applying tree selection (i.e. trees to be retained vs. removed) for this study. This is termed as experimental thinning in the following. The selection of the retained trees was based on favoring externally good quality stems of pine, reducing the spatial inequality, and thinning from below when selecting among otherwise similar candidates. The plot-wise total basal area of the trees to be retained was recorded and adjusted according to the management guidelines (Hyvän metsänhoidon... 2001, Fig. 1).

The trees to be felled in the experimental thinnings were marked and tallied for DBH (minimum 7.5 cm) by tree species, separating dead trees from those alive. Standard stand and tree characteristics were computed for the fellings (total stemwood volume of trees to be cut), removals (merchantable part of stemwood), and retained growing stock using the KPL-software package by Metla (Heinonen 1994). The following minimum top diameters of logs were applied: sawlogs: pine 15 cm, spruce 17 cm, birch 18 cm; pulpwood: pine and birch 7 cm, spruce 8 cm. The technical quality of sawlogs was not taken into consideration. The length of the pulpwood logs was set at three metres. All results were calculated by tree species and by timber assortments.

As the empirical data set from the stands was biased towards the stands premature for thinning, we augmented the cases for mature and over-mature thinnings by applying simulations as follows. First the development of the initially premature non-thinned stands was simulated to meet the criterion of thinning maturity (defined as H_{DOM} = 14.5 m) and a simulated mature thinning was then applied. Secondly, the development of both initially premature and mature stands was simulated until they became over-mature for thinning (H_{DOM} > 16 m) and over-mature thinnings were then applied. For the predictions of stand development and thinnings we used the stand simulation software MOTTI (Salminen and Hynynen 2001) developed in Metla. For peatland stands, the MOTTI-simulator applies distance-independent, individual-tree basal area growth models, including growth responses to thinning, by Hökkä *et al*. (1997), height-diameter models by Hökkä (1997), and tree mortality models by Jutras *et al*. (2003). The need for the ditch network maintenance is predicted using the model by Hökkä *et al*. (2000), and growth responses to the ditch network maintenance are accounted for as in Hökkä and Kojola (2003). For more details about the functioning of the growth and mortality models included in MOTTI, see Hynynen *et al*. (2002). For all simulated thinnings, we applied the same criteria and procedures for log dimensions, tree selection, and calculations of fellings and retained growing stock as for the experimental thinnings described above. Finally, the material consisted of 7 cases of premature, 11 cases of mature, and 15 cases of over-mature thinnings, either experimental or simulated.

Results

The volumes of the fellings varied from 25 to 124 m^3ha^{-1}, and those of the removals from 19 to 115 m^3ha^{-1}, similarly for the experimental and simulated cases (Table 2, Fig. 2). In the stands premature, mature, and over-mature for thinning, the average volumes of fellings were 51, 69, and 92 m^3ha^{-1} and those of removals 36, 59, and 84 m^3ha^{-1}, respectively, when taking into account both experimental and simulated thinnings (Table 2). The fellings comprised 39, 40 and 42% of the initial stand volume in premature, mature and over-mature stands, respectively.

The fellings in premature stands contained smaller stems than in mature and over-mature stands (Fig. 3). The basal area weighed mean DBH of the fellings was 128 mm, 148 mm, and 148 mm in premature, mature, and over-mature stands, respectively. In all maturity classes, the biggest stems of the fellings were individual overstorey trees with a growth history dating back long before drainage. As an average of all cases, the sawlog removal was only 9 m^3ha^{-1}. The proportions of wastewood in the fellings varied between 4 to 47% and they showed a decreasing trend from premature to mature and to over-mature stands.

Table 2. The structure of the fellings and retained growing stock

		Fellings			Retained growing stock					
Stand id	Thinning mode[a]	Removal, m^3ha^{-1}	Wastewood, m^3ha^{-1}	All, m^3ha^{-1}	Basal area, m^2ha^{-1}	Sawlogs, m^3ha^{-1}	Pulpwood, m^3ha^{-1}	Wastewood, m^3ha^{-1}	All, m^3ha^{-1}	n
Stands premature for thinning										
5922	1	56.8	8.4	65.2	12.9	15.2	59.1	3.9	78.2	
5923	1	51.9	14.0	65.9	13.7	13.6	61.8	5.3	80.6	
5932	1	18.8	6.2	25.1	13.4	3.9	65.6	4.9	74.5	
5944	1	33.0	29.6	62.5	13.2	11.1	61.4	8.4	80.9	
5945	1	43.6	24.8	68.4	13.4	14.5	63.6	4.7	82.8	
5949	1	25.5	15.0	40.5	11.5	3.8	48.2	4.3	56.4	
7164	1	24.1	4.1	28.2	14.0	19.7	75.2	6.4	101.4	
Average1		***36.2***	***14.6***	***50.8***	***13.2***	***11.7***	***62.1***	***5.4***	***79.2***	***7***
Stands mature for thinning										
5916	1	55.5	6.4	61.9	14.3	29.3	68.7	3.0	101.0	
5953	1	50.3	9.2	59.5	14.8	28.1	60.0	5.5	93.5	
5956	1	54.4	6.6	61.1	16.7	54.7	56.6	3.2	114.5	
5958	1	37.6	15.7	53.3	17.7	18.0	81.4	6.8	106.1	
Average 1		*49.4*	*9.5*	*59.0*	*15.9*	*32.5*	*66.7*	*4.6*	*103.8*	*4*
5922	2	65.6	6.7	72.3	15.0	32.5	65.9	2.1	100.5	
5923	2	70.4	10.3	80.7	15.0	29.4	68.0	2.1	99.5	
5932	2	75.2	5.0	80.2	15.0	40.1	60.9	1.9	102.8	
5944	2	65.8	16.0	81.8	15.5	22.0	79.1	3.2	104.4	
5945	2	50.7	12.8	63.5	15.5	33.9	68.6	2.3	104.8	
5949	2	69.9	8.1	77.9	15.0	33.9	61.3	2.1	97.3	
7164	2	55.3	5.7	61.0	15.5	35.6	87.0	2.6	125.2	
Average 2		*64.7*	*9.2*	*73.9*	*15.2*	*32.5*	*70.1*	*2.3*	*104.9*	*7*
Average, all		***59.1***	***9.3***	***68.5***	***15.5***	***32.5***	***68.9***	***3.2***	***104.5***	***11***
Stands over-mature for thinning										
5954	1	82.6	12.6	95.3	16.9	32.0	87.1	4.2	123.2	
5955	1	60.9	7.9	68.8	18.1	49.0	59.0	4.4	112.5	
5960	1	114.8	9.5	124.3	16.9	57.8	66.4	4.3	128.6	
5770	1	49.8	23.5	73.3	18.7	47.1	75.3	9.0	131.5	
Average 1		*77.0*	*13.4*	*90.4*	*17.6*	*46.5*	*72.0*	*5.5*	*124.0*	*4*
5916	2	95.0	5.5	100.5	15.0	47.0	69.1	2.0	118.0	
5922	2	79.8	5.5	85.3	17.0	63.6	58.8	1.8	124.2	
5923	2	79.6	6.3	85.9	16.5	56.6	61.7	1.6	119.8	
5932	2	113.1	4.1	117.2	16.5	80.3	44.0	1.4	125.7	
5944	2	84.0	7.7	91.7	17.0	59.6	65.8	2.2	127.6	
5945	2	70.3	7.3	77.6	17.0	64.3	60.1	1.8	126.2	
5949	2	92.7	6.3	99.0	16.5	66.6	52.0	1.7	120.3	
5953	2	74.1	9.2	83.2	16.0	48.8	65.6	1.9	116.2	
5956	2	90.1	5.2	95.2	18.5	91.4	56.4	1.6	149.3	
5958	2	61.3	12.0	73.2	19.0	55.8	89.0	2.8	147.6	
7164	2	109.1	4.9	114.0	16.0	80.8	59.8	1.7	142.4	
Average 2		*86.3*	*6.7*	*93.0*	*16.8*	*65.0*	*62.0*	*1.8*	*128.9*	*11*
Average, all		***83.8***	***8.5***	***92.3***	***17.0***	***60.0***	***64.7***	***2.8***	***127.5***	***15***

[a] 1= experimental thinning, 2 = simulated thinning

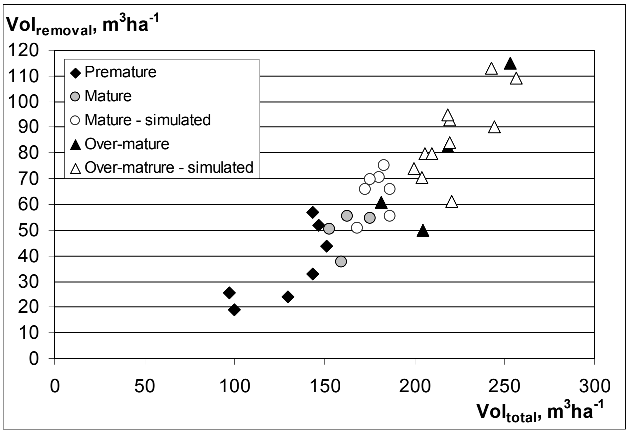

Figure 2. Removals (merchantable wood) in experimental and simulated thinnings relative to total stand volume before thinning

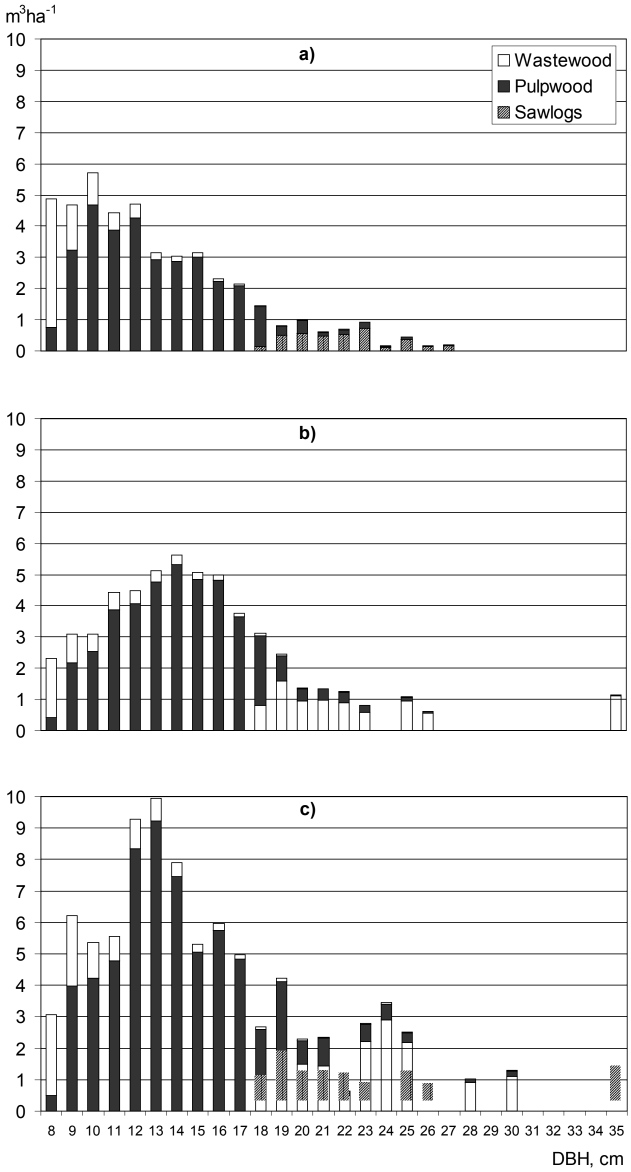

Figure 3. Mean volume (m^{3}ha^{-1}) of sawlogs, pulpwood and wastewood, by diameter class, in the fellings in a) premature, b) mature, and c) over-mature stages of thinning maturity

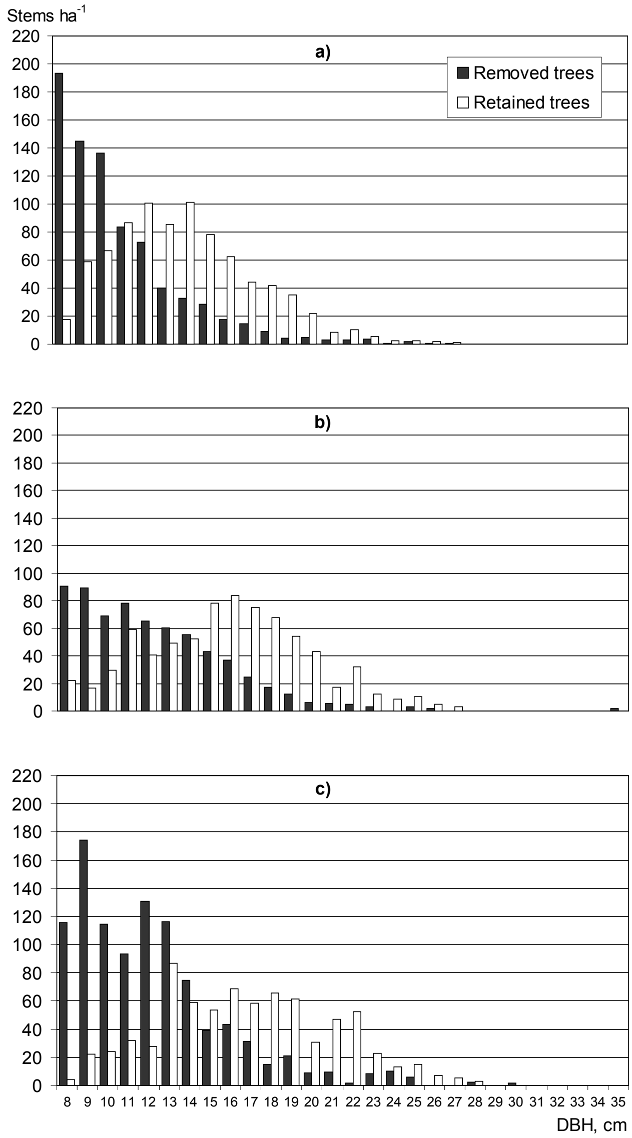

Figure 4. Diameter distribution of the fellings (black bars) and retained stand (white bars) in a) premature, b) mature, and c) over-mature stages of thinning maturity

Thinning decreased the number of trees in the growing stock (including trees with DBH≥7.5 cm) from the initial densities of 1430 - 1780 to 832, 761, and 762 retained stems per hectare in pre-mature, mature, and over-mature stands, respectively (Fig 4). The mean diameters weighed by basal area changed from 145, 167, and 171 to 156, 178, and 188 mm due to thinning in premature, mature, and over-mature stands, respectively. After thinning the retained stand basal area was 12 - 19 m^{2}ha^{-1} and stand volume 56 - 149 m^{3}ha^{-1}, depending on site type, location, and stage of thinning maturity (Table 2).

Discussion

The volume of the thinning removal depended firmly on the stage of thinning maturity, as expected. Thus, in the stands premature for thinning the removal was less than two thirds of that in mature stands. The differences in thinning removals among the maturity groups were due to both the number and volume of the removed trees. Smaller stand volumes, typical of premature thinnings, also contained a larger proportion of wastewood. Thereby, the average volume of wastewood decreased from the premature to the over-mature thinnings by 42%. In four of the seven premature stands the removals were very low, i.e. smaller than 35 m^3ha^{-1}, which is generally considered a limit of profitable harvesting in the first thinnings in Finnish forestry (Ylimartimo *et al*. 2001).

Fellings and removals from simulated thinnings on average were slightly larger than those from experimental thinnings. This was obviously due to somewhat greater stand volumes at the stage of the intended thinning maturity. Kojola *et al*. (2004) observed earlier that MOTTI-simulations underestimated the growth of these experimental peatland stands to some extent. Thus, the larger removals from the simulated thinnings were evidently not due to overestimation of simulated growth. More probably, the reason for the high levels of simulated stand volumes at the mature or over-mature stage of thinning maturity was that we used only dominant height as the criterion of thinning maturity. The increase in stand dominant heights to fully meet thinning maturity led to relatively large stand basal areas, which in turn resulted in large removals of basal area and, consequently, large removals of stand volume in the simulated thinnings.

Most of the removal was pulpwood at all maturity stages. The proportion of merchantable part of the stems is to some extent controlled by the minimum top diameters applied. Lowering the minimum top diameter of pulpwood logs from 7 cm to 5.5 cm would have increased the removal of merchantable wood by 6 - 7 m^3ha^{-1}. Thus, the relative impact of the minimum top diameter is clearly smaller than that of the stage of thinning maturity.

Our results showed larger removals from stands mature for thinning compared to some recent surveys of operational thinnings in peatland stands. For example, Sirén *et al*. (2002) and Sirén (2004) reported the average removal of 23 m^3ha^{-1} and 31 m^3ha^{-1} in northern Ostrobothnia and central Finland, respectively, in drained peatland stands that had been considered to be in need of thinning within the next five years. In eastern Finland, the corresponding average removal was 31 m^3ha^{-1} (Ylimartimo *et al*. 2001). On the other hand, the quantity of the thinning removals in our stands mature for thinning was of the same order as that reported in other studies concerning first commercial thinnings in stands of similar initial stockings. For example, the average volume of thinning removals on drained peatlands in southern Ostrobothnia was 52 m^3ha^{-1} (Tanttu *et al*. 2002).

Our interpretation of the results indicating very small removals in peatland thinnings is that those surveys have simply revealed a common feature of operational forestry, i.e. that the thinnings in drained peatlands tend to be applied relatively early in comparison to the maturity criteria of the present management guidelines (Hyvän metsänhoidon... 2001). This interpretation is supported by the observations in eastern Finland by Ojansuu *et al*. (2002) that first thinnings had regularly been suggested to premature pine stands, i.e. stands not fulfilling the criteria for thinning maturity. One reason for this may be that an urgent silvicultural need for thinning may occur in some but not all parts of the clustered and uneven stands, typical of drained peatlands. Pre-commercial thinnings would reduce such needs for premature first thinnings. Importantly, there is also evidence that delaying first commercial thinning by 2-3 metres in dominant height does not reduce the yield of merchantable wood over the whole rotation, if pre-commercial thinning has been applied (Kojola *et al*. 2004).

For corresponding upland stands, Hynynen and Arola (1999) have reported average removals of 35 m^3ha^{-1} and 64 m^3ha^{-1} in premature (dominant height 13 m) and over-mature (17.7 m) thinnings, respectively. Accordingly, Huuskonen and Ahtikoski (2005) have shown the benefits of delayed first thinnings in upland stands. These results are very similar to our results from peatlands. Thus, our results suggest that thinning removals from peatland stands would be similar to those from upland stands if the thinnings were done at the stage when the maturity criteria are actually met. Accordingly, thinnings in stands properly matured for first commercial thinning, resulting in the average removal of ca. 60 m^3ha^{-1} in our study, would probably enable a profitable harvesting operation in most cases unlike the barely harvestable average removal of 36 m^3ha^{-1} from the early thinnings.

In the management of Scots pine, the aims of the first thinnings are primarily silvicultural, i.e. to minimize self-thinning by reducing competition among the trees, and to allocate growth to the selected crop trees for the remaining part of the rotation. Therefore, the revenue from the removal should actually be a secondary criterion when assessing the benefits of first thinnings. The future development of the stand may be significantly affected by the early-rotation management, and thus, even an unprofitable first thinning may turn out to be profitable in the end. Considering the obvious trends of increasing supply and simultaneously decreasing price competitiveness of pine pulpwood, the managers of peatland pine forests should, however, pay attention to applying the necessary thinnings in a most profitable manner. This study, along with earlier findings on the impacts of thinnings on the yield of the retained stands (Kojola *et al*. 2004), suggests i) not to apply too early thinnings due to small and poorly profitable harvest removals unless absolutely necessary from the silvicultural point of view, and ii) to apply even rather heavy thinnings in stands properly meeting the criteria for thinning maturity.

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ВЛИЯНИЕ СРОКОВ ПЕРВОГО ПРОРЕЖИВАНИЯ НА ОБЪЁМ ЗАГОТОВЛЕННОЙ ДРЕВЕСИНЫ В БОЛОТНЫХ ЛЕСАХ С ПРЕОБЛАДАНИЕМ СОСНЫ

С. Койола, Т. Пенттиля, Р. Лайхо

Резюме

Настоящее исследование ставило своей целью определение объёма и структуры вырубленной и фактически заготовленной древесины при первых прореживаниях, проведенных на разных фазах созревания древостоя в осушенных болотных сосняках (*Pinus sylvestris* L). При определении спелости древостоя на обследованных участках леса в качестве рекомендованной нормы прореживания была принята действующая в Финляндии модель ухода за частными сосновыми лесами. Рубки прореживания на опытных участках и дополнительно смоделированные рубки были осуществлены на 15 участках лесных насаждений. Это – участки, широко представляющие разные места произрастания сосны на осушенных болотах, климатические зоны, разные сроки с первой прокладки осушительных канав, а также различные по фазам созревания древостоя участки: от слишком раннего прореживания (7 участков) до своевременного, соответствующего рекомендациям (11) и запоздалого прореживания (15). Средний объём вырубленной древесины составил при раннем прореживании 51 м^{3}га$^{-1}$, при рекомендованном – 69 м^{3}га$^{-1}$, а при запоздалом прореживании – 92 м^{3}га$^{-1}$. Соответственно, фактические объёмы заготовленной древесины составили при раннем прореживании 36, при своевременном – 59 и при запоздалом – 84 м^{3}га$^{-1}$. Выход древесины при рекомендованных и запоздалых рубках прореживания был достаточно высоким, что говорит о возможности рентабельной заготовки древесины при первом прореживании в отличие от ранних рубок ухода, при которых нельзя ожидать достаточной рентабельности из-за малых объёмов вырубляемой древесины и малого среднего объёма стволов. Учитывая явный рост поставок соснового баланса и одновременное снижение конкурентоспособности цен, результаты исследования не поддерживают проведения раннего прореживания, кроме необходимых для ухода за лесом случаев. Но с другой стороны, задержка с прореживанием до созревания древостоя и достижения им критериев спелости (например, преобладающая высота ствола около 15 м или выше) может повысить рентабельность рубок. Это в свою очередь будет способствовать проведению рубок прореживания в качестве положительной лесоводческой практики в болотных лесах.

Ключевые слова: *Pinus sylvestris,* болотные леса, лесоводство, первое прореживание, рубка прореживания, осушение.

Initial Effects of Wood Ash Fertilization on Soil, Needle and Litterfall Chemistry in a Scots Pine (*Pinus sylvestris* L.) Stand

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Abstract

Initial effects of wood ash and/or N fertilization were investigated in a field experiment located in a 38-year-old Scots pine stand on a Haplic Arenosol in Kačerginė, Lithuania. There were in total six treatments, three levels of wood ash addition (1.25, 2.5 and 5.0 t ha^{-1}), one level of N addition (180 kg N ha^{-1}), one combined treatment (2.5 t ha^{-1} of wood ash and 180 kg N ha^{-1}) and one untreated control. The treatments were repeated in four blocks.

The pH_{CaCl2} of the O horizon increased from 3.45 (control) to 6.15 for the highest ash dose and exchangeable Ca^{2+} and Mg^{2+} increased significantly ($p<0.001$). There were no changes in the mineral topsoil (0-5 cm) for the acidity but exchangeable Ca^{2+} and Mg^{2+} increased significantly ($p<0.05$) compared to the control for the highest ash treatment. Soil solution concentrations of Ca^{2+}, Mg^{2+} and K^{+} increased at 20 cm depth as a result of the ash treatment but at 50 cm depth only Mg^{2+} concentration was higher than the control. Leaching of NO_3^- and NH_4^+ increased in the N treatment compared to the control but no effect of the ash treatment was observed.

The wood ash increased the concentration of Ca in the current year but not one-year-old needles 6 months after the application. N concentration in the current and one-year-old needles and even litterfall increased as a result of the N treatment. Ca uptake seemed to be stimulated by high N availability as indicated by high Ca concentrations in needles from the N treatment. There were no other indications of interactions between the ash and N treatments.

Key words: wood ash, Scots pine, Arenosols, soil solution, needles, litterfall, chemical composition

Introduction

Biofuel extraction from forest through whole-tree harvesting where the fraction not used as commercial round wood is used for production of biofuel is steadily increasing (Kaberger 1997). Wood fuel in the near future can constitute a substantial proportion of primary energy sources in Lithuania. Due to an increase in production in the wood processing industry, the amount of wood residues is increasing and a concomitant increase in residues used for fuel has been observed. Each year, about 30% (close to 0.8 Mm^3) of the biomass is left on clearfelling sites and this can be used as fuel wood in future (Kairiūkštis and Jaskelevičius 2003). The increase in biomass export from the forest through whole-tree harvesting compared to traditional logging is rather small, between 15-30% by weight (Ingerslev *et al.* 2001). However, the export of nutrients from the forest ecosystem increases considerably, since the exported fractions branches, needles and tops have higher concentrations of nutrients than the stem-wood. Depending on nutrient and harvesting method, the increase in export when changing from conventional to whole-tree harvesting ranges from around 40% (P) to 180% (Mg) (Eriksson and Rosen 1994). In addition to the loss of nutrients, whole-tree harvesting intensifies the build-up of acidity in the soil that is caused by the excess uptake of cations over anions by trees (Olsson *et al.* 1996). To obtain a more sustainable utilisation of biomass fuels, the ash resulting from combustion of biofuels can be recycled back to the soil.

The major reasons for recycling wood ash would then be to return essential mineral nutrients to the forest and to counteract increasing soil acidity. Another argument that has been used to advocate ash amendments is the preservation of plant species diversity (Ohno and Erich 1990; Levula *et al.* 2000). The introduction of landfill taxes and more demanding regulations on landfill construction have also increased the cost of depositing the ash on landfill, making the returning of the ash to the forest a cheaper alternative. Thus, wood ash recycling to forests will probably increase since ash production is increasing and forest land is available and usually found close to ash producers.

Wood ash consists of inorganic minerals and organic compounds remaining in the ash due to incomplete combustion. The major proportion of the minerals in the ash is a mixture of oxides, hydroxides, silicates and carbonates of the base-forming cations. Apart from N, which is volatized during combustion, all the macronutrients are found in the ash. Some of the oxides and hydroxides in the ash dissolve easily in water and produce a strong alkaline reaction (liming effect) (Ljung and Nordin 1997). The solubility and the potential plant availability of the macronutrients in the ash are high, with the possible exception of P, and follows the order K>Mg>Ca>P (Eriksson 1998b).

The addition of wood ash usually increases pH and base saturation in the O horizon. The effect is more drastic if raw ash is used as compared to aggregated ash (Bramryd and Fransman 1995; Arvidsson and Lundkvist 2003; Saarsalmi *et al.* 2001).

The pH and base saturation seem to stabilize at a higher level 5-10 years after application and remain at a higher level for a long period of time (Bramryd and Fransman, 1995; Arvidsson and Lundkvist 2003; Saarsalmi *et al.* 2001). The effect on pH and acidity in the mineral soil, if found at all, is by far less pronounced and appears much later after the treatment than in the O horizon (Bramryd and Fransman 1995; Levula *et al.* 2000; Saarsalmi *et al.* 2001).

The effects on the individual cations differ considerably. The relative proportions of exchangeable K^+ and Mg^{2+} compared to Ca^{2+} decrease when the soil is treated with ash (Arvidsson and Lundkvist 2003). This may occur even if the amount of exchangeable K^+ increases, since the CEC increases after wood ash application (Arvidsson and Lundkvist 2003; Saarsalmi *et al.* 2001).

There are only a few studies on the possible leaching of nutrients after wood ash application. Arvidsson (2001) found no treatment effects on pH and soluble Al^{3+} in the soil water sampled at 50 cm depth following application of hardened and crushed wood ash at four different locations in Sweden during a period of 6 years after application. Furthermore, no differences in pH and soil solution acidity were found between treatment and control catchments at 30 cm depth during a 5-year period after wood ash application to forested catchments in central Sweden using a granulated wood ash (Fransman and Nihlgård 1995).

While the effect of wood ash application on pH of the soil solution in mineral soil is rather weak, there are consistent observations of increased downward transport of base-forming cations. Arvidsson (2001) found higher concentrations of Ca^{2+}, Mg^{2+} and K^+ in the soil solution at all of four different field experiments using two different crushed ash types, while Rumpf *et al.* (Rumpf *et al.* 2001) observed increased concentrations of both Ca^{2+} and K^+ below the organic layer and at 10 cm and 100 cm depth in the mineral soil.

Earlier studies on needle chemistry in Scots pine have revealed no or rather small and transient effects on Ca and K after wood ash treatments (Moilanen and Issakainen 2000; Vuorinen and Kurkela 2000; Jacobson 2001). Since wood ash amendment in tree stands on the mineral soils usually does not give any positive growth response in the tree stand (Saarsalmi *et al.* 2004; Jacobson 2001; Sikström 1992), a simultaneous addition of N has been proposed, especially on poor sites (Jacobson 2001). The effects of a combined N and wood ash amendment might be different compared to amendment with ash alone, *e.g.* concerning leaching and litterfall chemistry. There are few such studies in the literature. We are currently studying the ecological effects of wood ash application with and without N addition in a Scots pine stand in a field experiment in Kačerginė, Lithuania. Even though wood ash amendment should be considered a long-term measure in forestry, the most drastic changes are likely to occur directly after application of the ash. Better knowledge of the initial processes will facilitate the interpretation of the long-term effects. In this paper we describe how the application of raw wood ash affected the soil, soil solution, needle and litterfall chemistry in the first year after application.

Materials and methods

In 2002, a field experiment was established in SW Lithuania, in the Kačerginė forest district (54°55´N, 23°43´E) of the Dubrava Experimental and Training Forest Enterprise. The experiment was set up in a first generation Scots pine (*Pinus sylvestris* L.) stand, planted in 1964, on a sandy limnoglacial plain overlying old fluvioglacial sands. The soil is classified as a Haplic Arenosol (ISSS-ISRIC-FAO, 1998) (Table 1). The initial planting density was around 8 000 plants ha^{-1}. The bottom vegetation lay-

Table 1. Soil profile horizons and their basic characteristics for the Haplic Arensol used in this study. Horizon designation and subscripts (l – litter; lf – litter and fermentation; p – ploughing; s – illuvial accumulation of sesquioxides) according to FAO (1990)

Horizon	Depth, cm		pH ($CaCl_2$)	N, g kg^{-1}	C, g kg^{-1}	Texture
	upper	lower				
O_l	-2	-1.5	-	7.47	519	
O_{lf}	-1.5	0	3.5	12.2	463	
E	0	1	3.5	0.91	19.0	medium sand
A_p	1	30	4.3	0.20	3.41	medium sand
B_s	30	65	4.8	0.04	0.41	medium sand
C	65	100	4.8	0.02	0.06	medium sand

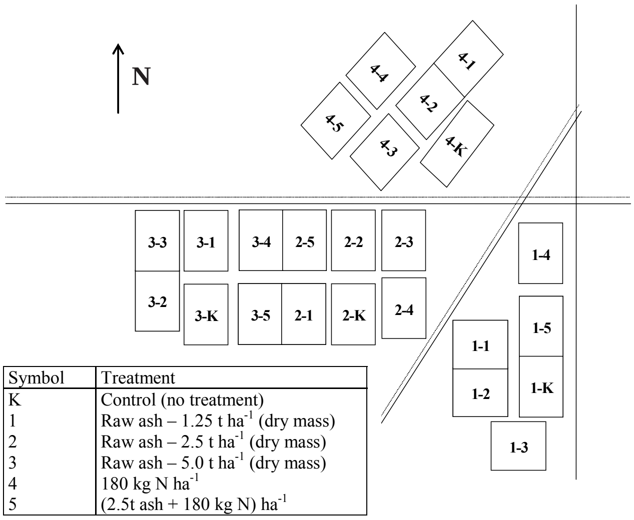

Figure 1. Experimental design of the wood ash fertilization experiment

er is dominated by mosses, with the most common species being *Pleurozium schreberi* (Brid.) Mitt., *Dicranum polysetum* Sw., *Dicranum scoparium* Hedw. and *Hylocomium splendens* (Hedw.) Schimp. The coverage of vascular plants is low (~ 7%) and the most common species are *Festuca ovina* L. and *Calluna vulgaris* (L.) Hull. This forest type of Scots pine stand is common in Lithuania. The experiment consists of 24 plots (25x20 m^2) grouped into 4 blocks with 6 treatments in each block: 1) 1.25 t ha^{-1} of wood ash; 2) 2.5 t ha^{-1} of wood ash; 3) 5.0 t ha^{-1} of wood ash; 4) 180 kg ha^{-1} of N; 5) 2.5 t ha^{-1} of wood ash + 180 kg ha^{-1} of N; and 6) untreated control (Fig. 1). The raw wood ash from a district heating plant and N fertilizer (ammonium nitrate) was spread after the installation of the tension lysimeters on 25 - 27 June 2002. The chemical composition of the wood ash applied is presented in Table 2.

Table 2. Chemical composition of the wood ash applied in the field experiment

Macronutrients, g kg^{-1}		Heavy metals, mg kg^{-1}	
P	2.15	Cr	9.51
K	5.29	Cd	0.62
Ca	72.0	Pb	4.53
Mg	9.45	Ni	8.05
		Cu	13.1
		Zn	73.7

The first soil sampling was carried out in October 2002, five months after wood ash application. From each plot, 20 soil sub-samples were collected from the O horizon, and from the upper layers of mineral soil (0-5, 5-10, and 10-20 cm). The soil samples were pooled to produce one composite sample from each depth and plot. Soil pH was measured with a glass electrode in the soil: water suspensions (1:2.5 W/W) in 0.01 M $CaCl_2$ for all soil samples collected. The soil chemical analyses were performed only on the O horizon and the 0-5 cm horizon samples according to the methods described in ICP-Forests manual (UNECE, 1998). The concentration of total N was analysed according to the Kjeldahl method. Total organic C was analysed by dry combustion at 900°C. *Aqua regia* extracts were prepared for the determination of total concentrations of macronutrients in the soil. In these extracts, Mg and Ca were analyzed by atomic absorption spectrophotometer (AAS), K by flame photometer and P using standard colorimetric methods. Exchangeable cations were determined in 0.1 M $BaCl_2$ extracts. Exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ were determined using the same methods as described above and exchangeable Al ions were determined by titration of the $BaCl_2$ extract.

Soil solution was sampled at 20 cm and 50 cm depth by tension lysimeters (P80 ceramic cups by Ceramitech) in April-May 2003. The lysimeters were installed systematically in all treatments and in the control. Altogether 144 tension lysimeters were installed, 6 in each plot (3 replicates per depth and plot). The lysimeters were de-pressurized to -70 kPa for sampling of soil solution.

The soil solution samples from both depths were analyzed for NH_4, NO_3, P, K, Ca, Mg ions, and DOC. NH_4^+ was determined by a colorimetric method (hypochlorite), NO_3^- spectrometrically using sulphasalicilic acid. P was determined as molybdate-reactive P by a colorimetric method. K^+ concentration was measured by flame photometer, Ca^{2+} and Mg^{2+} by AAS and dissolved organic carbon (DOC) by a titrimetric method (UNECE 1998).

Needles were sampled from 5 Scots pine trees in each plot. Sampling trees belonging to Class II according to the Kraft classification were chosen. The current year and one-year-old needles were sampled from the 5-7th whorl from the upper 1/3 of the crown in October 2002.

The needles were removed from the twigs and grouped in two groups according to the age: current year and one-year-old needles. Before analysis, equal quantities of each of the five samples from each plot were pooled to form a composite sample and were dried at 60°C for 24 hours (UNECE 1998). Total N was analysed by the Kjeldahl method. For the determination of total P, K, Mg, and Ca, the needles were dry-ashed at 500°C and the residue was dissolved in 20% HCl to bring the mineral elements into solution. P was determined by the V-Mo-blue colorimetric method, K by flame photometry and Ca and Mg by AAS.

Litterfall has been monitored continuously since July 2002 and was sampled from 144 litter traps in the Scots pine stand or 6 litter traps in each plot (surface area of a trap – 0.25 m^2) at the height of 1 m above the ground. The traps were made of wood and cotton bags allowing throughfall to percolate easily. Litterfall was collected every 4 weeks in spring, summer and autumn and once in wintertime, emptied in paper bags. Composite samples, made from 6 traps per plot, were air-dried and sorted into four fractions: needles, twigs and branches, bark and scales, and cones. The litterfall needles collected in May 2003, nine months after wood ash application, were analyzed in this study. The sorted samples were oven-dried at 60°C for 48 hours and weighed. The concentrations of N, P, K, Mg, and Ca were analysed in the litterfall needles using the same method as described above.

The data from the experiment have been statistically evaluated by ANOVA using the following model:

$$y_{ijk} = \mu + \alpha_i + \gamma_j + (\alpha\gamma)_{ij} + \beta_k + \varepsilon_{ijk}$$

where *y* is the estimated mean and *i*, *j* and *k* represent wood ash treatment, N addition and block, respectively. In cases where the model did not show significant differences (p>0.05) the eventual effects of single treatments were considered non-significant. It should be observed that the experiment was not balanced, since the wood ash treatments 1.25 and 5.0 t ha^{-1} did not have any combined treatment with N. In the event of significant effects, the direction of change and test of significance between treatment levels were investigated by pairwise t-tests.

Results

Chemical changes in the soil and soil solution

The pH of the O horizon (organic layer) increased from pH_{CaCl2} 3.45 (control) to pH_{CaCl2} 6.15 (5.00 t ha^{-1} of ash) three months after the application (Fig. 2A). The increase in pH was proportional to the wood ash dose. There was no significant difference in pH_{CaCl2} of the mineral topsoil (0-5 cm) between the treatments (Fig. 2B), nor in the layers below (data not shown).

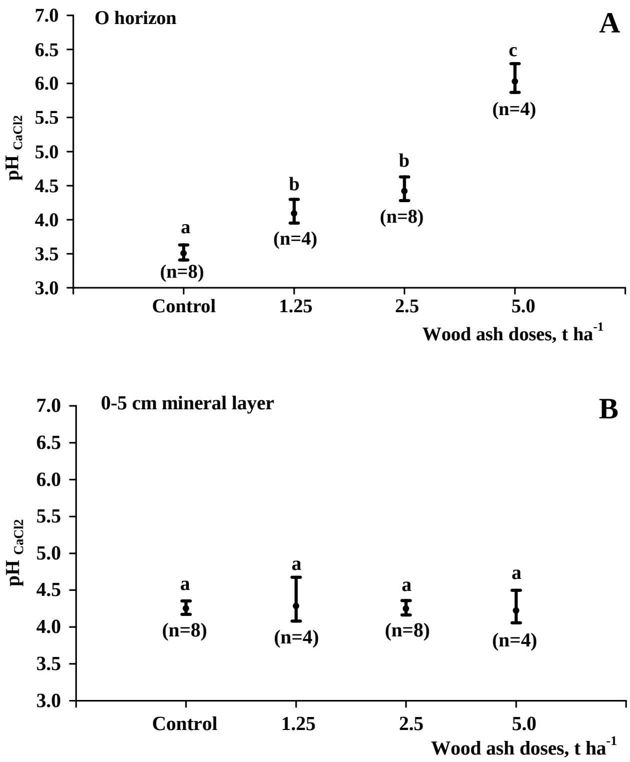

Figure 2. Effects of the wood ash treatment on average pH_{CaCl2} of the O horizon and the 0-5 cm layer of the mineral soil. The error bar indicates 95% confidence interval. Averages marked with the same letter are not significantly different (p<0.05).

Increases in *aqua regia*-extracted Ca and Mg in the O horizon were statistically significant between each wood ash treatment following a dose-response relationship (Table 3, Mg data not shown). For *aqua regia*-extracted K, all wood ash treatments and for *aqua regia*-extracted P the two highest wood ash treatments were significantly different from the control in the O horizon. The N treatment (180 kg N ha^{-1}) did not result in any statistically significant change in total N in the O horizon (Table 3).

The application of wood ash significantly increased the concentration of exchangeable Ca^{2+} and exchangeable Mg^{2+} in the O horizon but had only a

Table 3. Effects of the wood ash and N treatment on the mean concentrations of different elements in the O horizon and the 0-5 cm layer of the mineral soil. Uncertainty is given as 95% confidence intervals. Evaluation of treatment effects by ANOVA (see Materials and Methods). Values followed by the same letter in each column and depth are not significantly different from each other. All the significant effects presented in the table refer to the ash treatment. There were no significant effects caused by the N treatment

Treatment	N		P		K		Ca	
	mg g^{-1}							
				O horizon				
Control	12.0^{a}	±0.30	0.64^{a}	±0.12	2.90^{a}	±0.48	4.10^{a}	±0.31
1.25 t ha^{-1} ash	11.2^{a}	±1.1	0.78^{ab}	±0.10	3.98^{b}	±0.54	9.75^{b}	±1.95
2.5 t ha^{-1} ash	11.0^{a}	±1.05	0.83^{b}	±0.05	4.28^{b}	±0.65	13.7^{c}	±4.01
5.0 t ha^{-1} ash	9.45^{a}	±1.14	1.10^{c}	±0.04	7.40^{c}	±1.13	28.9^{d}	±3.29
2.5 t ash + 180 kg N ha^{-1}	10.6^{a}	±1.08	0.90^{b}	±0.23	4.78^{b}	±0.68	14.6^{c}	±3.87
180 kg N ha^{-1}	11.9^{a}	±1.08	0.66^{a}	±0.08	2.18^{a}	±0.22	4.60^{a}	±1.40
				0-5 cm				
Control	0.50^{a}	±0.10	0.27^{a}	±0.03	11.6^{a}	±1.27	3.03^{a}	±0.44
1.25 t ha^{-1} ash	0.44^{a}	±0.09	0.29^{a}	±0.03	10.5^{a}	±1.99	2.55^{a}	±0.46
2.5 t ha^{-1} ash	0.54^{a}	±0.02	0.29^{a}	±0.05	11.4^{a}	±0.52	2.84^{a}	±0.18
5.0 t ha^{-1} ash	0.54^{a}	±0.12	0.32^{a}	±0.04	11.7^{a}	±0.41	3.08^{a}	±0.45
2.5 t ash + 180 kg N ha^{-1}	0.47^{a}	±0.11	0.29^{a}	±0.04	12.1^{a}	±0.72	2.91^{a}	±0.65
180 kg N ha^{-1}	0.44^{a}	±0.05	0.30^{a}	±0.07	11.6^{a}	±0.42	2.93^{a}	±0.36

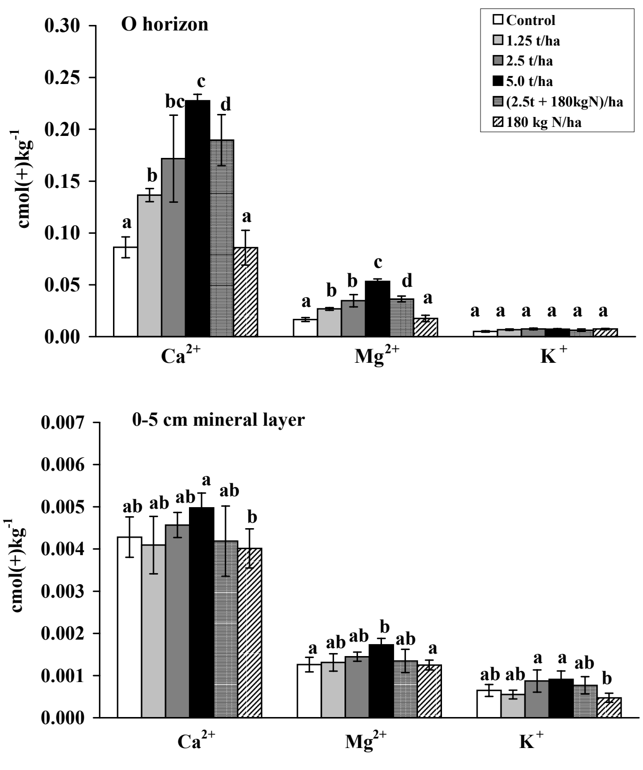

Figure 3. Effects of the wood ash treatment on the concentrations of exchangeable Ca^{2+}, Mg^{2+} and K^{+} in the O horizon and the 0-5 cm mineral layer of the soil. The error bar indicates 95% confidence interval. Averages marked with the same letter are not significantly different

small influence on the concentration of exchangeable K^{+} (Fig. 3). Although the differences were much smaller and there were fewer statistically significant differences, the same treatment effects were found in the 0-5 cm mineral layer as in the O horizon.

Nitrate (NO_3^-) and NH_4^+ concentrations in the soil solution were significantly higher for the N treatment than for treatments that had not received any N addition, both at 20 cm and 50 cm depth (Table 4). The concentration of NO_3^- was higher at 50 cm depth than at 20 cm depth for the N (180 kg N ha^{-1}) treatment. There was a weak tendency, although not significant, towards elevated NO_3^- concentrations in the 5.0 t ha^{-1} ash treatment but the NH_4^+ concentrations remained very low (<0.1mg L^{-1}) for all ash treatments. Phosphorous showed no treatment effects at any depth but the K^{+} concentration at 20 cm depth was significantly higher for the 5.0 t ha^{-1} ash dose compared to other treatments. Calcium ions and Mg^{2+} had significantly higher concentrations in the soil solution in the two highest ash treatments but only the Mg^{2+} concentrations remained significantly higher at 50 cm depth. The concentrations of Ca^{2+} and Mg^{2+} followed a dose-response relationship for the ash treatments. However, it should be noted that the highest Ca^{2+} concentrations were found in the combined ash and N treatment at both depths and that the Mg^{2+} concentrations were higher in the combined ash and N treatment than in the ash treatment with a corresponding ash dose (2.5 t ha^{-1}). The spatial variation in the DOC concentrations was high. There was a tendency for elevated DOC levels at the high ash doses at both depths, but there were no significant effects.

Chemical changes in needles and litterfall

There were no significant effects on N concentrations in the current, one-year-old and litterfall needles 6 months after the application of 5.0 t ha^{-1} of wood ash. The N concentration was significantly higher ($p < 0.05$) in the plots treated with 180 kg N ha^{-1} compared with the control in the current year, one-year-old and litterfall needles (Fig. 4, litterfall data not shown). The N concentrations in both the current year and one-year-old needles were similar. However, the differences in N concentrations due to treatments were more evident in the current year needles than in one-year-old and litterfall needles. The N concentrations in the one-year-old needles were higher compared to the concentrations in litterfall needles. In the current year needles, Ca concentration was significantly elevated by both the ash and the N treatment (Fig. 4). The concentrations of P, K,

Table 4. Effects of the wood ash treatment on the mean concentrations of some different ions and DOC in the soil solution at 20 cm and 50 cm depths. Values followed by the same letter are not significantly different from each other. Uncertainty of the means is given as 95% confidence intervals. Evaluation of treatment effects by ANOVA (see Materials and Methods). One asterisk (*) denotes that significance is given with respect to the ash treatment with no significant effect by the N treatment and two asterisks (**) denote that significance is given with respect to the N treatment with no significant effect by the ash treatment

Treatment	NO_3^-		NH_4^+		P		K^+		Ca^{2+}		Mg^{2+}		DOC	
Amount ha^{-1}	*mg L^{-1}*													
							20 cm depth							
Control	0.43^{a**}	±0.02	0.03^{a**}	±0.04	0.05^{a}	±0.07	0.59^{a*}	±0.57	4.08^{a*}	±1.23	0.71^{a*}	±0.08	39.0^{a}	±6.56
1.25 t ash	0.59^{a**}	±0.36	0.04^{a**}	±0.03	0.06^{a}	±0.07	1.70^{a*}	±1.36	5.2^{ab*}	±2.54	1.13^{ab*}	±0.17	45.3^{a}	±22.2
2.5 t ash	0.59^{a**}	±0.42	0.06^{a**}	±0.02	0.12^{a}	±0.11	0.76^{a*}	±0.48	6.83^{b*}	±2.45	1.41^{b*}	±0.56	51.0^{a}	±11.3
5.0 t ash	1.61^{a**}	±2.2	0.05^{a**}	±0.04	0.13^{a}	±0.09	2.55^{b*}	±1.43	8.70^{b*}	±5.77	3.29^{c*}	±1.40	52.3^{a}	±22.3
2.5 t ash + 180 kg N	7.01^{b**}	±2.4	1.39^{b**}	±1.46	0.06^{a}	±0.06	2.10^{a*}	±0.83	12.1^{b*}	±7.70	2.43^{b*}	±1.28	39.9^{a}	±4.99
180 kg N	3.61^{b**}	±1.93	1.99^{b**}	±1.99	0.15^{a}	±0.08	0.50^{a*}	±0.45	4.98^{ab*}	±1.87	1.03^{a*}	±0.27	41.8^{a}	±2.3
							50 cm depth							
Control	0.42^{a**}	±0.03	0.02^{a**}	±0.02	0.05^{a}	±0.04	0.35^{a}	±0.43	3.30^{a}	±1.21	0.75^{a*}	±0.19	23.4^{a}	±7.66
1.25 t ash	0.54^{a**}	±0.26	0.06^{a**}	±0.05	0.06^{a}	±0.07	0.70^{a}	±0.64	5.00^{a}	±1.32	1.10^{ab*}	±0.09	25.8^{a}	±11
2.5 t ash	0.51^{a**}	±0.10	0.04^{a**}	±0.03	0.10^{a}	±0.09	0.73^{a}	±0.47	6.20^{a}	±2.33	1.33^{bc*}	±0.39	40.4^{a}	±16.2
5.0 t ash	1.48^{a**}	±1.8	0.08^{a**}	±0.04	0.15^{a}	±0.14	0.90^{a}	±0.77	9.13^{a}	±6.62	2.25^{c*}	±1.33	46.2^{a}	±18.1
2.5 t ash + 180 kg N	10.1^{b**}	±5.13	0.33^{b**}	±0.27	0.06^{a}	±0.08	0.70^{a}	±0.70	9.75^{a}	±2.43	2.17^{bc*}	±0.46	26.7^{a}	±8.06
180 kg N	13.7^{b**}	±7.6	2.5^{b**}	±2.36	0.03^{a}	±0.02	1.98^{a}	±2.31	6.93^{a}	±3.85	1.34^{a*}	±0.69	25.0^{a}	±10.1

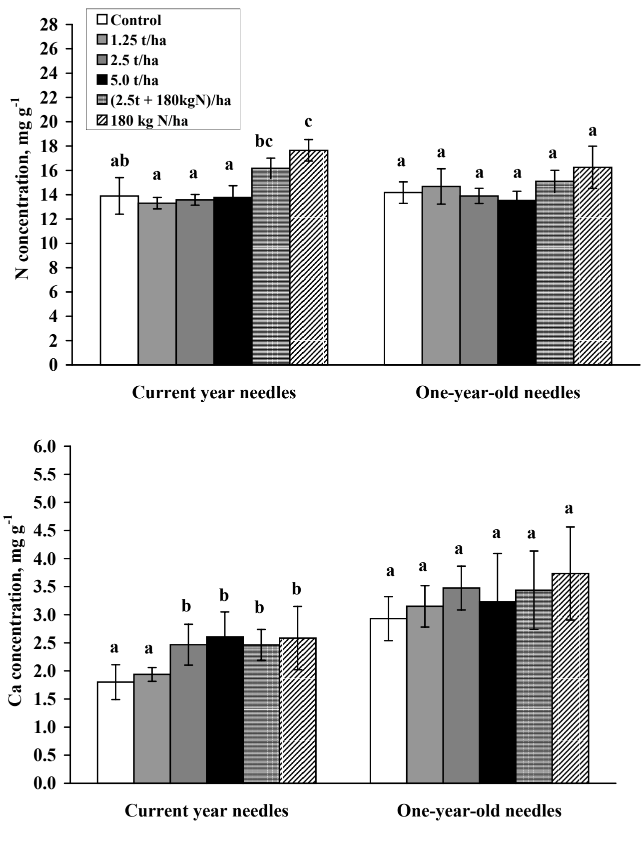

Figure 4. Effects of wood ash treatment on N and Ca concentrations in the current and one-year-old needles. The error bar indicates 95% confidence interval. Averages marked with the same letter are not significantly different.

and Mg were not significantly affected either by the wood ash or the N treatment for any of the needle types.

Discussion

Chemical changes in the soil and soil solution

The wood ash amendment caused rapid changes in the O horizon. The pH_{CaCl2} increased by as much as 2.7 units for the highest wood ash dose compared to the control and the levels of *aqua regia*-extractable Ca, Mg, K and P increased significantly, as did exchangeable Ca^{2+} and Mg^{2+}. For these variables there were also evident dose-response relationships. Even though wood ash experiments on the site type studied here are rare, the results are similar to those found for other site types (Saarsalmi *et al.* 2004). The rapidly increasing pH can be explained by neutralization of acidity in the O horizon caused by the alkaline components (mainly oxides, hydroxides and carbonates) in the ash (Steenari 1998). A contributing factor to the drastic effects is that the ash was applied as highly soluble raw ash, which is more reactive than ash that has been pre-treated to make it less soluble (Eriksson *et al.* 1998). Normally, the effects of ash on exchangeable cations shortly after wood ash amendments in the mineral soil horizons underlying O horizons are small or none (Eriksson 1998a) but appear several years after the treatment (Saarsalmi *et al.* 2001; Arvidsson and Lundkvist 2003). In this case there were significant effects on the exchangeable cations in the top of the mineral soil. The most important reason for these early effects appearing in the mineral soil is probably the thin O horizon (see Table 2), which does not have the capacity to hold all the cations in the applied ash. This is also indicated by the elevated concentrations of Ca^{2+}, Mg^{2+} and K^{+} found in the soil solution at 20 cm depth. Despite the effect on the exchangeable base-forming cations, there was no effect on pH.

Potassium in wood ash is usually highly soluble (Steenari *et al.*, 1999) but in the present study exchangeable K^{+} in the O horizon was unaffected by the ash treatment. This may be explained by rapid leaching of K^{+} and the poor ability of K^{+} to compete with divalent cations such as Ca^{2+} and Mg^{2+} for exchange sites. Increased levels of K^{+} in the soil solution were also found in the highest ash treatment. However, the *aqua regia*-extractable fraction of K was also higher than in the control, which indicates that some of the added K is still in the O horizon but found in rather insoluble mineral fractions, *e.g.* K containing primary minerals in sand and silt particles found in the ash (Steenari *et al.* 1999).

The concentrations of NO_3^- and NH_4^+ were significantly elevated in the N treatments even at 50 cm depth, indicating that some of the N had been leached from the soil profile. The DOC levels were not significantly affected by the treatments in this study, contrary to what had been found in other experiments (Eriksson 1996) but the high spatial variability between the lysimeters might have concealed such an effect.

Chemical changes in needles and litterfall

Our results showed that the N treatment resulted in significantly elevated N concentrations in the current year needles, one-year-old needles and litterfall while wood ash alone had no influence on N concentration in Scots pine needles nine months after the treatment. The lower concentration of N in older needles is in agreement with other studies, which have shown that older needles have lower N concentrations than the current-year needles (Finér 1992; Linder 1995). A contributing factor to the effect on the litterfall needles could be that Scots pine needle retention is low in the region: a needle retention of only 2.1-2.6 years is characteristic of the majority (70%) of Scots pine trees in Lithuania (Ozolinčius and Stakėnas 1996).

The Ca concentration in the needles was significantly increased by both the wood ash and the N treatment and there was a significant co-variance effect between the two treatments. No significant effects on Ca concentrations were found for the one-year-old needles for any of the treatments. The high availability of N in the nitrogen treatment seem to have stimulated uptake of Ca in younger needles.

The results from this study confirm that the effects of wood ash application on needle concentrations in Scots pine are quite small. Moilanen and Issakainen (2000) found a slight increase in the concentrations of Ca and K in the needles 18 months after wood ash application in a Scots pine stand where wood ash treatments applied with different procedures and at different doses were studied. Application of 3 t ha^{-1} wood ash to a Scots pine stand in Northern Finland showed no effect on needle nutrient concentrations one year after the treatment (Vuorinen and Kurkela, 2000). Jacobson (2001) showed that wood ash tended to increase needle K concentrations 1-2 and 3-5 years after ash application, but that this effect disappeared with increasing time after the application.

Conclusions

The O horizon has a high capacity to overwhelm added alkalinity and divalent cations and prevent penetration to the mineral soil. However, wood ash addition on a highly permeable soil with a low nutrient holding capacity like the soil in this study tends to result in initial leaching losses, especially of K^{+} and Mg^{2+}. Likewise, leaching losses of N, both as NH_4^+ and NO_3^-, occur after application of N fertilizer. It is difficult to improve the plant available K status in the soil by wood ash addition, since no increase in exchangeable K can be found after application of wood ash. The effects of wood ash on Scots pine needle chemistry are small and do not indicate any serious nutrient imbalances. Except for an increased uptake of Ca after N addition, there were no documented interactions between the N and wood ash treatments.

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ПЕРВИЧНЫЕ ЭФЕКТЫ ВЛИЯНИЯ УДОБРЕНИЯ ДРЕВЕСНОЙ ЗОЛОЙ В ДРЕВОСТОЯХ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) НА ХИМИЧЕСКИЕ СВОЙСТВА ПОЧВЫ, ХВОИ И ОПАДА

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Резюме

Первичные эфекты влияния древесной золой или азотом исследовалось в эксперименте, который был заложен в 38-летнем сосняке, растущем на песчанной Haplic Arenosol почве (окрестности Качергине, Литва). Всево в эксперименте существуют 6 вариантов: в трёх из них применялись разные дозы древесной золы (1,25; 2,5 и 5,0 т га$^{-1}$); в одном - только азотные удобрения (180 кг N га$^{-1}$); в одном - древесная зола (2,5 т га$^{-1}$) вместе с азотными удобрениями (180 кг N га$^{-1}$), а один вариант оставлен как контроль. Все варианты заложены с четырёхкратной повторностью.

Исследованиями, проведёнными 5-12 месяцев после закладки эксперимента, установлено, что только самая высокая доза древесной золы значительно (от pH_{CaCl2} 3,45 до pH_{CaCl2} 6,15) снизило кислотность O горизонта (лесной подстилки) и увеличило в нём содержание обменных Ca^{2+} и Mg^{2+}. При этом pH показатель поверхностового слоя минеральной почвы (0-5 см) не изменился, хотя в этом слое достоверно ($p<0,05$) увеличилось концентрации Ca^{2+} и Mg^{2+}. Кроме того, в почвенном растворе на глубине 20 см установлены повышенные концентрации Ca^{2+}, Mg^{2+} и K^{+}, однако, из этих катионов на глубине 50 см увеличилась лишь концентрация Mg^{2+}.

После применения древестной золы в почвенном растворе не повысились концентрации NO_3^- и NH_4^+, их выщелачивание увеличилось лишь после применения азотных удобрений.

Концентрация Ca увеличилась только в хвое текущего года. При этом, азотные удобрения повысили концентрации N не только в хвое текущего и прошлого года, но и в опаде. Поскольку в хвое увеличилась и концентрация Ca, делается предпосылка, что применение азотных удобрений вместе с древесной золой может стимулировать освоение Ca.

Ключевые слова: древесная зола, сосна, почвенны раствор, хвоя, опад, химический состав.

Effects of Liming on the Growth of Birch and Willow on cut-away Peat Substrates in Greenhouse

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Abstract

The effects of liming (doses 0, 6, 12, 24, 48 tonnes/ha of dolomite lime) on the growth and nutrition of birch (*Betula pendula* Roth, *Betula pubescens* Ehr.) and short-rotation willows (*Salix x dasyclados, Salix viminalis*) were studied in a greenhouse on peat obtained from two cut-away peatland areas. Peat was NPK-fertilized using either raw phosphate or superphosphate as phosphorus source. An increase in liming dose up to 48 tonnes/ha increased peat pH asymptotically from 3.5 to 6.0 and from 3.9 to 6.7 in the two peats. The substrate's pH did not affect the biomass production of silver and downy birch. Willows did not grow at all in the acidic Aitoneva peat without the substrate being limed. Willow growth was best when substrate pH was higher than 5.0. Liming decreased the foliar phosphorus and boron concentrations in birch and boron concentrations in willow. Rock phosphate and superphosphate gave almost equal results in birch growth, but willows grew significantly better when fertilized with superphosphate. Downy birch had significantly higher foliar potassium, calcium, magnesium and boron concentrations than silver birch. *Salix viminalis* had significantly higher foliar concentrations of phosphorus, potassium and boron than *S. x dasyclados.*

Key words: Cut-away peatland, liming, downy birch, silver birch, willow, *Salix*, phosphorus

Introduction

Peat cut-away areas differ considerably from forested peatland sites in regard to their soil properties. They are characterized by variation in peat thickness, low pH levels, high nitrogen concentrations, and low phosphorus and potassium concentrations (Aro *et al.* 1997). Nutritional problems may be encountered when afforesting cut-away peatlands and consequently success of afforestation will, in many cases depend on soil amelioration and fertilization (Kaunisto 1987, 1983, Valk 1986, Hytönen *et al.* 1995, Hånell *et al*. 1996, Aro *et al*. 1997, Hytönen and Kaunisto 1999, Aro and Kaunisto 2003).

Scots pine has been the main subject of study in the afforestation of cut-away peatlands, but experiments have also been conducted on the naturally use regenerated or planted closely-spaced birch and willow stands for energy wood production (Hytönen 1995, Hytönen *et al*. 1995, Aro *et al.* 1997, Gradeckas 1997, Hytönen and Kaunisto 1999, Aro and Kaunisto 2003). Generally, birch stands on peatland sites are dominated by downy birch (*Betula pubescens*). However, on cut-away peatlands silver birch (*Betula pendula*) has also been shown to regenerate naturally and thrives well (Kaunisto 1981, Aro *et al*. 1997, Hytönen *et al*. 1995, Hytönen and Kaunisto 1999).

Soil acidity is an important factor affecting soil processes and the development of plant root systems. Many plant species have been shown to have distinct requirements for the pH of their growing medium. Different willow species have different requirements regarding the substrate's pH (Lattke 1969) and thus increase in soil pH could be necessary when growing willows on cut-away peatlands (Hytönen 1996).

Liming is a technique which has long been used as a routine soil amelioration measure in agriculture. In peatland forests liming was suggested to activate soil microbial activity and increase mineralization of nitrogen and phosphorus availability. However, on nitrogen-poor peatlands liming has resulted in the decrease in mineral nitrogen due to denitrification and microbiological immobilization of mineralized nitrogen (Kaila and Soini 1957, Gardiner 1975, Kaunisto and Norlamo 1976). On nitrogen-rich sites, however, such as cut-away peatlands the peat's nitrogen concentration could be high enough to lead to the net mineralisation of nitrogen. The results, however, have shown that liming has during the first 5-10 years after the application mostly decreases tree growth in peatland forests or in peat cut-away areas (Kaunisto 1982, 1987) but later the growth can gradually improve (Meshenchok 1971). Liming affects also the availability of many nutrients to the trees. Liming can also influence the forest manager's choice of phosphorus fertilizers since the solubility of apatite widely used in fertilization of peatland forests is better in acid soils and thus liming can prevent the phosphorus fertilization effect of apatite (Salonen 1968).

The aim of the present study was to determine the soil pH requirements of silver and downy birch *(Betula pendula, Betula pubescens*) and exotic willow species used in short-rotation forestry (*Salix x dasyclados, Salix viminalis*) established on cut-away peat substrates. The effect of liming on the choice of phosphorus fertilizer was also studied.

Material and methods

Experiment

Well humified Carex-peat was collected from two peat cut-away areas, one located in Kihniö Aitoneva (62°12´ N, 23°18´ E) and the other in Haapavesi, Piipsanneva (64°06´N, 25°36´E). The pH and nutrient concentrations of each peat type were analyzed. The pH (water) of the Aitoneva peat was 3.5 and that of Piipsanneva peat 3.9. The corresponding figures for total nitrogen (Kjeldahl) were 1.4% and 2.1 %, for soluble phosphorus 1.7 mg l^{-1} and 1.0 mg l^{-1}, for exchangeable potassium 15 mg l^{-1} and 5 mg l^{-1}, for soluble calcium 350 mg l^{-1} and 660 mg l^{-1} and for soluble magnesium 77 mg l^{-1} and 100 mg l^{-1}, respectively.

The effects of liming (0, 6, 12, 24 and 48 tonnes of dolomite limestone), peat type (peat from Aitoneva and Piipsanneva cut–away peatland areas) and tree species (*Betula pendula* Roth., *Betula pubescens* Ehr., *Salix x dasyclados*, clone P6011, *Salix viminalis* clone S15111) and their interaction on the growth and nutrition were studied in a greenhouse. The dolomite limestone (Ca, Mg $(CO_3)_2$) had neutralizing capacity 35% of that of calcium. The experimental layout consisted of a randomized block design with two replications. All the seedlings were given basic nutrient doses of N (150 kg/ha), P (66 kg/ha), and K (125 kg/ha), and a mixture of trace elements (50 kg/ha). In order to exclude the limiting effects of poor nutrition, all treatments were NPK-fertilized. Nitrogen was administered in the form of calcium ammonium nitrate, phosphorus in the form of either superphosphate and potassium in the form of potassium sulphate.

Phosphorus fertilizer source, easily-soluble superphosphate (8.7% P, 20% Ca, 12% S, 0.2% Mg, 0.3% Na, 0.3 Fe) and poorly-soluble rock phosphate (14.8 % P, 38% Ca, 0.3% Na, 0.8% S, 0.4% Mg, 0.2% Fe) was compared using peat from Piipsanneva cut-away area and downy birch (*Betula pubescens* Ehr.) and *Salix x dasyclado*s. Rock phosphate is quarried from phosphate beds in sedimentary rocks and is almost insoluble in water. Superphosphate is a fertilizer produced by the action of concentrated sulphuric acid on ground phosphate rock. Treatment with sulfuric acid converts the ground rock phosphate to the more soluble form, a mixture of dihydrogen phosphate and hydrated calcium sulphate.

Prior to transplanting birch seedlings were germinated and raised to a height of 5-10 cm in unfertilized and poorly humified peat. The lime and fertilizers were mixed in the 1.9 litre pots into the top 10 cm layer. Two seedlings (birch) or two cuttings (willows) 10 cm in length were planted in each pot. After the first two weeks one dead silver birch seedling was replaced. The seedlings were grown for 101 days from the end of May to mid August in ambient light conditions. During this period, the seedlings were irrigated whenever necessary to eliminate water deficit as a limiting factor. Air temperature in the greenhouse varied between 17-24 °C.

Measurements and statistical analyses

At the end of the experiment all the seedlings were harvested by severing them at ground level. Leaves were separated, and the dry mass of the leaves and woody parts was determined by drying them to constant weight. At the end of the experiment, the substrate's pH (soil : water 1:2.5) was determined. All the leaves of the plants growing in the pots were collected for foliar analysis. For the nutrient analysis, microwave digestion of the ground leaves in HNO_3 + H_2O_2 solution was made (CEM MDS2000 Microwave Digestion System). Nitrogen concentration of the samples was measured by the Kjeldahl method (Halonen et al.1983) and phosphorus concentrations photometrically with vanado-molybdate method. Potassium, magnesium and calcium were determined with AAS (Varian SpectrAA-300). Boron was determined from H_3PO_4-H_2SO_4 extract photometrically with azomethine-H method.

Differences in biomass and foliar nutrient concentrations between the treatments were tested by using the analysis of variance separately for birches and willows. The variance model used included liming dose, peat type, tree species their interactions and a block. Phosphorus fertilizer types were tested separately.

Results

Effects of liming on peat pH

Liming leads to an asymptotic and significant increase in soil pH in both cut-away peats (F_{lime} =

43.39, p = 0.000). Liming increased the pH from 3.5 to 6.0 in Aitoneva and from 3.9 to 6.7 in Piipsanneva peat, respectively (Figure 1). The pH values of the two peat substrates differed significantly from each other (F_{peat}=6.29, p=0.015). The more acidic peat from Aitoneva persisted in having a lower pH than the peat from Piipsanneva at all lime doses.

Effects of liming on growth and foliar nutrient concentrations

Liming and consequently pH did not affect the height growth or the biomass production of silver birch or downy birch raised on the two cut-away peat substrates studied (Table 1, Figure 2). Downy birch grew taller than silver birch in this study, but this difference was not reflected in biomass production. Peat type significantly affected the biomass production of birch (Table 1, Figure 2). Both birch species grew better in Aitoneva than in Piipsanneva peat.

Table 1. Effect of liming dose, peat type and tree species (birches: silver birch and downy birch, willows: Salix x dasyclados, S. viminalis) and their interaction on the height and biomass production and foliar nutrient concentrations of birch and willow. F-values. Asterisks indicate statistical significance * = p<0.05, ** = p< 0.01, *** = p< 0.001

Species Group	Characteristic	Source of variance Lime	Peat	Species	L*P	L*S	P*S	L*P*S
Birches	Height	0.55	1.02	11.35**	0.39	0.76	6.02*	0.71
Willows	“	13.37***	14.13**	34.25***	14.66***	0.73	0.93	2.43
Birches	Above-ground	0.76	5.67*	0.11	0.48	0.12	0.17	0.57
Willows	mass	17.36***	8.53**	0.00	13.23***	0.95	1.79	1.19
Birches	N	1.65	2.38	0.60	0.41	0.95	0.46	0.90
Willows	“	2.04	0.35	46.29***	0.64	1.29	0.05	0.50
Birches	P	6.29**	67.09***	1.37	2.59	1.07	0.10	1.87
Willows	“	0.24	42.89***	53.23***	2.34	0.52	1.81	0.51
Birches	K	3.24*	4.32	35.44***	1.36	0.97	0.35	1.63
Willows	“	3.20*	2.01	5.07*	0.13	0.50	0.70	0.04
Birches	Ca	2.07	6.91*	10.01**	0.71	2.22	0.10	0.46
Willows	“	6.81**	3.85	0.56	1.81	1.17	1.41	0.16
Birches	Mg	0.92	1.56	8.17*	0.25	2.17	2.92	1.30
Willows	“	2.98	9.42**	2.60	0.81	0.26	2.00	0.48
Birches	B	3.56*	0.09	7.17*	0.34	0.25	0.54	1.58
Willows	“	19.64***	0.02	29.26***	1.04	8.80**	4.68*	0.54

Liming and peat type significantly affected the height growth and the total above-ground biomass of both studied willow species (Table 1, Figure 2). Neither of the willow species survived in the Aitoneva peat substrate without lime application, whereas liming led to only a slight improvement in the growth of willows in the Piipsanneva peat, the smallest dose (6 tonnes/ha) being sufficient to achieve this effect (pH 4.8). In Aitoneva peat, the optimum liming amount varied between 12 to 24 tonnes/ha (pH 5.4 – 5.7).

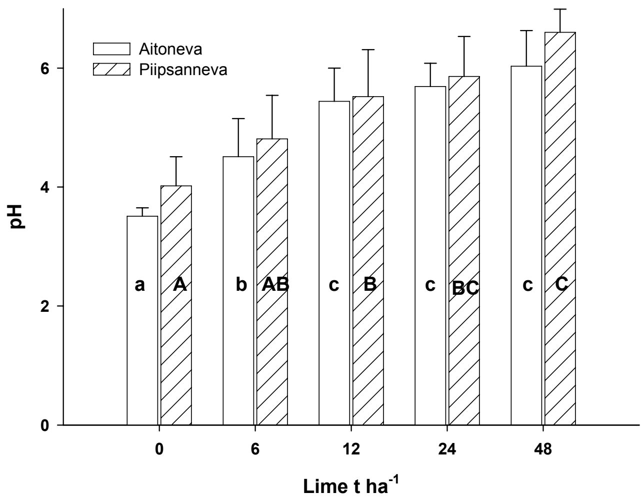

Figure 1. Effect of liming on the pH of the peat substrate from Aitoneva and Piipsanneva. Data from both experiments. The means not differing significantly from each other according to Tukey's test (p<0.05) are marked by the same letter (lower case: Aitoneva, upper case: Piipsanneva). Standard deviation marked above bars

Salix viminalis grew significantly taller on both peat types than *Salix x dasyclados* but they did not differ in terms of their total above-ground biomass production (Table 1). The statistically significant interaction between cut-away peat type and liming is due to *Salix viminalis* having died on the un-limed Aitoneva peat and after liming both willow species grew on Aitoneva peat better than they did on Piipsanneva peat. Thus, limed Aitoneva peat was more suitable for *Salix viminalis* growth than limed Piipsanneva peat.

Liming decreased foliar phosphorus and boron in both birch and boron and calcium concentrations in willow, but increased foliar potassium concentrations in birch and willow (Table 1, Figure 3). Both birch and willow showed foliar phosphorus concentrations that were higher on Aitoneva peat than on Piipsanneva peat. The foliar potassium, calcium, magnesium and boron concentrations of downy birch were higher than those of downy birch. *Salix viminalis* had significantly higher foliar concentrations of phosphorus, potassium and boron than *S. x dasyclados*.

Downy birch and willow grew better when fertilized with the same amount of elemental phosphorus from superphosphate than from rock phosphate but this was statistically significant only for willow (Figure 4). The effect of rock phosphate on the growth of birch was small at the highest lime amount. Foliar phosphorus concentrations of birch were highest when superphosphate was applied (Figure 5). However, phosphorus source did not affect the phosphorus concentration of willow leaves significantly. This was due to the fact that on un-limed peat substrate wil-

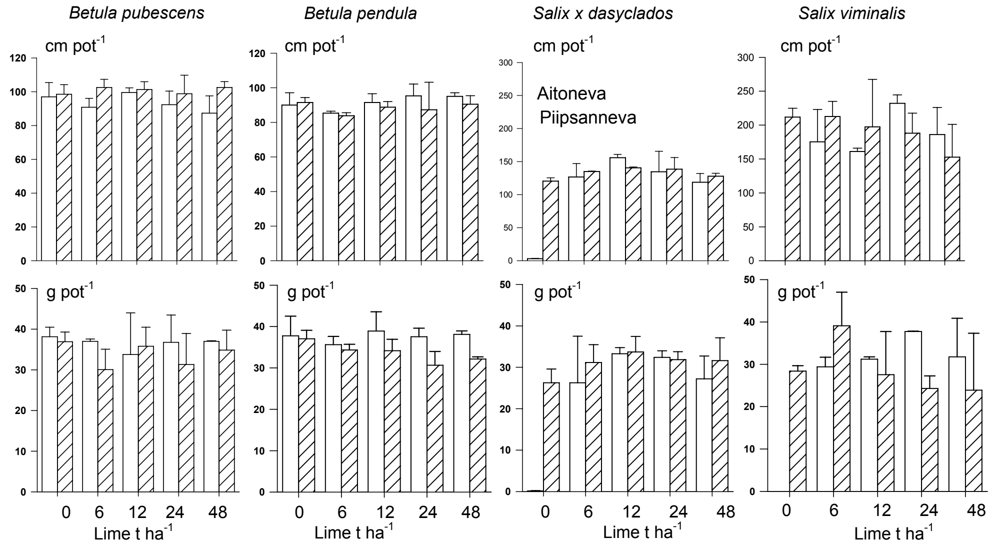

Figure 2. Effect of liming dose on the height and the above–ground biomass production of birch and willow. Standard deviation marked above bars. For pH values corresponding to liming doses see Figure 1 and for F-statistics see Table 1

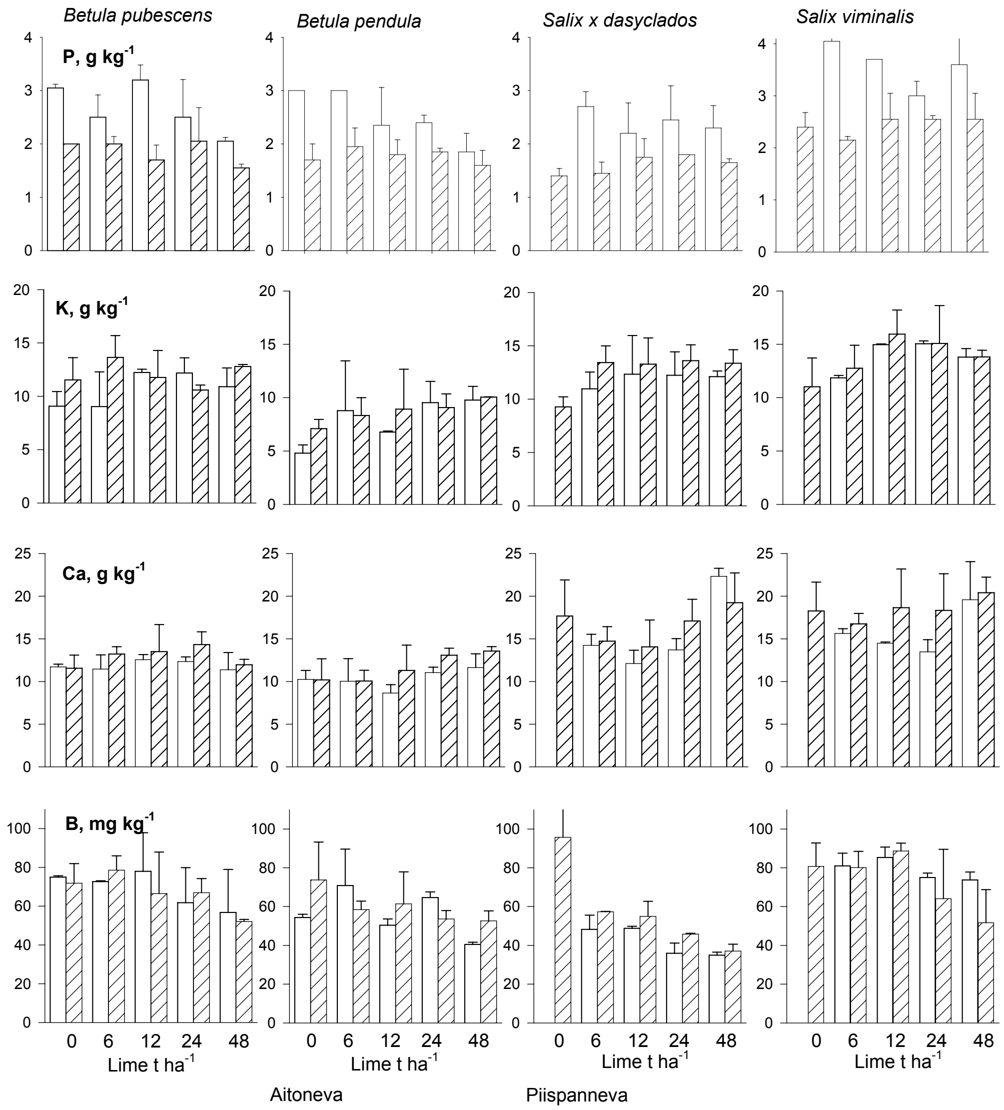

Figure 3. Effect of liming on foliar phosphorus, potassium, calcium and boron concentration in birch and willow. For pH values corresponding to liming doses see Figure 1 and for F-statistics see Table 1. Standard deviation marked above bars

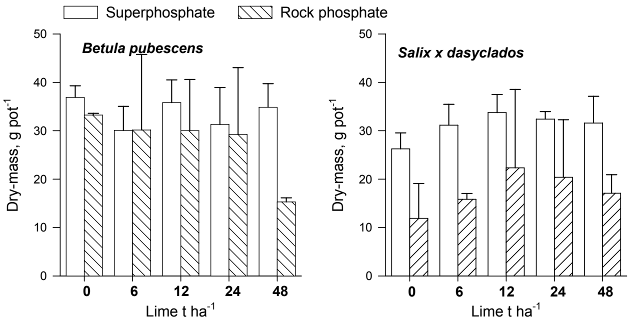

Figure 4. Effect of liming and phosphorus source on the above-ground biomass production of downy birch and *Salix x dasyclados* on peat substrate from Piipsanneva. Standard deviation above the bars. F phosphorus source: *B. pubescens* 3.61, p=0.090, *S. x. dasyclados* 21.82, p=0.001

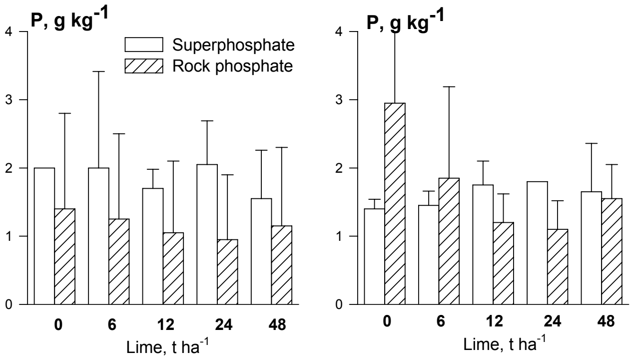

Figure 5. Effect of liming and phosphorus source on the foliar phosphorus concentration of downy birch and *Salix x dasyclados* on peat substrate from Piipsanneva cut-away peatland area. Standard deviation marked above bars. F phosphorus source: *B. pubescens* 10.50, p= 0.010, *S. x. dasyclados* 0.27, p=0.614.

lows fertilized with rock phosphate had quite high phosphorus concentrations. Superphosphate decreased significantly, probably due to dilution effect, the birch foliar nitrogen concentrations. Willow foliar calcium concentrations were significantly higher when rock phosphate was used than with superphosphate.

Discussion

In this study dolomite lime application increased the pH of well-humified Carex peat asymptotically with increasing application amounts. The highest lime dose (48 tonnes/ha) increased the soil pH by 2.5 pH units. Liming did not affect the growth of birches. They grew equally well on un-limed (pH 3.9 for Aitoneva peat) and on limed peat (up to pH 6.0-6.7) and thus no optimum pH range was found for the biomass production of birch. In agreement with the present study on well humified *Carex* peat, Ericsson and Lindsjö (1981) and Rikala and Josefek (1990) have shown on poorly humified *Sphagnum* peat in their greenhouse studies that neither height nor dry mass production of birch (*Betula pendula*) seedlings depend on the substrate's pH (range 3.8 – 7.0). Birches are known to be indifferent to the soil pH over a wide range and to be less sensitive to pH than most of the other species studied (Ingestad 1979). Longer term field studies have shown that liming has in some cases increased but mostly decreased the height growth of birches (Kaunisto 1973, 1981, 1987).

For willow survival and growth, increase in the pH was necessary with Aitoneva peat as substrate. Both of the studied willow species (*Salix viminalis* and *Salix x dasyclados*) died when grown on fertilized Aitoneva peat without liming. In the greenhouse study conducted by Ericsson and Lindsjö (1981), the root development of *Salix viminalis* grown in poorly humified peat was completely inhibited within the pH range of 3.8 – 4.3. The optimum pH for good development of willow root systems varies by species. The roots of *Salix pentandr*a L. and *Salix cinerea* L. have been observed to develop almost as well in a hydroponic culture with pH 3.5 as with pH 5.0 (Lattke 1969). With Aitoneva peat, the optimum pH for *Salix viminalis* and *S. x dasyclados* growth was 5.4 – 5.7 while for Piipsanneva peat it was 4.8 – 5.5. This corresponds well with the results of an earlier investigation showing that *S. viminalis* L., *S.* 'Aquatica', *S x dasyclados* require rather high substrate pH levels (5.0 - 6.0) (Ericsson and Lindsjö 1981). Also the greenhouse experiment conducted by Kaunisto (1983) showed that the effect of liming on the growth of willows was generally positive, albeit minor. To reach this optimum pH range, the liming amounts applied with Aitoneva peat were greater that those for Piipsanneva peat. In this study, a slight decline in growth was noted with the maximum lime doses at pH 6.0 – 6.6.

Liming significantly decreased the birch and willow foliar boron concentrations. The boron uptake of plants is affected by the soil pH, and the amounts of calcium and magnesium. Elevation in pH caused by liming can negatively affect the boron uptake of trees (Lehto and Mälkönen 1994) and increase boron fixation by the soils (Saarela 1985) and absorption to the forest mor layer (Lehto 1995). Liming has also been found to decrease foliar boron concentrations of Scots pine on both peat and mineral soil substrates (Kaunisto 1982, Lehto and Mälkönen 1994). Boron deficiencies resulting in growth defects caused by leader diebacks have been especially common in trees growing on limed abandoned fields (Hytönen and Ekola 1993). Liming also decreased the phosphorus concentration of birch seedlings indicating that calcium could decrease phosphorus uptake of birches.

Site-specific differences in foliar nutrient concentrations were also noted. Especially soil-inherent phosphorus concentration was reflected in foliar concentration even though the peat substrates were NPK-fertilized. The foliar phosphorus concentrations were significantly higher in the case of Aitoneva peat; it contained almost twice as much inherent soluble phosphorus as did Piipsanneva peat. However, similar differences in soil potassium concentrations were not reflected in the foliar potassium concentrations.

This study showed that the phosphorus fertilizer source was of little importance for birch growth in greenhouse. Also field experiments with rock phosphate and superphosphate have influenced the growth of Scots pine to a similar extent (Silfverberg and Hartman 1999), even though superphosphate has given the strongest initial response (Paarlahti and Karsisto 1968). No statistically significant interaction between phosphorus source and liming dose was found in this study. For willows, the use of fast soluble superphosphate was necessary in order to maximize the biomass production. This is in agreement with the results from field experiment on cut-away peatlands in which willows fertilized with the same amount of phosphorus as superphosphate produced over three times more biomass compared to fertilization with rock phosphate (Hytönen 1986). On limed peatland sites, slowly-soluble phosphorus fertilizers have failed to increase the amount of extractable phosphorus in the substrate and to ensure the availability of phosphorus for willows (Kaunisto 1983, Hytönen 1986, Yli-Halla and Lumme 1987). Kaunisto (1983) has demonstrated that when liming amounts of cut-away peatlands increased from 6 to 12 t/ha the soluble phosphorus amounts in the soil decreased even though at the same time the phosphorus fertilizer application as rock phosphate was doubled.

While there were no differences in the biomass production of birches the two birch species studied differed from one another in their foliar potassium, calcium, magnesium and boron concentrations. They were higher in downy birch than in silver birch. In agreement with the results of this experiment also in a field study in which silver and downy birches were compared it was found that downy birch had higher foliar calcium, manganese, iron, aluminium and boron concentrations than silver birch (Saramäki and Hytönen 2004). Also Koricheva and Haukioja (1995) found that leaves of downy birch contained significantly more manganese and iron than those of silver birch along a pollution gradient. According to foliar analyses *Salix viminalis* seems to be nutritionally more demanding species than *S. x dasyclados*.

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ВЛИЯНИЕ ИЗВЕСТКОВАНИЯ НА РОСТ БЕРЕЗЫ И ИВЫ НА БОЛОТНОМ ДОННОМ ТОРФЕ ДВУХ ВИДОВ В ТЕПЛИЧНЫХ УСЛОВИЯХ

Й. Хитёнен

Резюме

Исследование влияния известкования (0, 6, 12, 24, 48 тонн доломитной извести) на рост и обмен веществ берез (*Betula pendula* Roth, *Betula pubescens* Ehr.) и ив (*Salix x dasyclados, Salix viminalis*) было проведено в тепличных условиях на болотном донном торфе двух видов. В торф ввели удобрения NPK, с использованием в качестве источника фосфора сырого фосфата или суперфосфата. Увеличение количества извести вплоть до 48 тонн на гектар асимптотически увеличивало значение pH торфа. Значение pH субстрата не влияло на рост по высоте березы бородавчатой и березы пушистой, как и на производство у них биомассы. Ивы же вовсе не росли на кислом торфе (pH 3,5) без известкования. Лучше всего ивы росли при значении pH субстрата выше 5,0. Известкование уменьшило содержание фосфора и бора в листьях березы, а также содержание бора в листьях ив. Рост берез был почти одинаков при внесении сырого фосфата или суперфосфата, но ивы росли значительно лучше при удобрении их суперфосфатом. Содержание калия, кальция, магния и бора в листьях березы пушистой было выше, чем у березы бородавчатой.

Ключевые слова: березы, ивы, *Salix*, извести, фосфора, болотный донный торф

The Effect of Soil Properties on Natural Forest Regeneration on Drained Fens

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Grigaliūnas, V. and Ruseckas, J. 2005. The Effect of Soil Properties on Natural Forest Regeneration on Drained Fens. *Baltic Forestry,* 11 (2): 75–83.

The objective of this study was to assess the success of natural regeneration in cutovers on drained fens (eutrophic peatland) depending on the soil properties and the depth to the water table in the forests of Biržai and Panevežys state forest enterprises in Lithuania. The assessments were carried out in 100-300 *m* long transects allocated perpendicularly to the drainage ditches. A total of 131 water wells were drilled to measure the depth to the water table and 131 sample plots of 10 × 10 *m* were established. The soil properties were assessed in the soil chemistry laboratory. The results showed that natural forest regeneration on drained cutblocks in fens was affected by the following factors: the depth to the water table ($H_{V.01}$) (measured at the beginning of the growth period), the *pH* level, the potential hydrolytic soil acidity (*HA*), the base saturation and the thickness of the peat layer. Multiple regression analysis was used to assess the dependence of the number of regenerating trees (*N*) on the main factors ($H_{V.01}$ and *HA*): $N = 168059.7 - 3446.5\ H_{V.01} - 35.180\ HA$; ($R^2 = 0.8$, $F = 7.51$, $p < 0.0007$). The maximum critical depth to the water table (allowing sufficient number of regenerating trees) was mainly affected by the subsoil texture of the shallow peat soils (HS_s–*ph*) and was 18.0 ± 3.7 *cm*, 26.5 ± 6.6 *cm*, 26.6 ± 3.9 *cm*, 29.6 ± 6.6 *cm* and 42.2 ± 9.6 *cm* in the soils with subsoil of gravel, sand, sandy loam, light loam and medium loam, respectively. The mean hydrolytic acidity of the soil in the cutblocks with sufficient regeneration was 820.99 ± 56.05 *mekv/kg*, which was significantly lower than in the cutblocks with insufficient forest regeneration (ΔHA = 212.29 ± 94.99 *mekv/kg*, $t = 2.23$, $p = 0.038$). In conclusion, to improve the natural regeneration of forests in the clear-cuttings on low peatland soils, the soil water regime should be improved by the technical means to maintain the optimum soil moisture (mainly by damming the ditches) and, in soils of very high acidity (*HA* > 1100 *mekv/kg*), alkaline enrichment may be needed.

Key words: cutovers, drainage, natural regeneration, peat soils, water table

Introduction

The cutblocks in drained fens (eutrophic peatland) are defined as clearcut sites on drained forest wetland with the thickness of the peat layer exceeding 30 *cm*. The peat soils are different from the mineral soils in their moisture, nutrient and temperature regime as well as the prevailing vegetation. Therefore, the results of studies carried out on the mineral soils cannot be applied to the sites on peat soils (Saarinen *et al.* 2004). Drainage and clear-cutting in forested wetlands markedly affect the physical, chemical and biological properties of the soils and may result in conditions suitable for natural forest regeneration (Roy 1998, Berry and Jeglum 1988, Braekke 1990, Dube *et al.* 1995, Paavilainen and Päivänen 1995). However, according to Berry and Jeglum (1988), Roy *et al.* (2000), Kairiūkštis (1973) and Zalitis (1996) in the temperate zone, a rise of the water table was observed after clearcuts in forested wetlands. This watering-up may initiate paludification, which may disturb forest regeneration (Paavilainen and Päivänen 1995, Roy *et al.* 2000, Ипатьев *et al.* 1984). Forest drainage, implemented to lower the water table and decrease soil water content to a level that ensures sufficient aeration (Paavilainen and Päivänen 1995) could be used after clear-cutting to alleviate watering-up.

According to Kapustinskaitė (1983), the positive effect of drainage in Black alder (*Alnus glutinosa L.*) wetland dominated by *Cyperaceae* or a similar type of ground vegetation was that over 90% of Black alder trees were regenerating not only on elevated mounds (mounds occupied 18-23% of the total area) but also over the whole area including water-formed depressions. Thus, drainage may improve the commercial value of Black alder stands (Kapustinskaitė 1983, 1988).

According to Podzarov (Поджаров 1988), natural regeneration in Black alder stands on flooded sites (common conditions in Black alder stands in lowlands dominated by *Cyperaceae* or *Dryopteris* ground vegetation) is very scarce even during the years of abundant seed crop. In Byelorussia, drainage of such stands is suggested by establishing a shallow ditch network and allocating the ditches at the intervals of 400-500 m.

However, too intensive drainage treatment (where the intensity of drainage markedly exceeds the optimum drainage standards) may disturb forest regeneration in the forested wetlands. According to Kapustinskaitė (1983), on the intensively drained fens (i.e. in the 65 *m*-wide-belt adjacent to the drainage ditch), marked lowering of the peat layer and opening of the tree roots were observed. This caused drying out of one and two-year-old stump sprouts of Black alder (Kapustinskaitė 1960). In such cases, intensive drainage may disturb the natural regeneration of Black alder, especially if carried out during the second year after the clear-cutting (Kapustinskaitė 1983). In spite of good seed yield (40 million *per ha*), seed germination and seedling survival in dry peat soils are worse than in peat soils on undrained sites (Поджаров 1988). According to Podzarov (Поджаров 1988), the best natural regeneration of Black alder occurred on the sites dominated by the ground vegetation of *Urtica dioica*, where the access surface water occurs not later than in the middle of May. According to Ruseckas (2002), in the undrained Black alder stands of high quality (the site index class is I[a]) dominated by *Urtica dioica* the depth to the water table varies between 0-12 *cm* depending on the water excess in spring. Therefore, the optimum drainage intensity of 7 *cm* (with 50% probability) was developed mainly for the optimisation of the water regime of the undrained high quality Black alder stands. However, forested wetlands are often drained too intensively in Lithuania. If the water table drops down to 60 *cm* in fens, the vegetation common in eutrophic peatland ecotype may change to a less unfavourable valuable type of vegetation (Volskis *et al.* 1999).

Drainage and clear-cutting in forested wetland also affect nutrient balance of the soil. According to Kotrushenko (Котрушенко 1967), Koshelkov (Кошельков 1982), Saarinen (1996), Saarinen and Sarjala (1999), an imbalance of nitrogen and potassium may occur in the soil after drainage and clear-cutting. In drained peatland with a deep peat layer, the shortage of potassium may be the main reason for poor tree growth (Kaunisto and Paavilainen 1988). On such sites, the nutrient balance can be optimised by the means of phosphorus-potassium fertilization (Saarinen and Sarjala 1999).

There are no explicit studies addressing the above-mentioned problems in Lithuania. The objective of this study was to assess success of natural regeneration in cutovers on drained fens (eutrophic peatland) depending on the soil properties and the depth to the water table.

Material and methods

The study was carried out in the forests of Biržai and Panevėžys forest enterprises located in the northern part of the Lithuanian Midland lowland. This climatic zone is distinguishing by the lowest precipitation in the country (the mean annual amount of 650-700 *mm*) and the largest area of forested wetlands (forests on organic soils make up to 28-35%). Over 52% of the forested wetlands were drained in this region. The draining was especially intensive in the fens belonging to *Caricosa* and *Urticosa* forest types (70% of all drained area). These forests were drained not only to improve the wood yield but also to improve their accessibility. Without a proper drainage, it may hardly be possible to build roads on the land depressions with loam or clay subsoil (Pikk and Seemen 2000).

To assess the effect of the water table depth and soil conditions on natural regeneration of forests on fens, 31 drained cutovers were selected in the forests of Biržai and Panevėžys forest enterprises. Only the sites with 30-100 *cm* and thicker peat layer were selected. In addition, the depth to the water table was measured in nine undrained cutblocks and in eight Black alder stands of pre-mature age on undrained sites.

Most of the cutovers (approximately 80%) were drained by the means of the 1.2-1.9 *m* deep ditches established along the forest compartment lines. In such a case, the coefficient of drainage intensity (I_k) reflects the water table depth (H) better (R^2 from the regression of H on I_k is 0.57; $p < 0.05$) than the distance to the nearest ditch (L) (R^2 from the regression of H on L is 0.38). The coefficient of drainage intensity (I_k) was estimated according to the following formula: $I_k = T_1/L_1 + T_2/L_2$, where T_1 and T_2 are the depth of the two adjacent ditches, L_1 and L_2 are the distance to the corresponding ditch.

The mean width and length of the cutblocks were 80-100 *m* and 150-200 *m*, respectively. The longer axis of the cutblocks was positioned towards the North. The cutblocks were left for natural regeneration. The natural regeneration and soil properties were assessed in 31 transects (100 to 300 *m* long) located perpendicularly to the drainage ditch (Figure 1). A total of 131 water wells were drilled to measure the depth to the water table and 131 sample plots of 10 × 10 *m* were established. The water wells were located 20-50 *m* apart form each other depending on the width of the cutover belt and the distance to the nearest ditch. The depth to the water table was assessed on three occasions during one year: in spring (the beginning of the growth period), in July and at the beginning of September.

The correspondence of the depth to the water table to the optimum soil moisture level was assessed according to the hydro-climatic coefficient (k), the

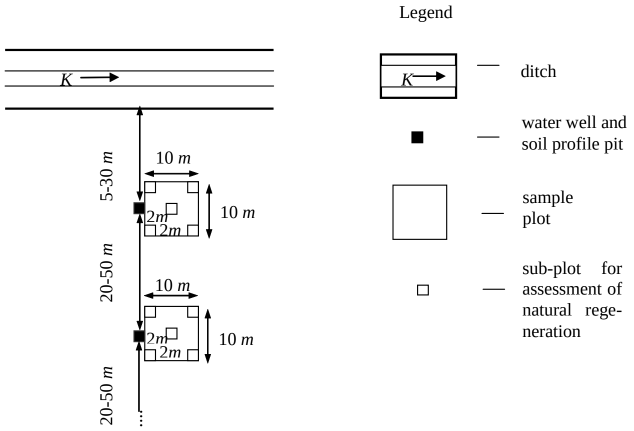

Figure 1. Experimental design showing allocation of sample plots, water wells, soil sampling profiles and sub-plots for assessment of natural regeneration

probability of which considers climatic conditions at the time of assessment and the climatic data over the past 50 years (Ruseckas 1989):

$$k = 0.230P_1 + 0.20P_2 + 0.1(P_3 - 0.15E_0 + 0.05S) \quad (1)$$

where P_1 is the precipitation amount over the winter of the current hydrological year (December, January, February); P_2 is the amount of water in snow and ice layer on the first of March of the current year; P_3 is the precipitation amount over March and April of the current year; E_0 is the sum of daily evaporation values during April of the current year; S is the number of days with permanent snow cover during March of the current year.

The probability (P) of the hydro-climatic coefficient (k) was estimated according to the variation pattern of the hydro-climatic coefficient over the past 50 years:

$$P = 44.67 - 2.9667k; \ (R^2 = 0.977, \ p < 0.05) \quad (2)$$

Sample plots of size 100 m^2 were established close to the water wells. In each sample plot, 5 sub-plots (size 4 m^2 each) were allocated to assess the number of regenerating young trees.

During the assessment of natural regeneration, the following data were recorded: tree species, age, stocking, the mean height, type of plants (sprouts or seedlings), viability, seedling distribution pattern and position in relation to the site micro-topography. The mean height of each height class was calculated. The viability was assessed according to the following classes: (1) viable, (2) not viable and (3) dead (Regulations on natural and artificial establishment of forest 2003).

According to the number of viable regenerating young trees, the cutblocks were subdivided into the following categories: (1) sites with natural regeneration of sufficient (satisfactory) stocking (the number of viable and evenly distributed young trees of Black alder and birch, Norway spruce and ash, as well as Scots pine was not less than 2200, 2000, 3500 young trees *per ha*, respectively (based on the standards given in the Regulations on natural and artificial establishment of forest (2003)), and (2) sites with natural regeneration of insufficient stocking (the numbers of the regenerating young trees were less than these for the first category indicated above).

To assess the type and the physical properties of the soils, a 1 *m* deep profile pit was dug in each sample plot. Soil sample rods were used to assess soil properties at 2 *m* depth. In the profile pits, the following assessments were made: thickness of the forest litter and the peat layer and the soil samples were taken at the depths of 2-10, 11-20, 21-30, 31-60, 81-100 *cm* for assessment of the degree of peat decomposition and soil texture. The degree of peat decomposition was measured according to the Post scale (Overbeck 1975). The soil texture of the upper 20 *cm* layer of the bedrock was assessed by the pipette method (Buivydaitė and Motuzas 2000) and the soil texture of the deeper bedrock layers - by the Kacinski method (Vaičys et al. 1979).

To assess soil chemical properties in the 17 cutblocks, 50 soil samples were taken from the surface soil layer (0-20 *cm*). In the soil chemistry laboratory, the following soil properties were determined: potential exchangeable soil acidity, potential hydrolytic soil acidity and the amount of bases in the soil. The hydrolytic soil acidity and the amount of bases in the soil were assessed according to Geohler and Drews (1971). The potential exchangeable soil acidity was assessed by using the potenciometric method of *KCl* extractives. The ash content in the peat was assessed according to the standard LST EN 13039.

Results and discussion

The effect of soil acidity on natural regeneration

There was a large variation in the soil chemical properties on drained fens (eutrophic peatlands). In the cutovers with insufficient natural regeneration, the potential exchangeable soil acidity varied from 4.1 to 6.1 and the mean exchangeable soil acidity was 5.10±0.12 (Table 1).

There was no significant difference in exchangeable acidity between the sample plots with sufficient and insufficient natural regeneration (Table 1). However, in the sample plots with sufficient regeneration,

Table 1. Chemical properties of peat soils on drained fens ("a" data for the sample plots with insufficient regeneration, "b" data for the sample plots with sufficient regeneration)

Chemical properties		Mean	Minimum	Maximum	Coefficient of variation
pH_{KCl}	*a*	5.10±0.12	4.10	6.10	12.4
	b	5.54±0.10	4.20	6.00	8.3
	a-b	-0.43±0.16 (t = 2.68, p = 0.0148)			-
Hydrolytic acidity, *mekv/kg*	*a*	1032.78±76.68	382.05	1712.20	37.9
	b	820.49±56.05	532.94	1587.47	30.6
	a-b	212.29±94.99 (t = 2.23, p = 0.038)			-
Amount of basis in the soil, *mekv/kg*	*a*	1566.52±64.68	887.55	2028.50	21.1
	b	1674.26±49.59	1313.25	2178.71	13.2
	a-b	-107.74±81.50 (t = 2.23, p = 0.2025)			-
Base saturation, *%*	*a*	60.66±2.35	34.14	84.15	19.1
	b	67.36±1.78	45.27	77.03	11.8
	a-b	-6.70±3.25 (t = 2.27, p = 0.037)			-

the values of pH_{KCl} were 5.54 ± 0.10, which is a significantly higher value than in the sample plots with insufficient regeneration (ΔpH_{KCl} = 0.43 ± 0.16, p < 0.05, t = 2.78).

The variation in the exchangeable acidity of the sample plots showed that the number of regenerating young trees was insufficient in most of the plots on the soils with *pH* less than 5.1 (of 14 only in 2 sample plots on the soils of such acidity contained sufficient number of regenerating young trees of dawny birch (*Betula pubescens Ehrh.*)) (Figure 2).

The most favourable conditions for forest regeneration were on the soils with conditionally acidic reaction (*pH* from 5.8 to 5.9) (Figure 2). On the above-mentioned soils, the number of sample plots with sufficient regeneration was three times greater than with insufficient regeneration. Witt (1990) and Carthaigh (1997) obtained similar results, which showed that the tree growth was the greatest on the soils with *pH* values ranging from 5.5 to 6.0. Vaičys *et al.* (1979) reported a slightly larger optimum range of the potential exchangeable acidity (pH_{KCl}) for

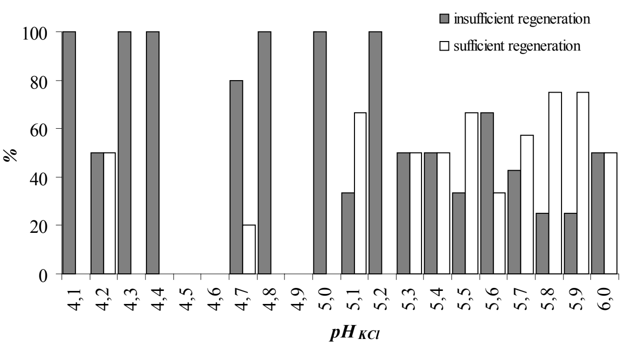

Figure 2. pH_{KCl} contents at the upper soil layer (0-20 *cm*) in the sample plots with sufficient (open bars) and insufficient (filled bars) regeneration

deciduous tree species (within the range of 4.7 to 7.0). We found a significant relationship between the number of viable trees (*N*) and pH_{KCl} values (r = 0.74, p < 0.05), which confirms the results on the effect of the potential exchangeable acidity on natural regeneration. The regression of the number of viable trees on pH_{KCl} yielded the following equation: $N = 0.1787\ Ln(pH_{KCl}) + 3.8503$, ($R^2$ = 0.543, p < 0.05).

In addition, the suitability of the cutovers in drained forested wetland to natural regeneration was assessed according to potential hydrolytic acidity of the soil, which is always higher than the potential exchangeable soil acidity (Buivydaitė and Motuzas 2000). There was a significant relationship between the number of viable trees (*N*) and the potential hydrolytic peat soil acidity (R^2 = 0.37, p = 0.036), (Figure 3). This indicates that the potential hydrolytic acidity as well as pH_{KCl} is a suitable index for assessment of suitability of cutovers to natural regeneration in drained forest wetlands.

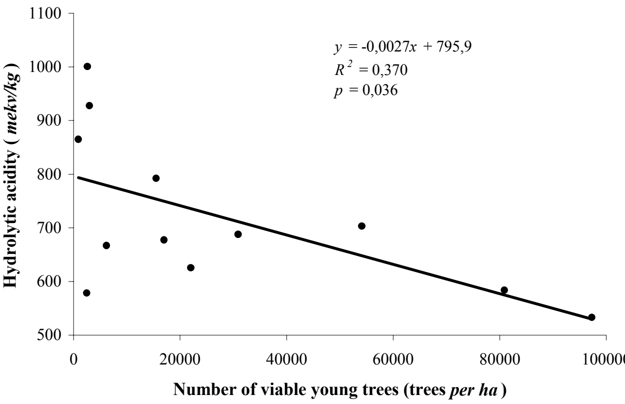

Figure 3. Dependence of the number of viable young trees on the hydrolytic acidity of the upper soil layer (0-20 *cm*)

The effect of soil base saturation on natural regeneration

The soil base saturation is one of the main indicators of soil fertility (Вайчис 1975, Buivydaitė and Motuzas 2000).

The soil base saturation in the sample plots with sufficient regeneration was significantly higher than in the sample plots with insufficient regeneration (Table 1). In the sample plots with soil base saturation of 31-45%, natural regeneration was insufficient (Figure 4). According to Vaičys (Вайчис 1975), such low soil base saturation is common in the intermediate type of peat soils. In the sample plots with soil base saturation of 45.1-60.0%, out of 15 only in 3 sample plots natural regeneration often was insufficient, natural regeneration of dawny birch with occasionally occurring Norway spruce (*Picea abies (L.)*

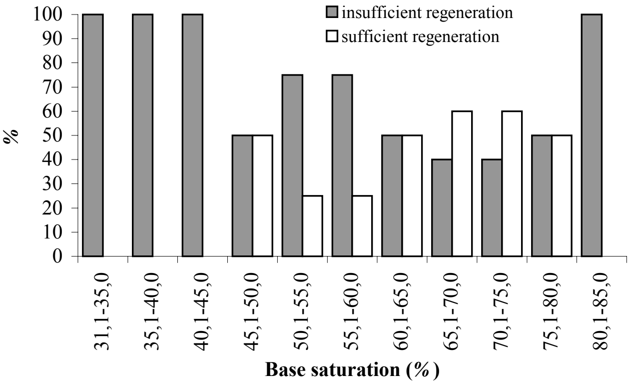

Figure 4. Percentage of the sample plots with sufficient and insufficient natural regeneration in each percentage class of soil base saturation

H. Karst) and Scots pine (*Pinus sylvestris L.*) seedlings was sufficient). In the sample plots with soil base saturation of 60.1-80.0%, natural regeneration of Black and Grey alder (*Alnus incana (L.) Moench*) and European ash (*Fraxinus excelsior L.*) was abundant. In the soils with base saturation of 65.1 to 80.0%, the plots with sufficient natural regeneration occurred 1.4 times more than plots with insufficient regeneration. Thus, the most favourable conditions for natural regeneration occur on sites with soil base saturation ranging from 65 to 80%. Therefore, in the cutovers in fens with the soil base saturation of less than 45% and potential soil acidity *HA* > 1100 *mekv/kg*, alkaline enrichment is recommended. Many studies indicate that alkaline enrichment positively affects the growth of deciduous and Norway spruce trees (Сабо 1980, Паавилайнен 1983, Корчагина, Ионин 1984, Ипатьев 1990).

The effect of water table depth on natural regeneration

As the water table depth is closely connected with the climatic conditions, it may be useful to review the climatic data over the study period. The spring of 2003 was dry (in 2003 the hydro-climatic coefficient reached 68.8% of the long-term mean value). The spring of 2004 was of medium humidity (the hydro-climatic coefficient was close to the long-term mean value). During the period of active growth (from May to August) in 2003 and 2004, the precipitation amount was 295 *mm* and 353 *mm*, respectively. These values were reaching 80 and 96% of the long-term mean values.

On undrained sites, at the beginning of the growth period in 2003 and 2004, the water table was 5 ± 2 *cm* and 12 ± 4 *cm* above the surface, respectively (these values were from 5 to 10 *cm* higher than in pre-mature Black alder stands on drained out sites). This data correspond to the reports from some studies, where a rise of water table from 7 to 17 *cm* was observed after the clear-cutting (Roy 1998, Roy *et al.* 2000, Ипатьев 1990). On drained cutovers with peat soils, the depth to the water table at the beginning of the growth period ($H_{V.01}$) was dependent on the drainage intensity (I_k) (Figure 5). In the spring of 2004 with an average humidity, the depth to the water table was 5-45 *cm*, which is from 17 to 57 *cm* deeper than in the premature Black alder stands on undrained sites. At the beginning of the growth period, the mean depth to the water table was 27.4 ± 2.1 *cm* and 45.1 ± 2.6 *cm* below the surface, in the cutblocks with sufficient and insufficient regeneration, respectively (Table 2). This indicates, some of the sites were drained out too intensively: in the plots with insufficient regeneration the water table was for 17.8 ± 3.3 *cm* (t = 5.34, p < 0.0001) deeper than in the plots with sufficient regeneration.

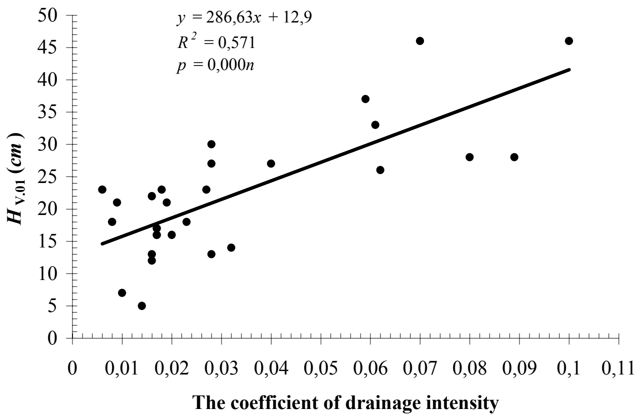

Figure 5. The dependence of the depth to water table at the start of growth period ($H_{V.01}$) on the coefficient of drainage intensity (I_k) (data from 2004)

The variation coefficient for the mean water table depth was very high on all sites regardless of the regeneration success (V = 48.5-59.9%) (Table 2). To investigate the cause of such a large variation, the effects of other factors influencing soil moisture were studied. Soil moisture and forest regeneration success are affected not only by the depth to the water table (Hillman 1992) but also on the subsoil texture (Ruseckas 2002).

The assessments of the effect of soil texture on the depth to the water table showed that in the cutblocks with sufficient regeneration and coarse subsoil texture (gravel, sand, sandy loam), the depth to the water table was for 15.9 ± 3.7 *cm* (p = 0.0001) less than in the cutblocks with insufficient regener-

Table 2. Mean depth to water table at the beginning of the growth period on shallow peat soils (HS_s-*ph*) depending on the subsoil texture

Subsoil texture	Plots with insufficient regeneration						Plots with sufficient regeneration						Difference			
	M, cm	*m,* (±) *cm*	*Min, cm*	*Max, cm*	*N*	*V*	M_S, *cm*	*m,* (±) *cm*	*Min, cm*	*Max, cm*	*N*	*V*	M-M_S, *cm*	$m_{(M-Ms)}$ (±) *cm*	*t*	*p*
Gravel	**53.7**	9.8	16	125	11	60.3	**18.0**	3.7	13	29	4	41.3	**35.7**	10.5	3.42	0.0418
Sand	**38.3**	3.6	11	95	30	51.7	**26.5**	2.7	9	46	19	62.3	**11.8**	4.5	2.62	0.0193
Sandy loam	**37.9**	3.6	18	57	12	32.8	**26.6**	3.9	3	46	13	52.5	**(11.3)**	5.3	2.14	0.0556
Mean for peatland with coarse-textured subsoil	**41.4**	3.1	11	125	53	53.6	**25.5**	2.1	3	46	36	57.2	**15.9**	3.7	4.31	0.0001
Light loam	**49.3**	7.8	12	62	6	38.8	**29.6**	6.6	5	65	8	63.3	**(19.7)**	10.2	1.92	0.1129
Medium loam	**54.8**	9.2	28	68	4	33.7	**42.2**	9.4	18	65	5	49.8	**(12.6)**	13.2	0.95	0.4122
Mean for peatland with medium textured subsoil	**51.5**	4.7	12	68	10	35.0	**34.5**	4.5	5	65	13	57.5	**17.0**	6.5	2.61	0.0290
Mean for peatland with heavy textured subsoil	**65.5**	5.0	52	80	7	18.1	**19.5**	3.6	13	28	4	37.1	**46.0**	6.1	7.8	0.0044
Mean for peatland	**45.1**	2.6	11	125	70	48.5	**27.4**	2.1	3	65	53	59.9	**17.8**	3.3	5.34	0.0001

M – mean, *m* – standard error, *Min* – minimum value, *Max* – maximum value, *N* – number of sample plots, *V* – coefficient of variation, *t* – Student t-test value, *p* – probability the t-test value. Where the difference between the sites with sufficient and insufficient regeneration was not significant, the difference values were included in the parenthesis.

ation. In the cutovers with water table depth greater than 50 *cm*, natural regeneration was very poor. This indicates that, in the cutovers with sand, sandy loam or gravel subsoil, lowering down the water table below the optimum drainage level is unprofitable and may also negatively affect natural regeneration (according to Ruseckas (Русецкас 1989), Smoliak (Смоляк 1969) and Meshechok (1969) the optimum drainage level for the growth of deciduous forests in fens is 7-21 *cm*, 10-15 *cm* and 30 *cm*, respectively). In agreement to this, Volskis *et al.* (1999) concluded that too intensive drainage in fens may lead to a lower commercial value of the forests.

Similar results were obtained on shallow peat soils on medium loam subsoil: in the plots with sufficient and insufficient regeneration, depth to the water table was 34.5 ± 4.5 *cm* and 51.0 ± 4.7 *cm*, respectively (the difference was 17.0 ± 6.5, p = 0.034). If at the beginning of the growth period water table in such soils is below the depth of 70 *cm*, natural regeneration totally fails and if water table is at the depth of 1-10 *cm*, natural regeneration is almost 100% successful (Figure 6). Thus, the critical water table depth, below which natural regeneration is at risk, depends on the subsoil texture of the shallow peat soils (Table 2).

In conclusion, shallow peatland sites with subsoil of more heavy texture are less sensitive to negative effects of too intensive drainage. To obtain successful natural regeneration in fens, lowering down the water table below the optimum level is not recommended on shallow peat soils with sandy as well as loam subsoil.

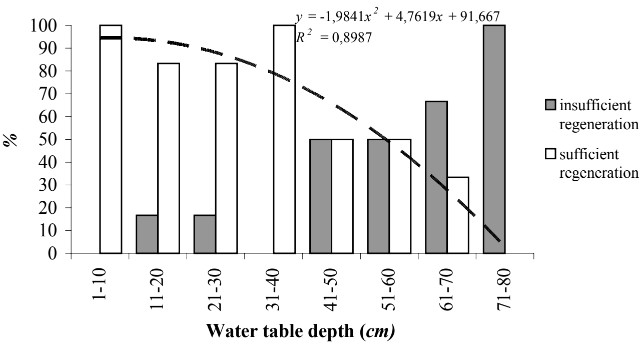

Figure 6. Percentage of the sample plots with sufficient and insufficient natural regeneration in each class of water table depth at the beginning of the growth period in the soils with loam subsoil

Relationships among the properties affecting natural regeneration

The above given results indicated that the following factors have an important effect on natural regeneration of forests on fens: the depth to the water table at the beginning of the growth period, the *pH* of the peat soil, the potential hydrolytic soil acidity and the base saturation in the peat soil. Most of these factors were correlated with each other (Table 3). For instance, the correlation coefficients between the base saturation of the upper peat layer (0-20 *cm*) and the potential hydrolytic acidity, pH_{KCl}, the base sum, the thickness of the peat layer, the amount of silt/clay fraction particles in subsoil were – 0.85, 0.79, 0.50, 0.55, 0.43 (p < 0.05), respectively (Table 3).

Table 3. Correlation coefficients among the soil properties affecting the natural regeneration of forest

Indices	$H_{V.01}$	D_h	F_m	pH_{KCl}	HA	sb	BS
D_h	-0.540	–	–	–	–	–	–
F_m	-0.275	0.770	–	–	–	–	–
pH_{KCl}	-0.595	0.387	0.202	–	–	–	–
HA	0.760	-0.448	-0.280	-0.826	–	–	–
sb	-0.139	0.320	0.363	0.221	0.030	–	–
BS	-0.750	0.545	0.433	0.793	-0.848	0.497	–
N	-0.353	0.280	-0.094	0.415	-0.608	0.002	0.538

$H_{V.01}$ – the depth to water table at the start of growth period (*cm*), D_h – thickness of the peat layer (*cm*), F_m – amount of silt and clay fraction particles (< 0.01 *mm*) in the subsoil (*%*), pH_{KCl} – the potential exchangeable soil acidity (*mekv/kg*), *HA* – the potential hydrolytic acidity of the peat soil (*mekv/kg*), *sb* – sum of basis (*mekv/kg*), *BS* – the base saturation of the peat soil (*%*), *N* – number of viable regenerating young trees (young trees *per ha*).

The multiple stepwise regression analysis (excluding the correlated variables), showed that natural regeneration of forest in fens are mainly affected by the following main components: the depth to the water table at the beginning of the growth period ($H_{V.01}$) and the peat hydrolytic acidity (*HA*). The multiple regression equation was the following:

$$N = 168059.7 - 3446.5 H_{V.01} - 35.180 HA \quad (3)$$
$$R^2 = 0.814,\ F = 7.51,\ p < 0.0007$$

where *N* is the number of viable trees *per ha*.

This equation confirms the hypothesis that the depth to the water table and hydrolytic soil acidity are the main factors affecting natural regeneration of forests on cutovers on fens. Therefore, to improve the natural regeneration of forests on such cutovers, the water regime of the upper soil layers should be optimised by regulating water flow in drainage ditches and the soils of very high acidity should be enriched with alkaline.

Conclusions

1. Natural regeneration of forest in cutovers on drained fens (eutrophic peatlands) is affected by the following factors: the depth to the water table at the beginning of the growth period ($H_{V.01}$), the *pH* of the peat soil, the potential hydrolytic acidity of peat soil (*HA*), the base saturation of the peat soil and the thickness of the peat layer. As determined by the multiple regression analysis, the depth to the water table at the beginning of the growth period and the potential hydrolytic acidity of the peat soil had the strongest effect (equation No. 3).

2. The critical water table depth, below which natural regeneration is at risk, depends on the subsoil texture of the shallow peat soils (HS_s-*ph*). In the peat soils with gravel, sand, sandy loam, light loam and medium loam subsoil, this critical water table depth was 18.0 ± 3.7 *cm*, 26.5 ± 2.7 *cm*, 26.6 ± 3.9 *cm*, 29.6 ± 6.6 *cm*, 42.2 ± 9.4 *cm*, respectively.

3. In the plots with sufficient regeneration, the mean potential hydrolytic soil acidity was equal to 820.49 ± 56.05 *mekv/kg*, which is markedly lower value than in the plots with insufficient regeneration (ΔHA=212.29 ± 94.99 *mekv/kg;* t = 2.23; p = 0.039).

4. To obtain successful natural regeneration of forests in cutovers on drained fens (eutrophic peatlands), the water regime should be optimised by technical means to maintain the optimum soil moisture level (in many cases by damming the drainage ditches) and the soils of very high acidity (HA > 1100 *mekv/kg*) should be enriched with alkaline.

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ВЛИЯНИЕ ПОЧВЕННЫХ УСЛОВИЙ НА ЕСТЕСТВЕННОЕ ВОЗОБНОВЛЕНИЕ ЛЕСА НА ВЫРУБКАХ ОСУШЕННЫХ НИЗИННЫХ БОЛОТ

В. Григалюнас, Ю. Русецкас

Резюме

Динамика естественного возобновления древесных пород на вырубках с болотными почвами низинного типа в зависимости от их агрохимических свойств и стояния уровня грунтовых вод была изучена в Биржайском и Паневежском лесхозах Литвы. Для этой цели, перпендикулярно осям канав, была устроена 31 трансекта 100-300 *м* длины. В трансектах для наблюдения за уровнем грунтовых вод, был оборудован 131 колодец. Возле каждого колодца для изучения растительности, была устроена пробная площадь 10x10 м. Химические анализы почвы были проведены в центральной лаборатории агрохимических исследований Литвы.

Выявлено, что на естественное возобновление древесных пород на вырубках с болотными почвами низинного типа влияет целый ряд почвеных факторов, это высота уровня грунтовых вод на начало вегетационного периода ($H_{V.01}$), глубина торфа, обменная (*pH*) и гидролитическая кислотность торфа *(HA),* насыщенность почвы основаниями. Влияние основных факторов (величин $H_{V.01}$, *HA*) на количество (*N*) всходов и подроста основных древесных пород на вырубках описано уравнением множественной линейной регрессии ($N \square 168059{,}7 \square 3446{,}5 H_{V.01} \square 35{,}180 HA$ ($R^2 \square 0{,}814$; $F \square 7{,}51$; $p \square 0{,}0007$)).

Выявлено, что критическая максимальная глубина стояния уровня грунтовых вод, при которой формируются молодняки леса достаточной густоты, зависит от грануллометрического состава подстилающей породы и в маломощных торфяных почвах (HS_s-*ph*) с подпочвой из гравия составляет 18,0±3,7 *см*, с подпочвой из супеска – 26,6±3,9 *см*, с подпочвой из легкого суглинка – 29,6±6,6 *см*, с подпочвой из среднего суглинка – 42,2±9,6 *см*.

Замечено, что на вырубках, на которых формируются молодняки леса достаточной густоты, гидролизная кислотность почв *(HA)* существенно меньше (ΔHA = 212,29 ± 94,99 *мэкв/кг*; t = 2,23; p = 0,038), чем на вырубках, на которых формируются неполноценные (недостаточной густоты) молодняки леса, и составляет в среднем 820,49±56,05 *мэкв/кг.* Сделан вывод, что для благополучного естественного возобновления осушенных вырубок с болотными почвами низинного типа следует на болотах уровень почвенно-грунтовых вод отрегулировать гидротехническими средствами до нормы осушения (в большинстве случаев для этой цели следует поднять уровень воды в канавах), а очень кислые почвы *(HA >1100 мэкв/кг)* известковать.

Ключевые слова: естественное возобновление леса, вырубки, болотные почвы, грунтовые воды, осушение

Forest Biota under Changing Concentration in Acidifying Compounds in the Air and Their Deposition

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Abstract

Effects of acid deposition on forest ecosystems despite a drastic decrease in sulphur emission and deposition at the end of the 1990s are still among the most significant ecological issues. The key reason for this is that atmospheric concentrations of ammonium and nitrate which have a tendency to increase in the last period became the main acidifying compounds of precipitation. These changes in acid deposition resulted in main objectives of the presented study which were to estimate the effect of rain acidity and atmospheric deposition of pollutants on crown defoliation and diversity of soil microarthropods, stream macrobenthos and small mammals (rodents) on territories under changing regional pollution level. Investigation was carried out in 3 Lithuanian Integrated Monitoring Stations over the period 1994-2004. The obtained data indicated that lower life forms were more affected than higher. Acid deposition was shown to have the most significant effect on pine tree defoliation as well as on the diversity of soil microarthropods and diversity of stream macroinvertebrates and least on the diversity of small mammals. These results have indicated that regional pollution level which is below the critical level for forest ecosystem has a significant effect on the biota.

Key words: acid deposition, crown defoliation, small mammals, soil microathropodes, stream macroinvertebrates, correlation analysis.

Introduction

Convention on Long-Range Transboundary Air Pollution has been one of the main ways of protecting the environment in Europe and North America from air pollution. A considerable decrease in sulphur emissions was a prime example of what can be achieved through intergovernmental cooperation (Bull *et al.* 2001). Acid rain was among the most relevant environmental stresses resulting in negative changes in forest ecosystems. Therefore it seems that the problem of acid rain has already been solved. Nonetheless, investigation of study sites demonstrates that even after complete implementation of the Gothenburg Protocol and other current legislation, acidification with commensurate adverse biological effects will remain a significant problem in Europe as well as in the USA and Canada (Wright *et al.* 2005). To date, it is necessary to see what further measures are needed to understand and estimate the effect of the changing environment on the biota. There are large uncertainties concerning the response of European forest ecosystems to reduced acid deposition (Falkengren-Grerup *et al.* 2002). At what level of acid deposition can we expect recovery of the ecosystems, especially their biological components (diversity and abundance)? What is the effect of different forms of nitrogen deposition (NHx and NOy)?

Activities of International Co-operative Programme on Integrated Monitoring of Air Pollution Effects provide for extended data on these issues and may be one of the ways of advancing our knowledge on recovery and functioning of the forest ecosystems under changing environment. Data obtained in Integrated Monitoring Stations (IMS) could revise the critical load of acid deposition not only for trees but also for such representatives of the biota as soil micro arthropods, stream macro benthos and small rodents. Therefore, in this study investigating “stress – effect“ relationship in forest ecosystems the main attention was paid to the changes in atmospheric deposition fluxes as well as their effect on different components of the biota, to the aim to answer the question whether pollution which is markedly lower than the critical level for forest ecosystem can result in changes in the biota.

Method and materials

The investigation was carried out in 3 Lithuanian Integrated Monitoring Stations (IMS) established in Aukstaitija, Dzukija (1993) and Zemaitija (1994) National Parks (NP) and representing three different landscape types of Lithuania: Aukstaitija IMS – in East, Dzukija IMS – in the South and Zemaitija – in the West of the country. In 2000 Dzukija IM Station was closed due to underfinancing and estimation of the pollution level was stopped. Therefore to pursue the objectives of the presented study only the data on pollution and biota over the period from 1994 to 1999 were used from this IM station.

Climate in Aukstaitija IMS is characterised as average cold with high humidity and abundant precipitation. Annual mean air temperature is 5.8˚C, mean annual precipitation amount – 682 mm. Length of vegetation period – 189 days.

Glacioaquatic accumulation forms with sand, gravel and stones are typical of Aukstaitija IMS (LT-01) catchment which with the decrease of altitude transfers into fliuvioglacial terrace delta plain with fine sand, and at the source- into marsh accumulation forms with organic sediments. Multi-aged and multi-layered mature and over mature pine and spruce stands on haplic arenosol, passing at lower places into albic and gleyic arenosol and into histosol (eutrophic deep peat soil) prevail in LT-01 catchment.

Climate in Dzukija IMS (LT-02) is very similar to the one in Aukstaitija IMS. Annual mean air temperature is 6.0˚C, mean annual amount of precipitation - 625 mm. The length of vegetation period is 195 days.

The geomorphologic structure of LT-02 catchment is formed by more intensive glacioaquatic and in addition eolian processes than in LT-01. Relief represents a re-modified fliuvioglacial plain, with clearly defined continental dunes of complicated shapes, where fine-grain sand dominates. Soils are formed on quartz sands of eolian origin and contain no carbonates. Forest specific diversity is much poorer than in Aukstaitija IMS. Premature and mature pure pine stands on the haplic arenosol, transfering into albic arenosol dominate in the catchment.

Zemaitija IMS (LT-03) is situated at 50 km distance from the Baltic Sea, which generally defines the climatic conditions of this territory. The mean air temperature is 5.9˚C, the amount of precipitation reaches up to 788 mm and is significantly higher than in other stations. The length of vegetation period is 187 days.

The geomorphologic structure of the catchment is different from that in other locations. In LT-03 the marsh accumulation forms with organic sediments transfer into limnoglacial accumulative forms and glacioaquatic accumulative sandy hilly formations with typical limnoglacial sand. Spruce forest with two or more age classes and with up to a 20-30% pine mixture on albic arenosol transfering to gleyic arenosol and various histosols (eutrophic shallow and deep and distrophic peat soil) dominates in Zemaitija IMS.

Crown condition of about 1000 trees (pine trees – 20%, spruce – 70% and birch – 10%) was assessed according to the methodology of ICP Forest monitoring programme over the period 1994-2004 (UN-ECE 1994) on 50 permanent observation plots (POP) in LT-01; of about 1200 trees (pine trees – 90%, spruce and birch – 10%) on 58 POP in LT-02 and of about 600 trees (pine trees – 10%, spruce – 85% and birch – 5%) on 37 POP in LT-03.

The diversity and abundance of soil microarthropods was investigated in autumn annually on prevailing forest type of catchments: in Aukstaitija IMS in haplic arenosol of mixed pine-spruce overmatured stand, in Zemaitija IMS in albic arenosol of premature spruce stand and in Dzukija IMS in haplic arenosol of pure premature pine stand.

Small rodents were investigated in bilberry pine-spruce forest and nemoral bog spruce wood in Aukstaitija IMS, in cowberry pine forests and pasture in LT-02 and in suboceanic bilberry spruce forest and pasture in LT-03. Small mammals in each IMS were caught by 150 snap traps over 3 day period. Specific diversity of small mammals community assessed by number of species (unit.), while abundance - by total number of caught small mammals (ind. per ha).

Investigation of stream macroinvertebrate diversity, abundance and biomass was carried out annually in May and October months in streams of IMS over 1994-2004. The bed of LT-02 and LT-03, where investigations were carried out consists of sand, gravel and pebble while the bed of LT-01 – of sand and peat.

Investigation of the abundance and diversity of the mentioned components of the biota was carried out according to the Manual for Integrated Monitoring (UN-ECE, 1993).

Sulphur dioxide (SO_2), sulphates (SO_4^{2-}), sum of nitrate ($\Sigma NO_3^- = NO_3^- + HNO_3$) and sum of ammonium ($\Sigma NH_4^+ = NH_4^+ + NH_3$) concentration in the air and SO_4^{2-}, NO_3^-, NH_4^+, hydrogen (H^+) ion and major base cation (Na^+, K^+, Ca^{2+}) concentration in precipitation as well as their wet deposition were estimated in IMS over 1994-2004.

The air sampling was carried out at weekly intervals. The sampling equipment for SO_2 and particulate sulphate collection consisted of a two-stage filter pack sampler with a cellulose filter (Whatman 40). SO_2 was collected by retention of particles using potassium hydroxide (KOH) impregnated Whatman 40 filter. ΣNO_3^- and ΣNH_4^+ were collected using an open-face separate samplers with an alkaline (KOH) and oxalic acid impregnated Whatman 40 filters, respectively.

Precipitation samples were collected weekly in a polyethylene bulk-collector from December to March and in an automatic wet-only sampler during the remaining months. All samples were stored at 4^0 C until laboratory analysis.

Ion chromatography using Dionex 2010i with conductivity detection was used for the chemical analysis of anions in precipitation and in water extracts from the impregnated Whatman 40 filters. NH_4^+ concentration in precipitation as well in the extraction solutions from oxalic acid impregnated Whatman 40 filters was analysed spectrophotometrically using the indophenol blue method. Precipitation pH and electric conductivity were determined with a pH glass electrode and an electric conductance meter, respectively.

The overall measurement and analytical procedures were based on a quality assurance/quality control (QA/QC) programme as described in the EMEP CCC manual for sampling, chemical analysis and quality assessment (EMEP 1997). Analytical methods were controlled through the international (EMEP and GAW) analytical intercomparisons.

For selection and chemical analysis of soil water lizimeters (plate type, surface area 625–1000 cm^2) were installed on prevailing forest type of each catchment. Water samples were collected from two layers: at 10-20 cm (main root zone) and 30-50 cm (below main root zone) depth, installing 3 collectors in each layer; sampling period 3–4 times per vegetation period.

Fisher test was used for estimating significance of spatial and temporal differences in changes of pollution among IMS; multiple regression analysis was used to estimate main acidifying compounds resulting in changes in precipitation pH over the different periods; linear, Spearman and partial correlation analysis - to derive relationships between the biological parameters and acid deposition within the IMS as well as among IMS by using techniques of "Statistica 6.0" software.

Results

Rain acidity and atmospheric deposition fluxes. Results on the main acidifying compounds obtained in IMS indicated a significant decrease in pollutants until 2000. Mean annual SO_2 concentration in the air of Aukstaitija IMS (LT-01) decreased by 82% (from 2.76 to 0.49 µgS/m^3) in Zemaitija IMS (LT-03) by 79 % (from 2.22 to 0.47 µgS/m^3), in Dzukija IMS (LT-02) by 63 % (from 2.30 to 0.84 µgS/m^3 in 1999). From this year onwards some increase in the concentration was recorded (Fig. 1). However, in 2004 SO_2 concentration decreased again to 0.51 µgS/m^3 in LT-03 and 0.55 µgS/m^3 in LT-01.

The most significant decrease in nitrogen compounds in the air lasted until 2001. ΣNH_4^+ concentration in the air in LT-03 decreased by 86% (from 8.55 to 1.15 µgN/m^3), in LT-01 – 77% (from 4.44 to 1.02 µgN/m^3) and in LT-02 – 65% (from 3.91 to 1.37 µgN/m^3). However, a slight increase in the concentration was registered in 2002-2003 and only in 2004 ΣNH_4^+ concentration in the air dropped to 1.1 µgN/m^3 in LT-01 and LT-03.

Only annual means of ΣNO_3^- concentration in the air were quite stable at the level of 0.5-0.7 µgN/m^3 in all stations. Nonetheless, the increase in ΣNO_3 mean annual concentration, since 2001 has been observed (Fig. 1).

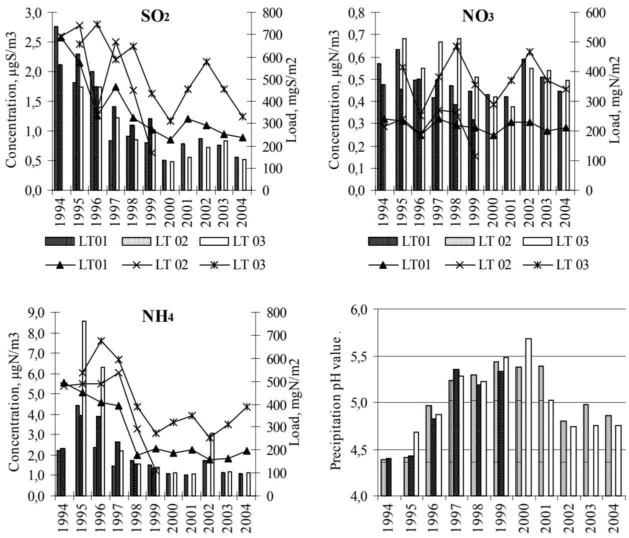

Figure 1. Changes in mean annual concentration of sulphur and nitrogen compounds in the air, their load and precipitation pH in IM stations over 1994-2004. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

The changes in annual wet deposition for the period 1994-2004 had a very similar pattern to that in the air. SO_4^{2-} deposition until 2000 decreased by 67% (from 685 to 225 mgS/m^2) in LT-01, by 52% (from 657 to 312 mgS/m^2) in LT-03 and by 40% (from 739 to 447 mgS/m^2) in LT-02. Between 2001 and 2003 a slight increase in deposition was recorded, however in 2004 it fell again to 235 mgS/m^2 in LT-01 and 328 mgS/m^2 in LT-03.

The decrease in annual wet deposition of NH_4^+ made from 492 to 198 mgN/m^2 in LT-01 and from 537 to 303 mgN/m^2 in LT-03 during the last 11- year period. No significant change in wet deposition of NO_3^- over the whole period was observed. The values of annual wet deposition of NO_3^- fluctuated from 241 to 211 mgN/m^2 in LT-01, from 241 to 270 mgN/m^2 in LT-02 and from 414 to 342 mgN/m^2 in LT-03.

Changes in the main acidifying components resulted in significant changes in precipitation acidity (pH). Between 1994 and 1997 precipitation pH increased from 4.4 to 5.4. For the period 1997 - 2001 pH values in precipitation were rather stable, while in the next three year period fell to 4.7-4.8 again (Fig. 1). A significant decrease in SO_2 concentration in the air had essential impact on a decrease in precipitation acidity over 1994-2000 (Table 1). A slight increase in NO_3^- and NH_4^+ concentration in precipitation as well as NH_4^+ concentration in the air resulted in significant ($p<0.05$) increase in acidity of the precipitation over the last period. A decrease in Ca^{2+} concentration in precipitation since 1999 (Aukstaitija IMS from 0.63 mg/l to 0.41 mg/l; Zemaitija IMS from 0.82 to 0.59 mg/l) had some additional significant effect on this process.

Analysis of the spatial pattern of regional pollution level indicated statistically significant differences in SO_2 concentration in the air ($p<0.036$) and acid deposition (NO_3^- $p<0.000$; SO_4^{2-}, $p<0.035$; NH_4^+, $p<0.058$) among IMS. As a result of this Western and Southern parts of Lithuania were more polluted, what was most likely related to proximity of these territories to the major pollutant sources in Central Europe as well as to the difference in the amount of precipitation.

Effect of acid deposition on soil and runoff water acidity. In Aukstaitija IMS at the first stage of investigation (1994-1996), water pH at the depth of 20 cm decreased from 6.08 to 4.99 (Table 2). From this year onwards soil water pH started to increase and in the last year made about 7.1. Between 1995 and 2004 soil water pH at the depth of 40 cm increased from 4.7 to 7.3. In Zemaitija IMS soil water pH was at the stable level - at the depth of 20 cm a little more than 4.0 and at the depth of 40 cm – 5.0. In Dzukija IMS between 1994-1999 soil water pH decreased from 5.6 to 4.7.

Key factors contributing to theses changes were wet deposition of the main acidifying compounds SO_4^{2-}, NO_3^- and NH_4^+. The strongest and the most significant relationships were found between acid deposition of the previous year and soil water pH (r= -0.5-0.6, $p<0.05$) while the relationships between acid deposition of the current year and soil water pH were far lower (r= -0.25-0.28, $p>0.05$) with exceptions for nitrate (r= -0.6, $p<0.05$).

Stream water pH was quite stable in all IM stations: in LT-01 and LT-03 at the level of 7.4; in LT-02 - 7.8 (Table 2). NO_3^- wet deposition was the key factor contributing to the changes in stream water pH in all IM stations over the whole period under investigation.

Relationship between tree crown defoliation and acid deposition. In 1996 mean defoliation of trees reached the highest level over the whole period under investigation: in LT-01 30.7±0.7%, in LT-02 35.6±0.9% and in LT-03 26.4±0.9%. Afterwards until 2001 a significant decrease in defoliation was observed (in LT-01 to 23.2±0.4%; in LT-02 to 30.0±0.8%; in LT-03 to 20.3±0.6%). Between 2001 and 2003 the increase in defoliation was recorded and in the last year tree crown defoliation in LT-03 in-

Table 1. Effect of the main acidifying components on precipitation acidity (pH)

Period	Concentration in the air			Concentration in precipitation				Statistical data		
	SO_2	NO_3^-	NH_4^+	SO_4^{2-}	NO_3^-	NH_4^+	Ca^{2+}	r^2	p	Std. error
1994-2000	+							0.722	0.000	0.224
2000-2004			+		+	+	+	0.839	0.032	0.170
1994-2004	+				+	+	+	0.706	0.000	0.217

Table 2. Soil and stream water acidity (pH) over the period 1994-2004

Year	Aukstaitija IMS (LT-01)		Dzukija IMS (LT-02)		Zemaitija IMS (LT-03)	
	Stream water	Soil water at 20 cm	Stream water	Soil water at 20 cm	Stream water	Soil water at 20 cm
1994	7.42	6.08	7.94	5.62	-	-
1995	7.32	5.89	7.87	4.63	7.16	4.81
1996	7.20	4.99	7.80	4.67	7.45	4.65
1997	7.42	5.05	7.86	4.67	7.27	4.38
1998	7.31	5.39	7.92	4.38	6.94	4.05
1999	7.37	5.53	7.86	4.73	7.30	4.26
2000	7.45	5.60	-	-	7.44	4.42
2001	7.52	5.48	-	-	7.42	4.29
2002	7.51	5.52	-	-	7.18	4.42
2003	7.42	5.84	-	-	7.34	4.30
2004	7.38	7.09	-	-	7.67	3.87

creased up to 23.6±0.6% while in LT-01 decreased to 23.3±0.6%.

Analysis of the relationships between pollution and crown defoliation of different tree species indicated the highest susceptibility of Scots pines to the impact of air pollution and acid deposition (Figure 2). SO_2 concentration in the air as well as SO_4^{2-} and NH_4^+ deposition had the most significant direct effect on pine crown defoliation what is in full agreement with ICP Forest Monitoring data (de Vries *et al.* 2000). Changes in crown defoliation of Norway spruce were least related to changes in acidifying compounds. It could be explained by the impact of forest pests (*Ips typographus* L.) over the whole period under investigation.

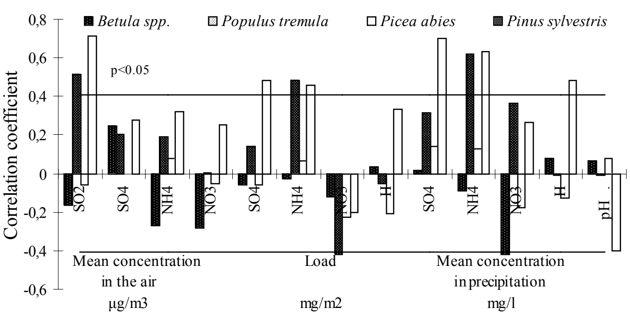

Figure 2. Relationships between crown defoliation of different tree species and air pollutants and acid deposition on IMS territories over 1994-2004

Relationship between soil microarthropods and acid deposition. Individual groups of microarthropods are bioindicators reflecting the impact of air pollution and acid deposition as well as climatic conditions on the biological processes in the soil. High doses of nitrogen fertilizers or high nitrogen loads reduce the abundance of microarthropodes, especially Collembola (Vilkamaa and Huhta,1986; Koposzki 1992; Deleporte and Tillier 1999) while a decrease in the nitrogen deposition in pine stands increases specific diversity of microarthropodes (Boxman *et al.* 1995). Notwithstanding this, in nitrogen-limited vegetation type increase in soil fauna on plots receiving liquid nitrogen fertilisers was detected (Lindberg and Persson 2004).

Data presented in this paper are in full agreement with these findings. Nutrition status of soils was predetermined by richness and abundance of microarthropod complexes. The least abundance and diversity of microarthropods was registrated in haplic arenosol of pure premature pine stand in Dzukija IMS – on average about 140 thou.ind./m^2 and 49 species. In Aukstaitija IMS in haplic arenosol of mixed pine-spruce overmatured stand community of microarthropods was richer. Their average abundance was 233 thou.ind./m^2 and the mean number of identified species - 56. In Zemaitija IMS in albic arenosol of premature spruce stand microarthropod community was richest - 385 thou. ind./m^2 and 65 species. Oribatidic mites represented the dominant group both in prevailing forest soils on IMS territories.

Common trend of changes in abundance and species number over the period under investigation was not statistically significant, however, between 1995-2001 some increase of microarthropod diversity is remarkable (Figure 3).

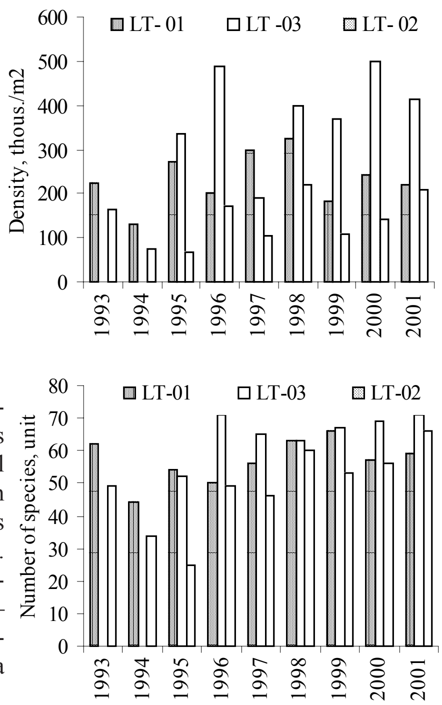

Figure 3. Abundance and species number of soil microathropods on IMS territories over 1994-2001. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

The changes in microarthropod abundance and specific diversity resulted in significant changes in the ratio of mineralization–humification process. Until 1999 the ratio in most cases showed a trend towards the dominance of humification, while since 1999 - towards the dominance of mineralization.

Estimated changes in soil fauna biodiversity and abundance were in full agreement with the changes in tree crown defoliation. Correlation coefficient between tree crown defoliation and arthropods diversity was the most significant and reached -0.8, $p<0.05$. Therefore, it was expected that the same pollution components which resulted in changes in crown defoliation will result in changes in biodiversity of arthropods. The obtained results confirmed this hypothesis (Figure 4). Correlative analysis of the generalized data of all three IMS indicated that the

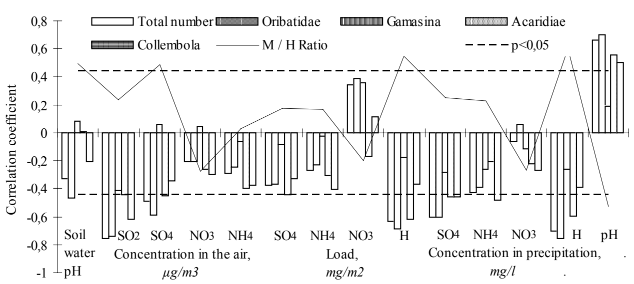

Figure 4. Generalized impact of environment acidifying compounds on soil arthropods diversity and mineralization-humification (M/H) ratio on IMS territories over 1994-2001

number of microarthropod species, especially Oribatidae, was the most susceptible to air pollution caused by SO_2 and SO_4^{2-} concentration in the air as well as SO_4^{2-}concentration in precipitation and precipitation pH. The latter had the most significant effect on integrated parameters of microarthropod abundance and number of species – on the ratio of mineralization–humification process in the soil ($r=-0.6$; $p<0.05$). An increase in precipitation pH resulted in the changes in M/H ratio towards the dominance of humification. Contrary to the estimated effect of precipitation pH, the effect of soil water pH was inverse and in general not significant.

Relationship between stream macroinvertebrates and acid deposition. The stream benthos in LT-01 was dominated by stoneflies (Plecoptera) and caddisflies (Trichoptera) with respect to abundance and biomass. Mayflies (Ephemeroptera) were the most numerous, while caddisfies comprised the largest part of the biomass in LT-02. In LT-03 the domination in abundance and biomass changed across different years between mayflies and amphipods (Amphipoda). The greatest specific diversity was determined for dipterans (Diptera) on all monitoring sites.

During 1994-1999, the increase in macroinvertebrate diversity and biomass was observed in all streams. Later, until 2004, diversity estimates remained at the same level.

In freshwater ecosystem decline due to increasing acidity is greater among the fauna than plants. Studies in Sweden indicated that diversity among benthic species decreased by 40% for a pH reduction of 1 unit, while plant species decreased by only 25% (Engblom and Lingdell 1991). Small organisms are commonly the first to be affected. In polluted areas population declines occur among tiny plankton, snails, crayfish, mussels and insects (Kahn 1985) until streams and lakes become inhospitable to many of animals like at the end of 1980th (COEJL 2003). Recently, in response to the decrease in emission the first signs of recovery for invertebrates in lakes and rivers in several countries were detected (Keller *et al*. 1999; Raddum *et al*. 2004; Harriman *et al*. 2001; Alewell *et al*. 2001). Meanwhile, at the most acidified sites of Central Europe, improvements of biology cannot be detected (Wright *et al*. 2005). Main reason – stream water pH should reach 7, as the negative effect of acidity starts at 6.0-6.5 pH level due to the loss of a few highly acid-sensitive species (Baker *et al*. 1990).

Water pH in streams in IM stations exceeds 7 and its effect on macroinvertebrates is negligible (Figure 5). Notwithstanding this, estimated trends in macroinvertebrate diversity correlated well with the changes in acidity of precipitation (pH<5) and atmospheric pollution by SO_2 or SO_4^{2-}.

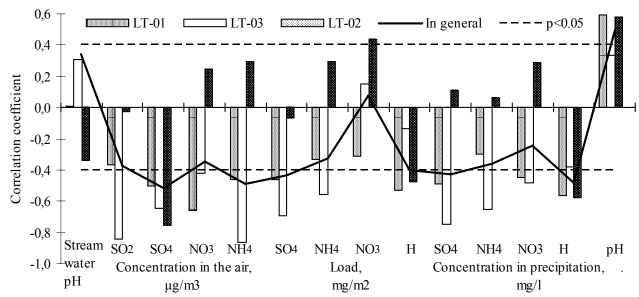

Figure 5. Impact of environment acidifying compounds on diversity of stream macroinvertebrates on IMS territories over 1994-2004. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

Relationship between small mammals and acid deposition. Small mammals due to their link between plants and other animals are an important component of forest ecosystems. However, relatively few examples are known of them suffering direct toxic effects from either acidity or gaseous air pollution instead of negative direct effect of heavy metals (Dudley and Stolton 1994).

Over the ten year period 15 species were registered and 1646 animals caught. The species most frequently met in all of the stations were: *Clethrionomys glareolus* (Schreber), *Sorex minutus* (Linnaeus), *S. araneus* (Linnaeus), *Apodemus* (*Sylvaemus*) *flavicollis* (Melchior) and *Microtus agrestis* (Linnaeus). Additionally in station LT-01 - *Microtus agrestis* (Linnaeus) and *Mus musculus* (Linnaeus); in LT-02 - *Microtus rossiaemeridionalis* (Ognev) and *Apodemus* (*Sylvaemus*) *sylvaticus* (Linnaeus); in LT-03 *Apodemus* (*Sylvaemus*) *uralensis* (Pallas), *Mirotus oeconomus* (Pallas) and *Micromys minutus* (Pallas) were found.

Over the whole period under investigation the greatest number of species was registered on the territory of LT-02 (13 species), lower in LT-03 and LT-01 (10 and 8 respectively). There was no significant trend in changes in species number and mammal abundance (Figure 6). However, data on abundance of small mammals which is one of the main ecological parameters of site condition (Pearce and Venier 2005) indicated the peak in 1999. Afterwards a decrease in abundance was observed in all IM stations.

Some increase in the diversity was recorded until 1999 in LT-01 and LT-03. However, between 1999 and 2003 a significant decrease in the number of species was registered in both of these stations (Figure 6). No regular pattern was observed over the period under investigation in LT-02.

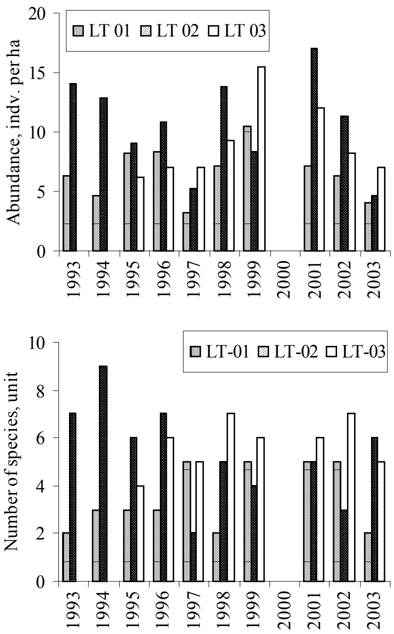

Figure 6. Abundance and species number of small mammals on IMS territories over 1994-2003. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

Strong year-to-year variation at the levels of small mammal population means that long time frames would be required to detect trends and their relationship with acid deposition. Nonetheless, 10-year experience allows starting this investigation. Air pollution had a more significant impact on the diversity than abundance of small mammals. SO_2 concentrations in the air as well as SO_4^{2-} and NH_4^+ concentration in precipitation had quite weak but significant relationship with mammal diversity (Figure 7). Negligible relationship between soil water pH at the depth of 20 cm and the diversity of small mammals was detected.

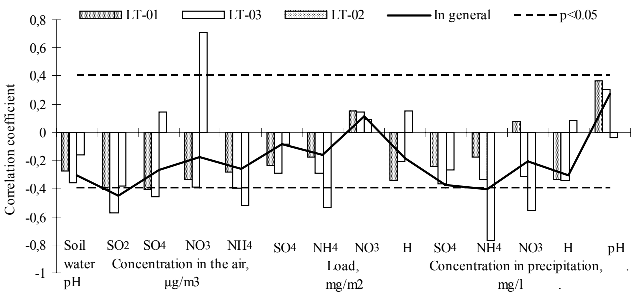

Figure 7. Impact of environment acidifying compounds on diversity of small mammals on IMS territories over 1994-2003. (LT-01 – Aukstaitija IMS; LT-02 – Dzukija IMS; LT-03 – Zemaitija IMS)

Discussion

Over the past 30 years, scientists have gained greater insight into the ways in which acidic deposition has altered ecosystems. Acids and acidifying compounds of atmospheric origin are transported through soil, vegetation, and surface waters, resulting in adverse ecological effects on forest and aquatic ecosystems (Driscoll *et al*. 2003). Forest ecosystems consist of different compartments which may be differently affected by changing environment pollution. Review of the data on the impact of air pollution on the biota has indicated that lower life forms are usually more affected by air pollution than higher. Plants are more affected than animals on land, but not in freshwater. Most affected species decline, but a minority increase (Dudley and Stolton 1994). Land mammals, contrary to aquatic are among the most resistant to air pollution and acid deposition (Air pollution and biodiversity 1997).

These statements are in full agreement with the findings presented in this study. However, contrary to the data presented by the mentioned authors, pollution level on the territories of IMS is remarkably lower than in the western or northern part of Europe. Notwithstanding this, acid deposition was shown to have the most significant effect on tree defoliation, especially of Scots pine trees as well as on the diversity of soil microarthropods (Figure 8). This could be explained by the estimated significant relationship between pine defoliation and soil microarthropods diversity, which, to our mind, could have causative character. Humus is a part of forest soil within which happen the most dynamic and complex chemical processes. Air pollution drops directly on to the humus layer through wet and dry deposition and influences its chemical composition changing the dynamics of complicated decomposition processes. Decomposition of organic material through microorganisms and soil fauna leads to mineralization and humification, and the rate of these processes determines the kind of humus, which develops (Niemtur *et al*. 2002). *Mull* type of humus, the formation of which is related to richer and more abundant microanrthropod communities, results in higher productivity and better condition of trees. Higher acidity of rain decreases specific diversity of arthropods and their abundance what results in the change of the mineralization-humification ratio towards the dominance of mineralization. Therefore soils over this period become poorer and contribute to higher level of pine defoliation. This finding confirms the statement that decomposition of organic material and the ratio of mineralization-humification process is used as an indicator of biocenosis and site condition.

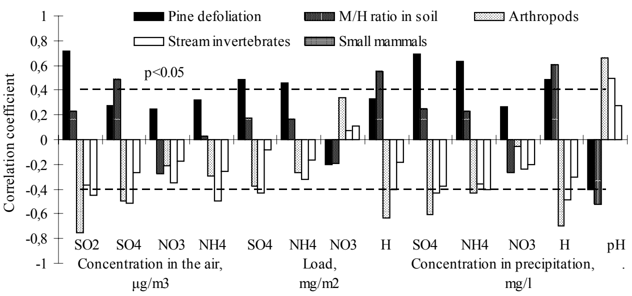

Figure 8. General effect of air pollution and acid deposition on different components of biota in forest ecosystems on IMS territories

A little lower was the effect of acidifying compounds on the diversity of stream macroinvertebrates (Figure 8). Streams runoff yield, which is very low resulted in significant effect of precipitation acidity instead of stream water acidity on macroinvertebrates. Abundant and more acid precipitation could change in a short time stream water pH, mean value of which reaches 7.0, until the level, when negative impact on macroinvertebrates could be estimated. According to this hypothesis the relationship between soil water pH and microarthropod diversity could be explained as well.

The least was the effect of acidifying compounds on the diversity of small mammals (Figure 8), which are likely to be limited to sensitive species, and acts on the whole through secondary effects, such as changes in food supply, or inter-specific competition (Dudley and Stolton 1994).

It should be noticed that in general the effect of pollution on the abundance of all investigated components of the biota was lower and in most cases not significant than on the diversity. The same detected relationships between pollution compounds and different components of the biota indicated causative effect of the regional pollution load. SO_2 concentration in the air and SO_4^{2-} and NH_4^+ concentration in precipitation are the main compounds of pollution resulting in changes in health and diversity of the biota. Therefore, acidity of precipitation is still one of the key factors among other natural and anthropogenic environmental factors contributing to positive or negative changes in biota in general.

Estimated concentration of sulphur and nitrogen compounds in the air and their deposition did not reach the critical level in the air NOx – 30 µgN/m^3; NH_3 – 8 µgN/m^3; SO_2 – 20 (15) µgS/m^3 (UN/ECE 1989) and critical loads 15 ir 20 kgN/ha for coniferous and deciduous forest respectively (Bobbnik *et al*. 1992) and 5 kgS/ha (UN/ECE 1997). However, the data obtained from these investigations indicate that these pollutant concentrations have significant impact on changes in the biota and these findings should be taken into account when we discuss the critical level of air pollution and critical loads, especially stating that pollution level below which significant harmful effects of specified sensitive elements of the environment do not occur (De Vries *et al*. 2000).

Conclusions

The changes in main acidifying components resulted in significant changes in precipitation acidity (pH). Significant decrease in SO_2 concentration in the air on average from 2.5 to 0.5 mgS/m^3 had the essential impact on a decrease in precipitation acidity over 1994-2000. Precipitation pH reached 5.4.

Slight increase in NO_3^- and NH_4^+ concentration in precipitation and NH_4^+ concentration in the air resulted in the increase in acidity of the precipitation over the last period (pH decreased to 4.7-4.8). Decrease in Ca^{2+} concentration in precipitation since 1999 (Aukstaitija IMS from 0.63 mg/l to 0.41 mg/l; Zemaitija IMS from 0.82 to 0.59 mg/l) had some additional significant effect on this process.

Wet deposition of the main acidifying compounds SO_4^{2-}, NO_3^- and NH_4^+ had the most significant effect on soil water pH at the depth of 20 cm especially in the previous year. Over the whole period under investigation wet deposition only of NO_3^- resulted in significant changes in stream water acidity (pH).

Due to detected causative relationships between soil microarthropod diversity and abundance and pine tree defoliation, key factors resulting in their changes were SO_2 concentration in the air as well as SO_4^{2-} and NH_4^+ concentration in precipitation.

Stream water acidity, pH of which exceeded 7, did not have essential effect on macroinvertebrate. Notwithstanding this, main acidifying compounds SO_2 and SO_4^{2-} concentration in the air as well as SO_4^{2-}, NH_4^+ concentration in precipitation and precipitation pH resulted in their diversity changes.

Due to the effect of acid deposition on small mammals through secondary effects, such as changes in food supply, or inter-specific competition, the relationship between pollution and mammal diversity was least significant. However, concentration of sulphur compounds in the air and precipitation as well as precipitation pH resulted in small mammal diversity changes.

Obtained relationships on IMS territories under regional pollution load, which do not exceed the critical values for the biota in general, confirm the statement of higher sensibility of lower life forms (plant and invertebrates) against acid deposition than higher forms (land mammals). Acidity of precipitation on these territories is still one of the key factors contributing to positive or negative changes in different components of the biota.

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ИЗМЕНЕНИЯ В ЛЕСНОЙ БИОТЕ ПОД ВОЗДЕЙСТВИЕМ КИСЛОТНЫХ СОЕДИНЕНИИ В АТМОСФЕРЕ И ИХ ОСАДКОВ

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Резюме

Кислотные соединения, несмотря на существенное снижение выбросов серы в конце 90тых годов прошедшего века, остаются одним из основных факторов влияющих на состояние лесных экосистем. Поэтому, установление воздействия кислых осадков на дефолиацию кроны сосны обыкновенной, а также и на разнообразие микроартроподов почвы, воденных безпозвоночников и мелких млекопитающих (в основном грызунов) суши на территориях станций интегрированного мониторинга в период с 1994 по 2004 г.г. явилось основной задачей представленной работы. Установлено, что концентрация SO_2 в атмосфере и концентрации SO_4^{2-} и NH_4^+ в осадках статистически значимо влияют на дефолиацию кроны сосны обыкновенной, а также и на разнообразие микроартроподов почвы, воденных безпозвоночников и мелких млекопитающих суши. Однако, уровень значимости этого воздействия зависит от уровня формы жизни, т.е. чем она выше, тем воздействие слабее. Представленные данные показывают, что даже загрязнение окружающей среды, уровень которой ниже критического, установленного для лесных экосистем, имеет значимое влияние на различные компоненты лесной биоты.

Ключевые слова: кислотные соединения, дефолиация кроны, микроартроподы почвы, водяные безпозвоночники, мелкие млекопитающие, корреляционный анализ.

Foraging Character of Deer Cervidae and Brown Hare (*Lepus europaeus*) on the Littoral Area of Pure Pine Forests in Lithuania

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Abstract

The main herbivorous mammals as Cervidae go in with hares Leporidae into general trophic chain as primary consumers. The basic interaction between these animals and forest woody vegetation mostly evidences in the feeding relations. Therefore the feeding character in herbivorous animals is the important item of this study. Limited factors could come drivers of the animal impact to forest. On the other hand, the interaction between animals and forest woody plants requires not only elements of this interaction but also an environment where this interaction occurs. Therefore, the habitat preference should be considered. We aimed to reveal the foraging character of deer and hares, and assess the animal - forest woody plants' interaction by considering the above-mentioned notes.

We employed the integrated method of belt transects (sample unit is 100 x 4 metres) and sample plots (50 x 2 metres, or 100m^2). The method of pellet group count has been used to assess the number and distribution of the local populations of investigated animal species, the age structure and sex ratio of local populations of moose and red deer, and age structure of the roe deer local population. We identified animal age and sex by pellet groups. Woody plants and their shoots within the feeding space of animals (that is from h = 0,1 to 2,2 m) were counted dividing damaged and untouched shoots. Browsing intensity ***I,*** and the share of woody species in animal diet ***P,*** were calculated by the consumption of all species of forest woody vegetation. Habitat preference of stands of the different age classes, composition and forest site types were estimated. The total number of sample plots is 504, and the total length of the route is 79.9 km on the study area of 2,736 hectares.

The specific climatic and geomorphologic diversity of landscape and local conditions as well as the absence of agricultural landed property determine the low carrying capacity and specific structure of the local fauna and their adaptations, as the mixed forest-forest edge ecotype in hares and forest ecotype in roe deer. The coexistence of forest plants and animals is directly and indirectly influenced not only by the determined abiotic and biotic factors but also by human factors including forest management, hunting and its restrictions, supplemental feeding in winter, picking of mushrooms and berries, and other recreational activities. The mentioned activities are particularly obvious on the study territory while the forests are managed by the separate regime that is approved by the legal acts for protected areas. The animal density is less than the permissible density in pure pine forests while there is the aberrant sex ratio and age structure in local populations. That is the indicator of disfavour in living conditions. Habitat preference values and plant consumption intensity varied temporally depending on the stand composition, forest site type and forest age as well as variability of the main weather parameters. The main criteria of the animal-plant interaction are the consumption of shoots and the browsing intensity of the main woody species. The shoot consumption in conifers more than 40-50% and more than 20-30% in deciduous species is the criterion of the irreversible decline in the certain species (e.g. *Populus tremula*, *Frangula alnus*).

Key words: herbivores, pure pine forests, protected area, population parameters, habitat preference, browsing intensity, level of shoot consumption

Introduction

Mammalian herbivores such as deer and hares undoubtedly have formative and significant influence to the forest. Long before the 20 century and later, the balance between herbivorous animals and territory carrying capacity has been pursued to maintain considering the supply of tree shoots, their consumption and share in the animal diet in winter (Petružis and Padaiga 1976, Padaiga 1996). Researchers and foresters from many countries underline the significant changes in stand composition, structure, competitive abilities and survival. The main reason for these changes is the multiple interactions between animals and forest vegetation. The herbivorous animals consume the largest part of forest woody vegetation and are rather important components in forest ecosystems. In the mean time, the permanent and changeable factors that associate with forest use (such as harvesting, forest fragmentation, management of animal populations, hunting, *etc*.), caused changes in the natural interaction between animals and forest vegetation. On the other hand, the non-existence of the real herbivorous animals and non-consumption of some part of the forest phytomass induces the instability in forest ecosystem when the compensatory forest increment of biomass is at a standstill (Ammer 1996, Reimoser, F. and Reimoser, S. 1997, Schulze and Reimoser 1998, Hester *et al.* 2000, Pietrzykowski *et al*. 2003). Among all herbivorous animals, Cervids are the main object of mentioned problem. All the more, there are three deer species that mostly overlap on the same territories in Lithuania. At the same time, we should not leave out of consideration other herbivorous mammals as hares Leporidae that go in with Cervids into general trophic chain as primary consumers. Cervids are rather economically most important not only as game, or in an aesthetic context but also because of their specific feeding as the browsing of leading and lateral shoots and bark stripping and, what is more, they are apprehensible more than abstract "biodiversity". In the context of biodiversity conservation, the role of indicator species comes to Cervids (Belova 1995, Hanley 1996). It is considered that deer studies often allow us to assess alternatives of the consumption of environmental resources (Hanley 1996). Eventually, the main interaction between animals and forest woody vegetation mostly evidences through the feeding relations. Animal feeding is an active action. Their typical herbivory displays though the foraging and its efficiency depending on the food accessibility and supply. There is the feedback even as herbivorous animals regulate plant abundance and act all components of ecosystem, respectively. At the same time, food supply limit animal number. Therefore, the feeding character in herbivores is the important item of this study.

The importance of the interspecific competition in deer has been underlined in Lithuania (Padaiga 1996). The roe deer is dominant species, if several deer species occupy the same territory, and shoot browsing of trees and shrubs is lower than 50%, The red deer is dominant species as the browsing exceeds 50% while the roe deer and moose are sparse. In Latvia, red deer replace moose in habitats where the summer browsing is not critical (Prieditis A. and Prieditis Ā. 1999). The competition and trophic niche width mostly increase in non-vegetative period and decrease under optimal feeding conditions accordingly to the food supply. This is attributed to rather changeable winter and early spring in Lithuania (Belova 1997). The most significant impact caused by mammalian herbivores to forest is notably evident in the later autumn – early spring when woody vegetation becomes the main food supply for deer. Therefore, the species juxtaposition in the same territory and non-vegetative period would be under consideration.

The impact caused by animals to forest depends on the historically formed environmental conditions and notably on the animal - plant coevolution and long-term soil development as well as an influence of the climate and weather (Hobbs 1996). Which way of feeding animals will choose, depends on their physiological needs relating to the seasonal changes in animal organism, digestive peculiarities, necessity to use woody food as well as distribution of these food in forests. Both permanent (such as soil conditions, forest site type, climate, communications *etc*.) and changeable (that are related to stand age, food biomass, accessibility *etc*.) factors are important. Animals have to adapt constantly to the changeable circumstances by theirs biological and behavioural strategies that display in the population parameters and impact caused by animals to forest. Consequently, it is important to know the limiting factors that could be drivers of animal impact to forest.

The interaction between animals and forest plants requires not only elements of this interaction but also the environment where the interaction comes to pass. We have to consider the habitat suitability to animals in forests of the different categories and ecological regions (Padaiga and Belova 1994) by assessing the main local limiting factors and indicated importance of the population density that indicates favourability of animal living conditions. This parameter affects the animal impact to forest and subsequently in the forest vitality, productivity, further influence of phytopathogenes and pests, and economic rates. If the animal impact to forest is evident and significant, and some purposive tree species are at risk to extinct, the lower animal density should be maintained considering the reasons for changes in animal influence (Schori 1997, Stromayer and Warren 1997, Schulze and Reimoser 1998; *etc.*). Considerable attention should be devoted to the forest category and character of habitat distinguishing the indicator species (Niemi, Hanowski *et al.* 1997, Belova 1999b, 2004, *etc*.). Animals require habitats different in space and time-wise, and wherein they find food and shelter. The feeding and shelter conditions determine, which habitat animals will choose. The importance of the knowledge and assessment of animal habitats is generally underlined. All succession stages should be in the habitats of deer (Halls 1973) and hares (Belova 1995, 2001). The earlier succession stages are the mainspring of animal feeding (Padaiga 1996, Christian 1997, *et al*, Padaiga and Belova 2001). By the optimal feeding model (Focardi *et al.* 1996, Latham *et al*. 1999), animals forage in patches where the food biomass exceeds the certain threshold. They go away as the food level decrease up to this threshold. The crossings of the different habitats are important for the animal-plant interaction. Animals, and especially females prefer these places (such as cutting area and stand, stand and meadow *etc*.) (Belova 1995, Padaiga 1996, Völk 1999, Bonenfant *et al*. 2003, *etc*.). The intensity of plant usage changes depending on the forest features (such as their species, age, height, development *etc*.) (Ander and Angelstam 1993, Heikkilä 1990, Ammer 1996, *etc*.). The key works in wildlife ecology and management, such as A. Leopold 1933, and further studies underline the necessity to consider the animal habitat conditions.

The indicated notes converged into the main purpose of this study that is to ascertain the foraging of deer and hare and assess the herbivorous animals - forest woody plants interaction on the territory of pure pine forests. This study is the inseparable part of the continuous investigations of interaction between the main components of forest biota on the base of monitoring network in the different nature regions of Lithuania.

Materials and methods

In order to meet the aim of study, we employed the integrated method of belt transects (sample unit is 100 x 4 m) and sample plots (50 x 2 metres, 100m^2). The pellet group count method (McCain 1948, Padaiga 1996, 1998, Belova 1989, 1997, Tottewitz and Stubbe 1998, Shank and Farr 1999, Campbell *et al.* 2004) has been used to assess the number and distribution of local populations of investigated animals, and age structure and sex ratio of the deer populations. We identified the age and sex of animals by pellet groups, namely, age by pellet groups of all three deer species, and age and sex by pellet groups of moose and red deer. The data obtained from the network of belt transects and sample plots underlay the base of the quantitative, qualitative and territorial assessment of deer populations. We conducted the counting of winter pellet-groups, which deer and hares had left on the study area, before the growing period in April 2001-2004. The total number of belt transects was 506 over 3 years.

We established rectangular sample plots strictly to the azimuth. This shape is accepted to be suitable to assess animal-plant interaction at the different layers of vegetation. It is more variable than transect and circular plot (Mosby 1960, Dasmann 1966, Petrak 1992). All woody plants and their shoots within the feeding space of deer and hares (*i.e*. from h = 0,1 to 2,2 m) were counted dividing damaged and untouched shoots. Browsing intensity *I,* and the share of woody species in animal diet *P,* were calculated according to the consumption of all species of forest woody vegetation by using the standard formulas (Aldous 1944, Padaiga 1996). According to the frequency of occurrence, we calculated the abundance of the each species of trees and shrubs on the feeding area using the formula $A = (G \times 100)/ T$, %, where *A* is the abundance of each species of trees and shrubs on the feeding area; *G* is the total number of the separate species of trees and shrubs in all sample plots; *T* is the total number of all species of trees and shrubs in all sample plots. The frequency of occurrence of woody species was calculated by the formula $O = (n \times 100) / N$, %, where *O* is the frequency of occurrence of each species of trees or shrubs; *n* is the number of sample plots where was found each species of trees and shrubs; *N* is the total number of all sample plots. The browsing intensity was calculated by the formula $I = (D \times 100)/ G$, %, where I is the browsing intensity of the each species of trees and shrubs; *D* is the number of damaged trees and shrubs in the separate species in all sample plots, and *G* is the above-indicated total number of the separate species of trees and shrubs both damaged and healthy.

What is the share of each species is in the animal diet during the non-vegetative period, we determined using the formula, $P = C \times 100/ \Sigma C$, %, where *P* is the share of the separate species of trees and shrubs in the animal diet in the non-vegetative period; *C* is the coefficient of consumption of each species of trees and shrubs that is calculated by browsing intensity *I* and abundance *A* of each species of trees and shrubs $C = I \times A$, %; and ΣC is the sum of the *C* of all species of trees and shrubs.

The preference index of habitats was calculated by the formula $P=(E_1/E_2-A_1/A_2)/(E_1/E_2+A_1/A_2)$ (Jacobs 1974, Belova 1995), where P is the preference index, E_1 is the number of pellet-groups in a certain plot, E_2 – the total number of pellet-groups, A_1 – the area of a certain plot, and A_2 – the total area. We estimated this index for habitats of the different stand age class, composition and forest sites. The preference value varies from +1 (positive preference), to 0 (random choice) to –1 (total avoidance), and show what habitat is most or less preferred by herbivorous animals in the different trial periods. The data were processed by the methods of statistics using *MS Excel* and *STATISTICA*. The significance level used was P<0 05. The total number of sample plots is 504, and the total length of the route is 79.9 km on the study area of 2,736 hectares.

Study Area

We conducted our study in the pure pine forests of the Kuršių Nerija National Park (KNNP) in western

Lithuania (55˚30' N 21˚07' E). The status of study area *per se* is motivated by the striving of ecologically, economically and socially based forest management including maintaining of sustainable forestry, landscape protection, key habitats and species, their diversity as well as protection and sustainable use of game resources. Management activities injurious to the environment and unrelated to functions of national park are restricted. The territory of national park is the integrated protected area under multifunctional management. The Kuršių Nerija National Park (KNNP) was established in 1991 aiming to preserve the most valuable complex of Lithuanian seaside with its unique landscape and the dune ridge, natural and ethno-cultural heritage, for sustainable use and care. In the classification of IUCN, KNNP has been recognised as Category II. Since 1997 KNNP has been a member of EUROPARC federation. In 2000, KNNP was included into UNESCO World Heritage List as a valuable cultural landscape. The total area is 26,474 hectares including 9,774 ha (36.9%) of the land and waters as the Baltic Sea (47.2%) and Curonian Lagoon (15.9%). That is the narrow sandy peninsula, which separates the Baltic Sea from Curonian Lagoon (Figure 1).

Northern area is the narrowest part with the width from 400 m to 3.8 kilometres at Bulvikis Horn. Moving dunes have covered moraine ground and the swamp, which remains appeared as the raised bog presently. Parabolic dunes were overgrown by the forests. Fragments of the old growth forests are preserved on the study territory. Because of the strong human impact, since the 16th century the natural environment has been destroyed and that caused severe sand shifting. Thus, the saplings of dwarf mountain pines were planted from 1825, and reforestation project has been implemented. Now forests (70.1% of the total area) are represented by the littoral pine stands with the main species *Pinus sylvestris* (53% of the total territory) and less share of the mentioned dwarf mountain pine *Pinus montana* (27%) There are some communities of the *Vaccinio-Betuletum* represented by *Betula pendula* (15%), *Alnetum (Alnus glutinosa* that covered only 206 ha or 3% of the territory), some stands of *Picea abies* (1%), and plant associations of verdurous dunes. Other tree species make up 1% including some hectares of *Quercus robur,* and *Fraxinus excelsior*. There are also several introduced species like locust *Robinia pseudoacacia*, aspen and poplar *Populus* sp*.,* field maple *Acer campestre,* sycamore *Acer pseudoplatanus*, tartar maple *Acer tataricum*, common beech *Fagus sylvatica*, red ash *Fraxinus pensilvanica* and Austrian pine *Pinus nigra*. Pure pine forests constitute nearly 80%, and sand area of dune meadows comprises 25.4% of the land. Only a small part is constituted by roads (24%), urban area (1.5%), swamps (0.3%) and meadows and pastures (0.2%). The share of arable area is quite small (0.05%), the same as gardens (0.02%) and inner waters (0.01%). There are 37 mammal species including 10 rare and 7 species entered into the Red Data Book, and above 200 bird species including more than 100 breeding species. The diversity of areas under different functional purposes is characteristic of the study area including the following five functional zones: conservation zone (no active intervention) including strict nature reserves (1,850 hectares or 18.9% of the total area) and nature reserves (5,653 ha, 57.8%); protective or buffer zone (73 ha, 0.8%); recreation zone that is rather larger than the conservation zone (1,937 ha, 19.8%) as well as commercial (2.3%) and urban (0.4%) zones.

Unique conditions are on the study territory. This is littoral lowland in the natural district of pine forests that belongs to the maritime climatic subregion IIa. Because of the specific topographical position of the peninsula, the climate is mild and greatly influenced by the Baltic Sea. There is the largest number of sunny days and high air humidity particularly in winter 82%, and in spring 76%. The annual long-term precipitation is 643 mm and reached 912 mm while 75% of the precipitation falls in a warm season. The warming effect of the sea is stronger (up to 3˚ C) than in the other parts of Lithuania. Under sea influence, autumn and winter are warmer than spring: the air temperature differs from eastern regions by 3 -3.5˚. The mean annual long-term air temperature is 6.2-6.4˚C, and reached –0.8-2.0˚C in winter. The snow appears at the end of November. The

Figure 1. Scheme of the study area on the territory of the Kuršių Nerija National Park

snow cover forms at the end of December – beginning from January that is 10-15 days later than on the other territory of Lithuania. Meanwhile the snow cover is quite changeable as 50% of winters are with unstable snow cover and the average depth of snow of h=18 cm.

During the total trial period the weather was changeable while the weather inclemency was undistinguished in the initial non-vegetative period of 2000/2001. In the next period of 2001/2002, the weather was moderately severe but changeable in the early spring (air t˚ = -8˚C - +10˚C). It disturbed the feeding of roe deer in this region (Belova 1999b,c). In the study period of 2003/2004, the weather was quite severe. The wintry weather has steadied from November yet, and the air temperature was negative (-4˚C). The snow cover was most unstable in all study periods. Snow cover changed from 1 cm to 15 cm. In the first and last study periods, it melted later, and was out of the critical isoline. In the next December - January the heavy snow reached 60 cm. However, it was also unstable further. In 2002/2003, the instability of snow cover went with instability of air temperature that had reached – 23- -27˚C. Consequently, the weather in the non-vegetative period was disadvantageous for animal feeding and for thermal balance of moose. In early spring of the last study period 2003/2004, the weather and air temperature completely changed, that is in later March the air temperature changed from +3 to - 19˚C, and from -8˚C to +9˚C. Indicated climatic situation induces the changes in animal habitat selection. In the non-vegetative period, that lasted ca. 98 days on the study area, these weather conditions impelled animals to feed in the forests.

Results

The quantitative and qualitative characteristics of the populations and habitat use of herbivorous animals

The common species of herbivorous animals in the Kuršių Nerija National Park are the Roe deer (*Capreolus capreolus* L.), the Moose (*Alces alces* L.) and the Brown hare (*Lepus europaeus* Pallas). The number of pellet-groups left during non-vegetation period, the browsing pressure per 1,000 hectares, the animal sex ratio and percentage of fawns in the successive years are shown in Table 1 and Figure 2.

During successive years the density of Cervids and hares evidently fluctuated. The highest density of moose was fixed in 2002 (3 animals per 1,000 ha) and the lowest in 2003 (1 animal per 1,000 ha). The highest density of roe deer and hares was in 2001 (17 and 8 animals per 1,000 ha) while in 2003 the density of these herbivorous animals decreased (13 and 7 animals per 1,000 ha, respectively).

Table 1. The quantitative and qualitative changes in the local populations of deer and hares in 2001-2004 on the territory of the Kuršių Nerija National Park

Parameters	Species of herbivorous animals											
	Alces alces				*Capreolus capreolus*				*Lepus europaeus*			
	2001	2002	2003	2004	2001	2002	2003	2004	2001	2002	2003	2004
Total counting area, ha	2,736											
Length of the belt transect, km	13.8	18.7	25.8	21.6	13.8	18.7	25.8	21.6	13.8	18.7	25.8	21.6
Area of the belt transect, ha	5.52	7.48	8.71	8.64	5.52	7.48	8.71	8.64	5.52	7.48	8.71	8.64
Animal-season	5	8	3	1	47	17	31	32	21	7	17	5
Animal density, n*/1,000 ha	**2**	**3**	**1**	**0,5**	**17**	**6**	**11**	**12**	**8**	**2**	**6**	**2**
Sex ratio □□ : □□	**1:0.2**	**1:0.2**	**1:2.2**	**1:0.5**	x	x	x	x	x	x	x	x
Share of Juv, %**	**35**	**88.3**	**29.6**	**40**	**9**	**26**	**6.1**	**10.9**	x	x	x	x

*n – animal number

** Juv% - share of juveniles in the local population by calculating the pellet groups

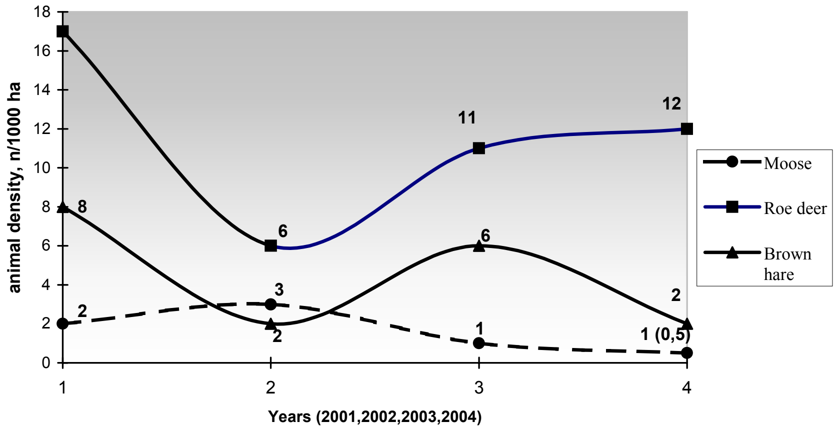


Figure 2. Changes in density of herbivorous animal, n/1,000 ha over the investigative periods from 2001 to 2004

The moose density was lower than the ecological density (2-3 animals per 1,000 ha) that is permissible on the protected areas, however it is more than economical permissible density (1-2 animals per 1,000 ha). In the same time, the density of the roe deer was observed to be lower than the economical permissible. There was no any red deer on the area of KNNP yet. Some individuals were constantly registered in the last three years. That were male, female and two fawns, however, they were not just yet involved into the census. These animals occur in the northern part of the study area close to the thickness of the *Pinus montana* and are not spread through the territory except the stag. He was tracked in the south-eastern part of study territory moving away per 5-8 km from the locality of female and fawns. Meanwhile female and young deer stay there.

According to the qualitative assessment of the local populations, in the first study period of 2000/2001 the males dominated in the moose population. There was a slim share of the juveniles in the roe deer population. The considerable decrease in the number of roe deer together with decrease in share of juveniles in the local population shows that the indicated period was unfavourable for animals. Roe deer density noticeably decreased from 17 to 6 animals per 1,000 ha. Further it started increasing but did not reach the economical permissible and ecological density yet (*i.e.* 10-20/1,000 ha). It should be noticed that the trend of the increase in roe deer population is indicated over the whole territory in Lithuania. In the moose local population the share of fawns comes to increase later on but further it decreases again, nearly 7 times. After the period of mild winter the share of juveniles increases near to optimal (that is 26% in moose and 30% in roe deer) in the roe deer and moose populations. Further, the decline in moose and roe deer number occurs again, and it slightly increases in the last study period only. As moose females increased in number, the sex ratio skewed noticeably from the optimum when the optimal population increment is ensured (*i.e.* ♂♂ : ♀♀ = 1 : 1.1 – 1.2).

The decreases in number are explained as retreat of animals into areas of the more favourable feeding, and animal grouping there. Habitat preference values varied temporally and reveal that habitats are the most preferable depending on the stand composition, forest site type and forest age (Figure 3a-c).

In all trial periods moose mostly grouped in the mature and overmature mixed pine stands *Myrtillosa* and *Vaccinio-myrtillosa* with an average cover of deciduous undergrowth in the western part of peninsula (66.7% of all occurred animals). In the severe winter moose also occurs in the young pine plantations of I age class (89.8% of all occurrence) and in the pine associations of verdurous dunes preferring *Cladoniosa* sites. The preference of the clumped plant associations of verdurous dunes in animals of all species depends on the food availability and weather severity. Roe deer also preferred mature forests of the 4th age class and older (58.7% of all occurred animals) of the *Vaccinio-myrtillosa* and *Myrtillosa*, and notably less grouped in the stands of the 2nd age class. The *Cladoniosa* sites were disliked over all time spans of the investigation. There is underpopulation of hares. Animals grouped in the certain parts of the forests and adjacent open territories as forest gaps, dunes and verdurous dunes. The clumped distribution is characteristic of the local hare population. That is the general tendency of the hare distributions in the pure pine forests (Belova, 1996). In the initial study period hares less grouped in the mature and middle-aged pine forests mixed by birch, and in the verdurous dunes (17.8%, 9.7% and 8.5%, respectively). The main grouping habitats were differently aged young natural and previously planted forests and plant communities of the verdurous dunes, gaps and middle-aged forests and sea dunes on the seashore. Lately, in the periods of the changeable and severe winters, hares go out from the prior wintering habitats of verdurous dunes and gaps to the middle-aged stands. In the last period 2003/2004, they come back to plantations and gaps as well as mature and middle-aged forests.

The herbivory as the main relationship among animals and woody plants in forests

There are 15 species of forest woody plants and dwarf shrubs in the feeding space of herbivores and their diet on the study area. The most widespread woody plants in winter habitats were Scots pine *Pinus sylvestris* (its average occurrence is 72.24%), birch *Betula pendula* (35.12%), juniper *Juniperus communis* (23.84%) and dwarf mountain pine *Pinus montana* (12.99%). The average abundance of these woody vegetation species is 61.54; 9.18; 4.55 and 4.87 %, respectively. Herbivorous mammals use shoots most in non-vegetative period and less in the growing period preferring the well-developed annual shoots of oak *Quercus robur*, aspen *Populus tremula*, brier *Rosa canina* and broom *Sarothamnus scoparius*. However, these species are comparatively scarce of the abundance up to 1 % (Table 2). *Populus tremula* became quite sporadic species and was not registered in the last study period. That is a downtrend of the species on the study territory. This species was particularly consumed in the previous periods with the browsing intensity up to 81.8%. The main

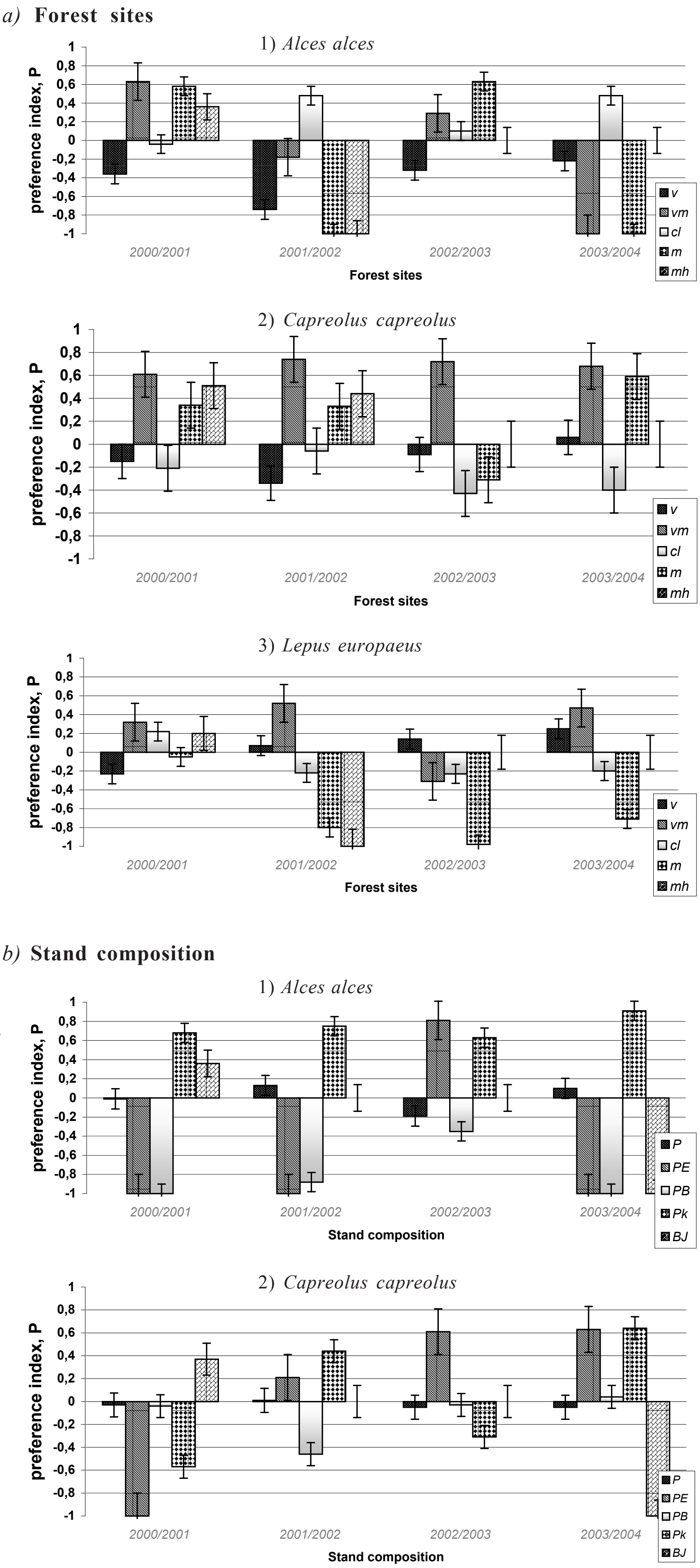
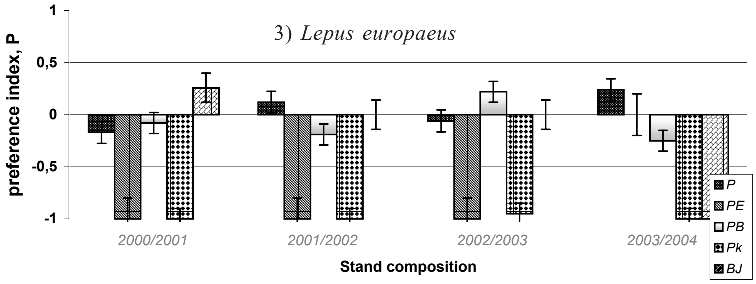


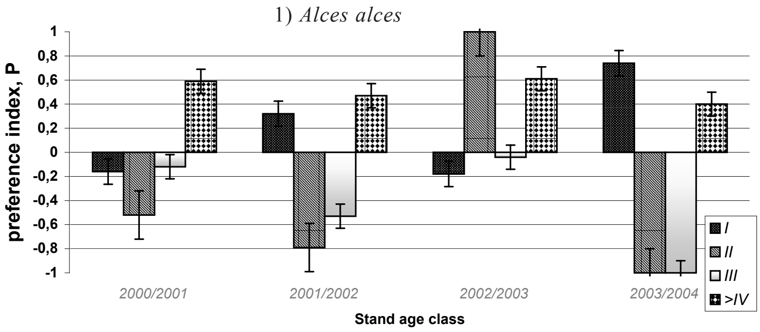
Figure 3. Changes in the habitat preference of Cervidae and *Lepus europaeus* in pure pine forests of different age classes forest sites and stand composition in the Kuršių Nerija National Park from 2000/2001 to 2003/2004 non-vegetative periods

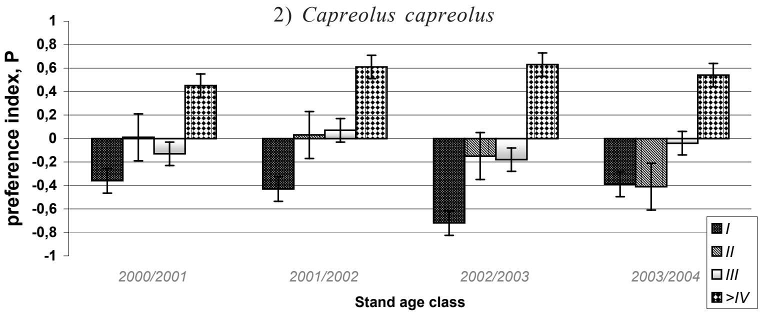
P	- pure pine	*Pinus sylvestris*
PE	- pine with spruce	*Pinus sylvestris - Picea abies*
PB	- pine with birch	*Pinus sylvestris - Betula pendula*
Pk	- mountain pine	*Pinus mugo*
BJ	- birch with black alder	*Betula pendula - Alnus glutinosa*

v - *Vacciniosa*
vm - *Vaccinio-myrtillosa*
cl - *Cladoniosa*
m - *Myrtillosa*
mh - *Mixtoherbosa*



c) **Stand age class**





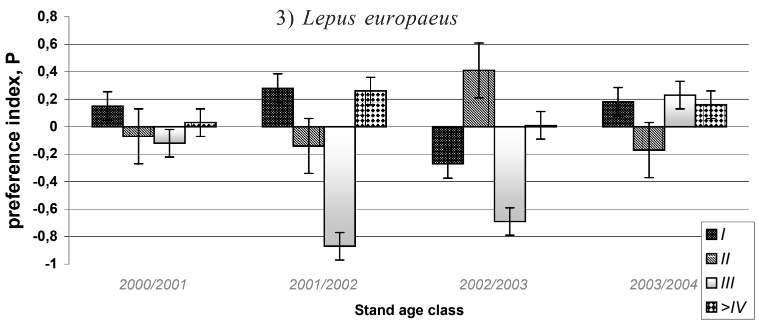


Figure 3. (Continuation)

species in diet were rowan *Sorbus aucuparia,* birch *Betula pubescens,* alder buckthorn *Frangula alnus,* broom *Sarothamnus scoparius* and Scots pine *Pinus sylvestris* as well as dwarf shrub *Vaccinium myrtillus.* The share of these species comprises from 1.1 to 53 % in diet while their browsing intensity on average reached 60% (Table 3). The most preferred deciduous species and variable accessible dwarf shrubs are typical of the underbrush of the mature and overmature stands where animals grouped in the non-vegetative period. The predisposition to choose the most preferred and at the same time rare plant species is obvious in the consumption of shoots too. Most consumed are shoots of *Frangula alnus* (75%), *Populus tremu-*

Table 2. Changes in the occurrence and abundance of forest woody species in pure pine forests of the Kuršių Nerija National Park

Species	Occurrence number, years 2001	2002	2003	2004	Occurrence %, years 2001	2002	2003	2004	Abundance %, years 2001	2002	2003	2004
Pinus sylvestris L.	98	103	113	89	72.59	73.05	71.07	55.97	67.78	61.78	55.06	52.57
Pinus montana Mill.	20	19	17	33	14.82	13.48	10.69	20.75	4.28	5.72	4.61	6.17
Picea abies L.	6	5	5	5	4.44	3.55	3.14	3.14	0.21	0.28	0.33	0.50
Quercus robur L.	3	5	8	8	2.22	3.55	5.03	5.03	0.1	0.18	0.36	0.65
Betula pendula Roth.	43	54	56	60	31.85	38.3	35.22	37.74	6.39	9.71	11.44	12.50
Populus tremula L.	2	2	0	1	1.48	1.42	0	0.63	0.05	0.07	0	1.19
Frangula alnus Mill.	6	3	8	1	4.44	2.13	5.03	0.63	0.75	0.53	0.9	0.08
Sorbus aucuparia L.	14	15	23	28	10.37	10.64	14.47	17.61	8.18	9.36	11.64	13.88
Juniperus communis L.	45	29	28	24	33.33	20.57	17.61	15.09	4.84	5.37	3.45	3.83
Salix spp.	11	18	14	21	8.15	12.77	8.81	13.21	1.38	3.05	1.99	4.22
Alnus glutinosa (L.) Gaertn.	4	2	1	1	2.96	1.42	0.63	0.63	0.47	0.32	0.23	0.27
Rosa canina L.	2	0	1	0	1.48	0	0.63	0	0.23	0	0.33	0
Daphne mezereum L.	1	0	0	0	0.74	0	0	0	0.14	0	0	0
*Sarothamnus scoparius (*L.) Wimm.	0	2	3	1	0	1.42	1.89	0.63	0	0.6	1.72	0.54
Vaccinium myrtillus L.	2	3	7	4	1.48	2.13	4.4	2.52	5.25	3.05	7.89	3.60

Table 3. Changes in the browsing intensity and share in the animal diet of forest woody species and dwarf shrubs in pure pine forests of the Kuršių Nerija National Park

Plant species	Browsing intensity, *I* %, years 2001	2002	2003	2004	Share in diet, %, years 2001	2002	2003	2004
Pinus sylvestris L.	1.94	2.16	2.47	0.44	8.65	12.70	7.84	1.80
Pinus montana Mill.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Picea abies L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Juniperus communis L.	2.89	0.65	1.92	0.00	0.92	0.33	0.38	0.00
Quercus robur L.	100.00	80.00	72.73	35.29	0.66	1.34	1.53	1.80
Betula pubescens Roth.	50.73	13.72	11.01	10.12	21.36	12.71	7.27	9.88
Populus tremula L.	100.00	100.00	0.00	0.00	0.33	0.67	0.00	0.00
Alnus glutinosa (L.) Gaertn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sorbus aucuparia L.	98.29	43.45	45.30	55.25	52.98	38.80	30.40	59.87
Frangula alnus Mill.	96.88	93.33	88.89	100.00	4.78	4.68	4.59	0.60
Salix spp.	74.58	22.99	3.33	20.00	6.78	6.69	0.38	6.59
Rosa canina L.	100.00	0.00	100.00	0.00	1.52	0.00	1.94	0.00
Sarothamnus scoparius (L.) Wimm	0.00	100.00	100.00	100.00	0.00	5.69	9.94	4.19
Daphne mezereum L.	100.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00
Vaccinium myrtillus L.	3.11	56.32	78.57	54.26	1.10	16.39	35.73	15.27

la (65%), *Quercus robur* (59%), and also Roe deer and hares preferred *Sarothamnus scoparius* (92%) and *Vaccinium myrtillus* (61.2%) when the snow cover is short-term and not more than 10cm. The distribution of faecal pellets and shoot browsing around a tree indicate the longer feeding in snowy periods in the same places. The shoot browsing reached more than 40-50% of the consumption level in the deciduous species but the browsing intensity of scarce species is quite higher than shoot consumption (Table 3), the occurrence and abundance of these species (Table 2).

The bark stripping was observed in only *Pinus sylvestris*. It occurred sporadically in the pine plantations of the 2nd age class. The number of damaged trees changed from 0.2% of the bark consumption, which comprised 564 cm^2 in 2001/2002 to 1.7% of the bark consumption, which constituted 2079.9 cm^2 in 2002/2003, and was not found in the last study period on the whole. By the wound freshness, the peak of the bark consumption was typical of the late winter (February) and early spring (March-April), and in mild midwinter when the air temperature does not change sharply. That was corroborated by our previous studies on regularities of the bark stripping (Padaiga and Belova 2001) determining the bark-stripping course and its dependence on the environmental factors.

The changeability of weather and snow cover shows up from the density independent factors. This causes the changes in animal feeding habit: browsing

Table 4. Changes in the shoot consumption of woody species and dwarf shrubs in pure pine forests of the Kuršių Nerija National Park

Plant species	Shoot consumption, %, years 2001	2002	2003	2004
Pinus sylvestris L.	1.74	1.65	0.34	0.14
Pinus montana Mill.	0	0	0	0
Juniperus communis L.	92.75	58.97	14.8	0
Quercus robur L.	18.75	3.87	3.84	9.63
Betula pubescens Roth.	81.82	64.29	0	0.99
Populus tremula L.	70.26	74.77	54.7	0.19
Alnus glutinosa (L.) Gaertn	60.75	24.52	20.5	0
Sorbus aucuparia L.	0.79	0.07	0.2	25.24
Frangula alnus Mill.	89.69	8.53	1.1	14.29
Salix spp.	0	0	0	28.15
Salix caprea	14.29	0	45.8	0
Rosa canina L.	86.96	0	0	0
*Sarothamnus scoparius (*L.) Wimm	0	91.49	100	87.82
Daphne mezereum L.	15.01	61.2	75.9	0
Vaccinium myrtillus L.	1.74	1.65	0.34	84.17

of shoots or bark stripping. The changeability of the air temperature and snow cover negatively influences browsing intensity R= -0.36 ±0.022, *t*= 11.82, and R= -0.167±0.033, t=5.95. The shoot consumption of the main tree species directly and negatively related to the weather variability (from r= -0.95 for Scots pine to –0.34 for birch, p<0.05) except willows, brier, broom, and dwarf shrubs (Tables 5 and 6).

The decrease in the air temperature results in less bark stripping because of an impeded use of bark crystallizing liquids in a tree bark (Padaiga, Belova 2001). Meanwhile, the consumption of tree shoots of the main woody species closely and positively depends on the animal density n/1,000 ha. In this case strong positive dependence is notably expressed between consumption shoots of Scots pine, oak, aspen, alder buckhorn and birch and moose density (Table 6). Increase in the roe deer density leads to the higher consumption of shoots of *Juniperus communis, Sorbus aucuparia* and *Salix caprea* while consumption of the shoots of aspen, oak and birch negative related to roe deer density in contrast to the case of moose.

Discussion and conclusions

The range of the main herbivorous animals in the Kuršių Nerija NP as Roe deer (*Capreolus capreolus* L.), Moose (*Alces alces* L.) and Brown hare (*Lepus europaeus* Pallas), is supplemented with Red deer (*Cervus elaphus* L.). These animals directly related to woody vegetation mostly through the feeding. According to the hierarchical range, the feeding importance reaches the shelter one because of the food shortage

Table 5. Dependence of the main parameters of herbivorous animals - woody plant interaction on the animal density, n/1,000 ha, and weather conditions in non-vegetative period: Browsing intensity, %

Parameters	Animal density, n/1,000 ha						Changeability in the air temperature, V%		Changeability of the snow cover, V%	
	Moose		Roe deer		Hare					
Browsing intensity, % of:	*R*	± *m*	*R*	± *m*	*R*	± *m*	*R*	± *m*	*R*	± *m*
Pinus sylvestris	0.553	0.029	-0.182	0.040	0.492	0.031	-0.228	0.039	0.042	0.041
Juniperus communis	0.181	0.040	0.650	0.024	0.978	0.002	-0.462	0.033	-0.609	0.026
Quercus robur	0.693	0.022	0.249	0.039	0.702	0.021	-0.747	0.018	-0.073	0.041
Betula pubescens	0.301	0.038	0.765	0.017	0.762	0.017	-0.812	0.014	-0.420	0.034
Populus tremula	0.911	0.007	0.000	0.042	0.192	0.040	-0.957	0.004	0.414	0.034
Sorbus aucuparia	0.072	0.041	0.883	0.009	0.715	0.020	-0.694	0.022	-0.543	0.029
Frangula alnus	-0.214	0.040	0.388	0.035	-0.254	0.039	-0.270	0.038	-0.024	0.041
Salix spp	0.342	0.037	0.701	0.021	0.572	0.028	-0.873	0.010	-0.266	0.039
Rosa canina	-0.130	0.041	0.640	0.025	0.962	0.003	-0.103	0.041	-0.781	0.016
Sarothamnus scoparius	-0.225	0.039	-0.813	0.014	-0.778	0.016	0.769	0.017	0.481	0.032
Vaccinium myrtillus	-0.297	0.038	-0.706	0.021	-0.514	0.031	0.853	0.011	0.257	0.039
Daphne mezereum	0.225	0.039	0.813	0.014	0.778	0.016	-0.769	0.017	-0.481	0.032

p<0.05; n – animal number

Table 6. Dependence of the main parameters of herbivorous animals - woody plant interaction on the animal density, n/1,000 ha, and weather conditions in non-vegetative period: Consumption of shoots, %

Parameters	Animal density, n/1,000 ha						Changeability in the air temperature, V%		Changeability of the snow cover, V%	
	Moose		Roe deer		Hare					
Consumption of shoots, %	*R*	± *m*	*R*	± *m*	*R*	± *m*	*R*	± *m*	*R*	± *m*
Pinus sylvestris	0.908	0.007	0.035	0.041	0.279	0.038	-0.951	0.004	0.352	0.036
Juniperus communis	0.247	0.039	0.790	0.016	0.860	0.011	-0.734	0.019	-0.517	0.030
Quercus robur	0.996	0.000	-0.998	0.000	-0.414	0.034	-0.960	0.003	0.939	0.005
Betula pubescens	0.661	0.023	-0.636	0.025	0.492	0.031	-0.338	0.037	0.273	0.038
Populus tremula	0.981	0.002	-0.987	0.001	-0.502	0.031	-0.983	0.001	0.968	0.003
Sorbus aucuparia	0.245	0.039	0.793	0.015	0.703	0.021	-0.803	0.015	-0.420	0.034
Frangula alnus	0.862	0.011	-0.121	0.041	0.425	0.034	-0.674	0.023	0.257	0.039
Salix spp	-0.476	0.032	-0.189	0.040	-0.768	0.017	0.409	0.035	0.234	0.039
Salix caprea	0.225	0.039	0.813	0.014	0.778	0.016	-0.769	0.017	-0.481	0.032
Rosa canina	-0.324	0.037	0.190	0.040	0.611	0.026	0.435	0.034	-0.605	0.026
Sarothamnus scoparius	-0.228	0.039	-0.804	0.015	-0.708	0.021	0.793	0.015	0.434	0.034
Vaccinium myrtillus	-0.510	0.031	-0.598	0.027	-0.709	0.021	0.899	0.008	0.238	0.039
Daphne mezereum	0.225	0.039	0.813	0.014	0.778	0.016	-0.769	0.017	-0.481	0.032

p<0.05; n – animal number

in non-vegetative period (Belova 1999a, 2001). This is accompanied by exterior disturbances and stimulated the gathering of animals in the places of more favourable feeding. That is a consideration to motivate the choice of the study period investigating the animal-plant interaction. This study has provided information on the main criteria of animal - woody plant interaction as the consumption of shoots of woody vegetation and browsing intensity. The gathering of herbivores should affect their main food objects as the woody vegetation, in certain places in the non-vegetative period depending on the main density-independent factors as weather conditions. Whether herbivores prefer the same or different habitats, this will determine their impact to forest.

The foraging strategy of herbivores revealed that in accordance with ecophysiological adaptations and features of digestive system, the red deer mostly gets advantage in feeding as the feeder of intermediate type, and both roe deer and moose are attributed to concentrate selectors (Hofmann 1989, 1998, Petrak 1991, Homolka 1996). The specific habit of these species is use of the most nutrition parts of the plants then red deer. Although the morphological - physiological features of digestive system are species specific, it is important to consider the animal adaptability, habitat character, geographical and ecological peculiarities including seasonal changes in animal environment as well as the food capacity of habitat (Belova 1997, 2003). Despite the fact that roe deer are the concentrate selectors and more close to moose by their morphological - physiological features, the gramineous species comprise 81% of the diet in roe deer while woody species only 11% (Prusaite *et al*. 1983, Baleišis *et al*. 2003) especially on the open areas of the low forest cover. Meanwhile the woody food predominates in winter and later autumn. We should underline that three ecotypes of *Capreolus capreolus* are found in Lithuania such as forest, forest edges and field ecotypes depending on the local forest cover. Thus, animals of the field ecotype stay in fields all year round while other ecotypes prefer deciduous of medium and small size (Baleišis *et al* 2003). Previous studies of the niche overlapping in herbivorous animals (Belova 1997) have indicated that there are 96.2% of woody species in the diet of red deer and 92.4% in the diet of roe deer in non-vegetative season. There are 14 common species of the main 90 most preferable plant species, which are mostly used by herbivores but at different time (there roe deer debarked the bark of willows S*alex* spp. in December and January, and red deer debarked from January and later on) and are unlikely available to animals of different species. The overlapping of trophic niches is highest in roe deer and hares, roe and red deer, and red deer and moose. 6.2% of plant species are only in the diet of red deer, 32.1% are common with roe deer diet and 25.9% with moose diet. By common plant species the competitive ability of red deer to roe deer is 16.3% and to moose is 13.1%. That is the stronger competition is between roe and red deer (Belova 1997, 2001). Nevertheless, the competition between the two species of browsers, *Alces alces* and *Capreolus capreolus* is revealed itself in pure pine forests (Table 5 and 6) that are comparatively scanty in food.

Particular features of study area are comparatively even changes in weather conditions and contrasts are unrepresentative as distinct from the continental pure pine forests. Specific climate and geomorphologic diversity of landscape as well as the absence of agricultural landed property determine the low carrying capacity and distinctive structure of local fauna and their adaptations, as the mixed forest - forest edge ecotype of hares and forest ecotype of roe deer. The coexistence of forest plants and animals is directly and indirectly influenced not only by the determined abiotic and biotic factors but also human factors including forestry, hunting and its restrictions, supplemental feeding in winter, picking of mushrooms and berries, and other recreational activities. The last-mentioned activities are particularly obvious on the study territory while forests are managed by the separate regime that is approved by the legal acts for protected areas. The investigation of forest management shows that the open area tends to decrease in forests (*Kuršių Nerijos NP*….2001). The main reason for this process is the natural reforestation on areas uncovered by forest and non-forest area. The specific management includes reforestation on the fire-damaged and reconstructive areas of died *Pinus montana*. The thinning, sanitary and landscape cuttings are permissible, and local forestry aims to sustain and restore present forests and their components. Thus, there are no any clearcuts and the limit area for planting trees while the main task is to maintain the natural processes of reforestation on the recreational and protected areas. These patches became most attractive to hares. The underpopulation of hares and their clumped distribution are specific features. Hares mostly grouped in the certain parts of forests and adjacent open territories as forest gaps, dunes, sand-blow plains *"palve*" and hummocky area ahead of the Great moving dunes eastwards from the Baltic Sea. This area is sufficiently overgrown with grassy vegetation, small shrubs, birch and natural *Pinus* spp. groups in plant. Roe deer and moose prefer the mature and overmature stands (preference index ranged from 0.4 to 0.6) in all time spans. They distribute differently under the severe winter conditions, when moose mostly (preference index reached 1 and more) gathered and foraged in the patches of young pine (browsing intensity reached 2.47%, and it was highest comparatively with other periods). Thus, the competition for the limited resources mostly reveals under the disadvantageous conditions, moreover, that study area is not rich in food. Usually relations between deer species are not distinctive, and they avoid contacts because of an indifference. While animals tried to meet their needs, but they failed to do it, then another time their memory suspends the need and incentive an animal to avoid unpleasant situation (Belova 1997, 2001).

Recalculating the present deer density into the conditional density on the grounds of the equivalent that is 1 moose = 3 red deer and 1 red deer = 4 roe deer (Padaiga 1996), general conditional number of deer reaches 8/1,000 ha. This parameter corresponds to the economical permissible deer density in pure pine forests. Herewith, the sex ratio and age structure of local populations are aberrant, and that is the indicator of disfavour of living conditions. Consequently, the changes in the sex ratio in behalf of females in the local moose population indicate that there was deterioration of animal living conditions on the territory of littoral pure pine forests. Increase in the juvenile number is the parameter of conditions favourable for survival, and it has the compensatory character. The increase in females provokes a tendency of increase in consumption of the main woody species because females usually select more productive feeding habitats and use more qualitative food then males. In this case no any animal death have been recorded, while the moose hunting was still forbidden in the whole country.

The intrusion of sparse local group of red deer into specific moose habitats persists in pure pine forests. However, they have not an advantage over the other herbivorous animals yet. Habitat preference values and plant consumption intensity varied temporally depending on stand composition, forest site type and stand age as well as variability of the main weather parameters. Increase in roe deer density leads to the higher consumption of shoots of different woody species in contrast to the case of moose that is juniper *Juniperus communis,* rowan *Sorbus aucuparia* and goat willow *Salix caprea.* Whereas the consumption of shoots of aspen *Populus tremula*, oak *Quercus robur*, and birch *Betula pubescens*, negative related to roe deer density. Investigations indicate the necessity to consider the main criteria of animal-plant interaction as the consumption of shoots of the main forest woody species and the browsing intensity.

Considering the delineation of territory for game animals and determination of the main forest categories, the main parameters for monitoring of the animal – plant interaction are the browsing intensity, the level of shoot consumption and abiotic factors in non-vegetative period that limited these parameters. One of the main implications of this study is consideration of the critical threshold in consumption of woody plants, which is important for the ecological balance between animals and plants. That is the shoot consumption of 40-50% for the deciduous species and 20-30% for conifers (Padaiga 1996, Belova 2004, 2005). This corresponds to “floral index” (Guibert 1995) proposed to maintain the animal-plant ecological balance. In this case, an index value of 27% indicates that deer number is under carrying capacity of habitats while optimal values are 27-37%, and 37-50% shows the destruction of balance, however it could be renewed.

It should be underlined that the shoot consumption more than 50% in conifers and more than 20-30% in deciduous species is the criterion of the irreversible process of decline in the certain species: in our case these are *Populus tremula*, *Frangula alnus*. The way of restoration of the ecological balance is the monitoring of animal number, population parameters, hunting and state of their foraging habitats.

The number of pellet groups is considered as the index of habitats (Morellet *et al*. 1996) while the plant consumption shows an animal impact to the environment. The pellet group count in early spring before the growing season is the basis of quantitative and qualitative assessment of the sex ratio and age structure in local populations. An increase in the number of females indicates the deterioration of animal living conditions on the territory of littoral pure pine forests. The increase in females provokes a tendency of an increase in consumption of the main woody species because females usually select more productive feeding areas and use more qualitative food than males. However the increase in the number of juveniles is the parameter of conditions that are favourable to survive and contains the compensatory character.

All investigated herbivorous animals are game, and their resources are used depending on the census results (hares) and the impact caused by deer (roe deer and moose) to the forest trees on the sample plots. On the bases of the request of KNNP representatives (users of hunting grounds tender their application for the use of game resources), the general hunting policy and following restriction or permission to use the certain species is implemented.

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КОРМОДОБЫВАНИЕ ОЛЕНЯМИ CERVIDAE И ЗАЙЦЕМ-РУСАКОМ *LEPUS EUROPAEUS* В ЛИТОРАЛЬНОЙ ЗОНЕ ЧИСТО СОСНОВЫХ ЛЕСОВ ЛИТВЫ

О. Белова

Резюме

Основное взаимодействие между древесной растительностью леса и растительноядными Cervidae наряду с Leporidae, представляющими первичных потребителей в одной трофической цепи, наиболее проявляется трофическими связями. Следовательно, потребление пищи растительноядными определяет направление данного исследования. Важно знать лимитирующие факторы, выступающие в качестве стимулов влияния зверей на лес. С другой стороны, для взаимодействия между растительностью и растительноядными, необходимы не только обе части этого взаимодействия, но и среда, где оно проявляется. Это обосновывает необходимость определения предпочитаемости местообитания и цель исследования по оценке характера кормодобывания оленьих и зайцев и их взаимодействия с лесной растительностью, учитывая вышеизложенное.

Для исследования использовали комбинированый метод ленточных трансект (единица пробы 100 x 4 м) и пробных площадок (50 x 2 м, 100 м^2). Численность и распределение местных популяций зверей, их половая и возрастная структура определялись методом учета групп экскрементов на трансектах и площадках. В пределах кормового пространства зверей (от h = 0,1 до 2,2 м) учитывали все древесные растения и их побеги, разделяя поврежденные и нетронутые. Рассчитывалась интенсивность обгладывания ***I,*** и доля древесных растений в рационе зверей ***P*** на основании потребления древесных растений всех пород. Определялась предпочитаемость местообитания различных по возрасту, составу и типу лесонасаждения. Исследовано 504 пробных площадок на маршруте длиной 79.9 км на общей площади 2 736 га.

Специфичность климата и герморфологическое разнообразие ландшафта и условий местности при отсутствии сельскохозяйственных угодий обуславливает низкую кормовую емкость и особую структуру местной фауны и их адаптации как смешанный лесо-лесоопушечный экотип зайцев и лесной экотип косуль. Сосуществование лесных растений и зверей подвергается прямому и побочному воздействию не только определенных абиотических и биотических, но и антропогенных факторов, как лесное хозяйство, охота и ее ограничения, дополнительная подкормка зимой, сбор грибов и ягод и другие рекреационные активности. Последние особо явны на территории исследований, тогда как уход за лесом осуществляется по особому режиму, правовыми актами установленными охраняемым территориям.

На территории чисто сосновых лесов плотность населения зверей непревышает допустимой плотности, но половая и возрастная структура местных популяций отклоняется от оптимума, что является показателем неблагоприятности жизненных условий. Значения предпочитаемости местообитания и потребления растений флуктуируют в соответствии с составом, возрастом насаждения, типом леса и варибильностью погодных параметров. Основным параметром взаимодействия между древесной растительностью леса и растительноядными является уровень потребления побегов и интенсивность обгладывания основных древесных пород. При этом уровень потребления побегов хвойных более 50% и лиственных – более 20-30% является критерием невозобновляемого процесса упадка определенных пород, из них *Populus tremula*, *Frangula alnus*.

Ключевые слова: растительноядные, чисто сосновые леса, охраняемые территории, предпочитаемость местообитания, популяционные параметры, интенсивность обгладывания, уровень потребления побегов

Habitat Use by the Wolf (*Canis lupus* L.) in North Lithuania

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Abstract

Habitat use by wolves was researched with the aim to understand their visiting frequency of different landscape sites, priorities for resting place selection and the influence of anthropogenic factors on wolves' activity. Snow tracking of wolves was conducted through the winters of 2003/2004 and 2004/2005 with weather conditions permitting. With the use of GPS recording wolves were tracked 83.7 kilometres.

Results indicate habitat use by wolves is spread throughout the landscape; forest (43%), agricultural land (24.8%), road (12.3%), forest edge (10.6%) and frozen waterways (5.2%). Wolves are not restricted to any landscape type. However, they prefer forest stands over 20 years of age and rarely pass through clearcut areas. Frequently wolves visited mixed soft deciduous stands with spruce.

Wolves gave preference to young stands as resting sites. The highest number of recorded resting sites was between 2,580 - 3,400 m from a village and the mean distance from the forest edge was 200 m. Wolf tracks were found 50 - 300 m from homesteads.

Key words: wolf, habitat use, tracking, forest stand, resting place, territory marking, behaviour.

Introduction

The natural range of wolf (*Canis lupus*) distribution in Europe used to cover most of the continent (Okarma 1997), but present distribution of the wolf is a consequence of the past extermination programmes, as well as the contemporary barriers to dispersal and lack of suitable habitats (Mech 1995, Mladenoff *et al.* 1995, Linnell *et al.* 2001).

Many authors mention wolves in the XIX century in Lithuania, but solid evidence about their abundance is hard to find (Prūsaitė 1961). The abundance of wolves was very unstable in the XX century. From 2001 year it declines (LRAM 2004). In 1999 the monitoring of large predators started, however after three years was stopped due to a lack of funding (Bluzma *et al*. 2001). Recently the Institute of Ecology conducted a questionnaire and the Ministry of Environment organized a wolves' census (Balčiauskas *et al*. 2002, 2005, Bukelskis *et al*. 2004).

It is very important to assess the value of this large and active predator in a natural environment and in a constantly altered human environment. There is not enough information on how wolves' behaviour is influenced by habitat modification by an anthropogenic factor. Territorial behaviour of wolves in Lithuania has not been investigated. There is very fragmented forest landscape and it raises a lot of questions about wolves lives in this landscape in Lithuania. The present situation shows a necessity not only to follow the dynamics of the wolves' population, but also to investigate the territorial distribution of this predator in a changing landscape.

Study area

The Gulbinas forest and the surrounding forests in Northern Lithuania were chosen for the investigation. The total study area occupied about 250 km^2. In the Šiauliai district, forest cover (35.03%) is higher than the mean of Lithuania (31.7%) (Lithuanian statistical yearbook of forestry 2004). Comparative index of forest edge perimeter and forest area (D), which shows the complexity degree of forest shape, is 1.28 in the Šiauliai district (Deltuva 1999). The investigated forest mosaic represents the average type of Lithuania. The most important environmental conditions limiting the density of wild animals are feeding capacity and the conditions of optimal refuge sites (Padaiga 1996). Fertile soil is typical of the study area and determines rich composition and abundance of vegetation, which in turn contributes to a higher diversity and abundance of wild animals. The prevailing mixed stands of spruce (*Picea abies* (L.) Karst.) with birch (*Betula pendula* L.), aspen (*Populus tremula* L.), grey alder (*Alnus incana* L.) and black alder (*Alnus glutinosa* L.) determines the high density of ungulates. In the Šiauliai district the abundance of wolves is higher than the average of Lithuania. This is typical not only of the later decades, but also of the later centuries too. According to D. Vilinski (Вилинский 1876) the high abundance of wolves in the Šiauliai district is because there are many wet and hard impassable places. The Gulbinas Forest was mentioned as an important place for wolf reproduction, even at the time of population decline in the 1060's, when about 100 wolves were recorded in Lithuania. During these times wolves inhabited 36 districts with higher forest coverage out of the 82 districts (Prūsaitė 1961). Wolves have maintained a continuous population in the study area.

Material and methods

Snow tracking methodology was applied to investigate the habitat use of wolves. It is an indirect (according to activity signs of animals) method of observation (Belova 2001). Snow tracking was conducted through the winters of 2003/2004 and 2004/2005 with weather conditions permitting (adequate snow cover). 83.7 kilometres of wolves' paths were tracked.

Tracks were recorded with the GPS "EMAP" (Global Positioning System). The data were processed by the computer program ARCVIEW GIS 3.2. The following data were measured and recorded in forest stand maps (M 1:10000) and in tables during tracking:

1) Distances in the forest: a) in mature and premature stands (age more than 40 years), b) in middle-age stands (age 21 - 40 years), c) in young stands (age 6 - 20 years), d) in young stands (age less than 6 years) and e) in clearcuts;

2) Distances in shrubs;

3) Distances by the forest edge (distance from the forest border less than 60 meters);

4) Distances on the ice (frozen waterways);

5) Distances on agricultural land;

6) Distances on roads: a) district roads, b) local roads (with gravel surface), c) forest or field road (with natural surface);

7) Resting places;

8) Territory marking places: a) excrements, b) urine, c) scratch of the soil;

9. Territorial behaviour changes influenced by the approach of human activity: a) exploitable clearcuts, b) clearcuts and young stands aged <5-year, c) roads (district, local and forest), d) homesteads, e) recent tracks of human activity.

According to conditions for the living of wild animals the forests habitats in Lithuania are divided into pure pine (0%), pine with spruce (0.1%), wet pine (0.9%), spruce with deciduous (50.6%), deciduous with spruce (38.5%) and wet deciduous (9.9%) stands (Padaiga 1996). The number in brackets shows the percentage of such stand in the study area.

During this investigation young stands were divided into two groups, because in young stands <5 year old conditions are similar to open places, and 6 - 20 year old young stands characterize high stocking levels, heavily impassable. The total of useful distance (excluding the distance used for looking for tracks of wolves) was spread throughout such elements of the landscape: forest, forest edge, shrubs, agricultural land, road and frozen waterways. During the tracking, changes in the wolves' behaviour influenced by the approach of human activity places or objects were recorded. Other tracks of wolves were registered, however were not tracked further. The frequency of place urination was not investigated due to possible inaccuracy after snowfall.

Wolves' resting places distribution using the distances from the forests edge, homesteads and villages were compared using Kruskal-Wallis non-parametric test (Statistica 5.0).

The search routes were picked by considering the highest possibility of finding the tracks of wolves. Some places of the tracking routes containing a high number of tracks were bypassed. In such cases estimations were made on the number of wolves and their travel directions. Wolf tracks were followed for as long as possible, often requiring more than one day of tracking. Tracking stopped if snow cover condition changed unfavourably and on the loss of the wolves' tracks.

Results

Different landscape elements used by wolves.

There were three wolves in the winter of 2003/2004 and six wolves in the winter of 2004/2005 in the study area. Tracks of a solitary large male were observed as well. The selected pack has a home range, which covers four forest districts in three state forest enterprises and two hunting clubs.

Wolves travelled the greatest distance (43%) in the forest (Figure 1). In this instance stands and clearcuts are considered as forest. Wolves travelled 24.5% of the distance recorded in agricultural land, 12.3% on roads, 10.6% in the open forest edge (field near the forest border), 5.1% on frozen waterways, 4% in shrubs and 0.5% in the covered forest edge (inside forest).

Wolves' tracks may be found in stands of various age as well as in clearcuts (Figure 2). Wolves give priority to forest stands aged >20-year, with a strong

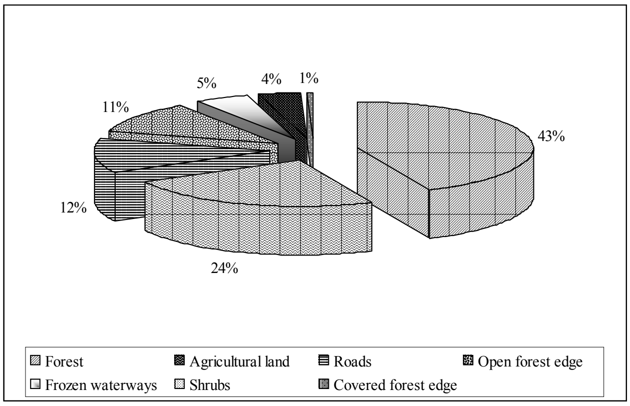

Figure 1. Distribution of wolves' tracks in landscape elements

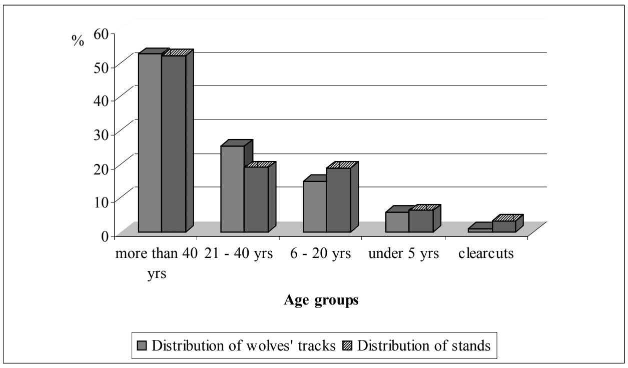

Figure 2. Comparison of wolves' track lengths and stand area depending on age

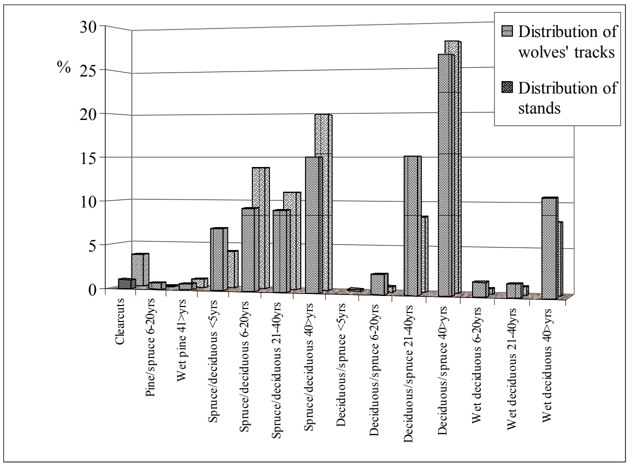

Figure 3. Distribution of wolves' tracks in forest stands containing a dominant tree species and age

Figure 4. A wolves' resting place in a mixed spruce with deciduous forest (II age class)

Figure 5. A wolves' resting place in a mixed deciduous with spruce forest (II age class)

preference for forest stands aged between 20–40-year. However, wolves rarely visit clearcuts.

Distribution percentage of wolf tracks subject to dominant tree species and stand age (Figure 3) was compared. Wolves in this region have no significant preferences of forest type in winter. All types of forest (with some positive selection of deciduous stands) and even clearcuts are walked by wolves.

The resting places

Ten places used by wolves for resting were found, and of these nine were in the forest, and one in an open field. The resting places, found in the forest, were in the young stands: two cases in the first age class, three cases in the second age class, three cases in the third age class(Figures 4 and 5) and one case in the fourth age class (Figure 6). Five resting places were in mixed spruce with deciduous stands (90% Spruce and 10% Birch; 80% Spruce, 10% Birch and 10% Grey alder; 70% Spruce and 30% Grey alder; 60% Spruce and 40% Birch; 50% Spruce, 40% Birch and 10%Grey alder), two resting places were in mixed deciduous with spruce stands (60% Birch, 3% Black alder and 10% Spruce; 50% Asp, 30% Birch and 20% Spruce), one resting place was in mixed deciduous stand (60% Asp, 20% Birch, 10% Grey alder and

Figure 6. A wolves' resting place in a mixed spruce with deciduous forest (IV age class)

10% Black alder) and one resting place was in a pure grey alder stand. The resting place found in the open field was near a ditch full of shrubs, roe deer fur was found here.

The wolves' resting places location from villages, homesteads and the forest edge differed significantly; H (2, N= 27) = 22,86765 p =,0000 (Figure 7). The distance from a village ranged from 260 - 4,450 m with most of the resting places found between 2,580 - 3,400 m from a village. The distances from the nearest homestead were between 760 - 2,640 m. The distance from the edge of forest ranged from 10 - 420 m, on average 200 m. The resting places of two wolves were found in open areas; the distance from the forest was 290 m.

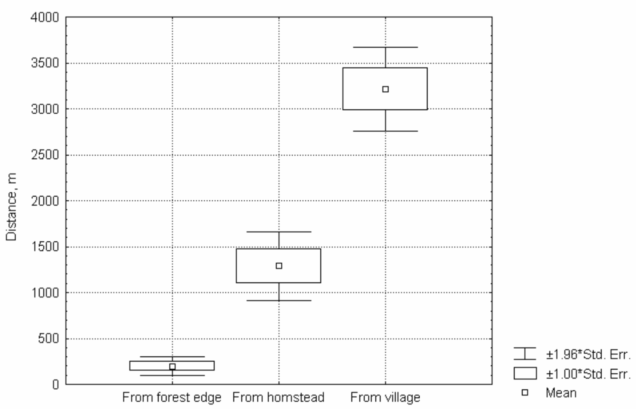

Figure 7. Wolves' resting places distribution using the distances from the forests edge, homesteads and villages

The territorial marking

Wolves marked their territory by urine, excrements and other methods. During the investigation the main attention was focused on the place of the urine marking. A total of 56 markings were found. Objects marked by urine were recorded including the recurrence rate (Table 1).

Table 1. Frequency of object marking by urine

No.	Marked object	Number of marks	
		n	%
1.	Hump of grass	21	37.5
2.	Spruce (H<1m)	7	12.5
3.	Trunk of mature tree	6	10.7
4.	Pendulous branches of spruce	5	8.9
5.	Shrub	4	7.1
6.	Hump of soil	4	7.1
7.	Small stool	3	5.4
8.	Broken off dry branch	2	3.6
9.	Stone	2	3.6
10.	Pendulous branches of willow	1	1.8
11.	Edge of reed	1	1.8
Total		56	100

The most frequently urine marks were found on humps of grass 37.5%, usually on reed grass. The second most frequently used mark of urine was found on young spruces, <1 m high (12.5%). Excrements were found in the forest and on the forest edge and were concentrated in one area. Only one case of soil scratching was observed.

The influence of human activity on wolves' behavioural traits

Only once a wolf track was recorded approaching an exploitable clearcut. In this case the wolf avoided the clearcut preferring to stay 20 m from its edge. However, this could be an example of atypical behaviour, as the wolf had strayed from its pack and was outside the territory surrounded by fladry. The insecurity and fear of the wolf was visible during the tracking, for instance, the usual route from one forest to another was bounded across. On approaching a road from the forest the wolf was hesitatingly moving back, forth and parallel to the road before crossing. In another case two wolves travelled leisurely along the road next to forest stand being cleared.

Clearcuts were not frequently visited by wolves. However, wolves showed no apparent fear or effort to avoid old clearcuts.

The wolves' tracks indicated no fear when approaching or crossing open areas, leading to the observation that wolves are accustom to landscape change. Young stands <5 years least influenced the behaviour of wolves with the track and stand percentage repartition practically the same (Figure 2). On two occasions wolves explored human traces (2-5 m) when crossing paths. In one case wolves constantly used the footpath of foresters.

Wolves showed no tendency to fear homesteads, with tracks found 50 - 300m away from homesteads. On two occasions wolves approached within 50 - 100 m of a homestead, three occasions within 100 - 150 m and on two occasions within 150 - 200 m. Wolves constantly used a path, which was 300 m away from two homesteads. The wolves' tracks showed no increased caution (stopping and windings) when approaching a place of human activity. In one case wolves changed their direction and approached within 100 m of a village. This is believed to be due to the ownership of dogs on all homesteads passed by the wolves.

Discussions

The distribution of wild animals in the area is irregular, depending on species requirements and density. Constantly used wolves' tracks, the number of territorially concentrated resting places and places of excrements were found in the study area. Such evidence indicates this area is the core area of the wolf pack. Wolves often visit agricultural land, as the investigated place belongs to the north central district of Lithuania, which characterizes the most opportune conditions for the breading of wild animals (Padaiga 1996). The proportion of agricultural land in the total paths length may be overestimated, because it was tended to pick up the wolves' path that followed the agricultural land. But it can not be said, that wolves avoid agricultural land.

The effect of forest edge influence is typical of a zone of 60 - 100 (200) m wide (Padaiga 1996). During the investigation, the forest edge was calculated as an open territory not wider than 60 m from the edge of the forest. Ungulates and hares use the forest edge to feed, as this zone provides good feeding and protective conditions. This frequently used feeding area provides a good site for wolves to find potential prey. Covered forest edge was only occasional in the wolves' paths.

Comfort and fast movement was also the very reason for wolves' preference for forest roads and frozen waterways. Results prove wolves immediately veer from frozen waterways, when obstacles such as shrubs or grasses appear in their way. Wolves indicated a strong preference for their chosen routes. Selecting forest as the preferred path followed by other roads, block lines, technological lines, ditches and frozen waterways respectively. Rather often wolves use other animal tracks. It is biologically very fitting that wolves should select the same routes as their prey animals, because in this way they avoid unnecessary travels (Pulliainen 1965). Their prey sometimes used tracks of the wolves as well (Kübarsepp *et al.* 2003). Young dense forest stands and shrubs were strongly avoided by wolves. Shrubs on the wolves' routes comprised only 4.1%, whereas overgrown shrubs are rarely observed in the study area.

As mentioned above, wolves travelled 12.3% of the distance on roads: regional (3%), local (45%), forest and field (52%). The network of local, forest and field roads is denser compared with the regional roads network, so it is the bigger possibility that the direction of them would coincide with wolves' movement direction. Also all wolf tracks travelled perpendicular to the regional road. The quiet of forest, field and local roads can have influence for preferring them too. This could explain why wolves travelled more on forest, field and local roads. But it is important to mention, that regional road was crossed multiple times by wolves. A research project on wolves' habitat use in Bialowieza Primeval Forest showed that roads were used 36% of the total distance travelled by wolves (Jedrzejewska *et al*. 1998). However the percentage might be over exaggerated, as wolf trackers would firstly notice tracks along and across roads.

According to Jedrzejewska *et al.* (1998) and Bibikov (1985), wolves willingly use the possibility to travel on roads, as roads provide a comfortable surface and during winter the snow cover is often shallow. Throughout the project wolves showed no signs of hesitation, fear or concern when approaching roads used by humans. There were no observations of disturbance to the route of wolves caused by fresh vehicle tracks. Conversely, wolves move along the ruts in less driven roads. However, N. A. Zvorikinas (1950) states wolves usually avoid tracks of man by fleeing. In this study wolves explored and used the tracks left by humans. L. D. Mech (1998) maintains the notion that wolves can manage to adapt to human activity.

Wolves more often visited forest stands >20 years of age. Middle age forest stands are the least beneficial for foraging, but provide good protective conditions for herbivores. (Padaiga 1996). Ecological conditions of premature and mature stands are totally different. Deciduous undergrowth, underbrush, sub shrubs and herb vegetation flourish when old stands mature, becoming less dense and yielding more light. The abundance of ground vegetation provides much feed for herbivores – the potential prey of wolves. It was suggested, that wolves movements are mostly influenced by the localisation of prey animals as well as by controlling pack territory (Kübarsepp *et al.* 2003). Wolves rarely visited forest stands <20 years old. A reason for their low visitation could be explained by the high fertility of these forest stands, which contribute to a very dense impenetrable ground layer. Clearly wolves most seldom visited clearcuts; however it could not be stated, that wolves avoided and feared clearcuts. Wolves' tracks can be found in any forest stand age group and clearcuts. Still and all it can be said, that wolves in this region have no significant preferences for forest type in winter. Besides it has not been observed that hunting pressure influences wolves' distribution.

The research conducted in Bialowieza primeval forest indicates individual peculiarity of habitat use is not typical of wolves. All forest types (with a higher priority for coniferous stands) and irregular little forest stands in agricultural land were visited by wolves looking for prey and cover (Jedrzejewski *et al.* 2001). In summary, it is important to mention that spruce (48%) and birch (37%) are the dominant forest type in the study area. As wolves have a long history with the study area one can believe that such forest stands provides a stimulus for wolves when selecting habitat.

Thompson (1952) reported that wolves regularly used the same travel routes when moving in a certain area. So special attention was required to the sites wolves' visited 3 or more times, as these sites might become potentially attractive.

Analysing the question on habitat selection by wolves, one firstly needs to take into consideration the distribution of potential prey source. If there is an abundance of potential prey for wolves then the number of wolves will increase. Accordingly ungulates are more abundant in areas where their food selection is rich and diverse. Thus the fertility of soils is one of the main factors influencing the abundance of animals. As a consequence forest stands growing on rich soils were visibly seen as a site often visited by wolves.

Wolves most often visited mixed deciduous stands dominated by birch or black alder with spruce 56.3%, followed by stands of spruce with deciduous species 31.2% and pure birch and black alder stands 12.5%. Of the sites visited by wolves 3 or more times 84.2% of the sites were mixed forest stands.

The most often visited sites hosted a large age diversity indicating age class is not a priority for wolves. The same can be said about the tree density and area of the sites. Thus the sites visited most by wolves are rich soils that host a diverse range of rich vegetation.

Conclusions

1. Wolves most often visited forests, followed by agricultural land, roads and forest edge respectively.

2. Wolves prefer forest stands aged >20-year and can cross any stands irrespective of age (including clearcuts) if required, but in general will avoid clearcuts.

3. Wolves selected to rest in places situated in young stands, between 2,580–3,400 m form villages and on average 200 m from the forest edge.

4. Wolves are accustom to human activity and are able to evaluate the dangers and advantages associated with humans.

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МЕСТА ОБИТАНИЯ ВОЛКОВ (*CANIS LUPUS* L.) В СЕВЕРНОЙ ЛИТВЕ

Р. Шпинките-Бачкайтене

Резюме

Территориальное распределение волков было исследовано с целью выяснить частоту их посещаемости в отдельных типах ландшафта, приоритеты выбора мест дневки, а так же установить, как антропогенный фактор влияет на деятельность волков. Исследования были проведены в двух этапах в 2003/2004 и в 2004/2005 году, когда был подходящий для тропления снежный покров. По волчьему следу пройдены 83,7 км. Маршруты регистрировались с помощью GPS.

Маршруты перемещения волков в элементах ландшафта распределились по следующему: леса (43%), сельскохозяйственные угодия (24,8%), дороги (12,3%), опушки (10,6%), канавы, ручьи, пруды покрытые льдом (5,2%). Целенаправленно идя, волки могут зайти в древостои разного возраста и вырубки, но преимущество отдают древостоям старше 20 лет и редко заходят в вырубки. В часто волками посещаемых участках преобладали лиственные породы с елью, но определяющей особенностью можно выделить плодородность земли.

Дневки волков были в молодняках. Множество дневок (70%) найдено на расстояние 2580-3400 м от поселков и в среднем в 200 м от границы леса. Следы волков были найдены на расстояние 50-300 м от усадьб.

Ключевые слова: волк, территориальное распределение, древостой, место дневки, территориальное мечение, поведение.

CHRONICLE

XXVIIth Congress of the International Union of Game Biologists IUGB (August 28th – September 3rd 2005, Hannover/Germany)

Game animals are an inseparable and synergetic part of the forest biota. They comprise nearly half a total number of mammal and 1/5 of bird species. According to the CIC definition and legal acts of the Republic of Lithuania game are wild animals, which due to their value and emerged traditions were hunted in the past or are or would be hunted in the future. These animals are genetically, ecologically and economically valuable natural resources. Game have an important formative role in the forest ecosystem, affect its composition, sustainability and themselves are under feedback impact. The subject of the use and conservation of game resources directly related to the forest and game management and nature protection. These resources have formed through the centuries and are important in the context of ecology, economy, science and education, recreation, aesthetics and others. The use of game resources or hunting reaches deep prehistoric times. Our ancestry hunted in the name of their survival and got in supply of food, working tools, protected themselves, their shelters as well as later crop. Some species have disappeared (e.g. aurochs, wild horse, flying squirrel, brown bear, wolverine in Lithuania, and presently European mink), however, the main reason was not only hunting or other direct extermination, as far as concerning their sensibility to the changes in habitats, less reproductive potential, limited distribution area and specialization, and as they did not sustain the competition for the vital resources with more adaptable species. The long-term human expansion into nature caused deep and often irreversible changes in nature from genetic to landscape level. These changes affect animals, their response to usual natural processes, also animal habitats, food and migration through the territories. Many species were harmed by acculturation of landscape, its equalization, expanding of fields and road network, monocultures in agriculture and forestry, melioration, forest fragmentation and other. In spite of these changes, game animals are comparatively flexible to human factors while they are conservative to natural factors and have adapted to them in the course of evolution.

The question how to restore the balance between animals and their environment, to implement sustainable use of game resources and conservation of species and their habitats has been pealed as one of the main points at the XXVIIth Congress of the International Union of Game Biologists *IUGB* that had been held at the University of Veterinary Medicine, Foundation in Hanover, Germany, on August 28th – September 3rd 2005.

Recognising no mean importance of game in the forest and other ecosystems as well as the substantial links between the Game management and other sciences, knowledge of the new events in wildlife studies goes more relevant. The XXVIIth IUGB Congress joined together wildlife researchers, wildlife and game managers, veterinary specialists and conservationists worldwide to share their knowledge and to present their latest research. Representatives of governmental and non-governmental institutions also participated that allowed the exchange of information between researchers and decision markers. The Congress has focused on a wide area of research in game management and wildlife.

The significant input of the International Scientific Committee members from different countries under the leadership of Chairman Prof. Dr. Reinhold R. Hofmann, retired Director of IZW Berlin, Germany, and Organising Committee (Prof. Dr. Dr. Klaus Pohlmeyer, Germany, and Dr. Anne Strattner, Germany, *et al.*) enabled representatives from different countries to take active part in the Scientific Programme, to impart benefits of their knowledge, and extend and make new useful scientific contacts. Scientific Committee members conducted the Congress topics: Habitat network for large wildlife and habitat fragmentation (under supervision of Dr. Michael Petrak, Germany; Dr Patrick Duncan, France and Prof. Dr. Ilse Storch, Germany); Wildlife in urban areas (under supervision of Dr. Ulf Hohmann, Germany, Dr.

Andreas König, Germany; Dr. Sandra Gloor, Switzerland and Francesc Llimona, Spain); Small game and predation (Dr. Ingrid Hucht-Ciorga, Germany; Prof.Dr. John Carroll, USA; Dr. Franēois Reitz, France; and Dr. Peter Lüps, Switzerland); Wildlife diseases (PD Dr. Dr. Kai Frölich, Germany; PD Dr. Marco Giacometti, Switzerland, and Dr. Christian Gortįzar, Spain); Wildlife ecotoxicology (Dr. Ralf Barfknecht, Germany; PD Dr. Uwe Kierdorf, Germany, Prof. Dr. Frieda Tataruch, Austria, and Dr. Robert Luttik, Netherlands); Sustainable use, population assessment and biomonitoring (Prof. Dr. Reinhold R. Hofmann; Prof. Dr. Falk Huettmann, USA, and Prof. Dr. John D. Skinner, Republic of South Africa), and Free topics (Dr. Walburga Lutz and Dr. Dr. Sven Herzog, Germany).

Thus, representatives from Alaska to Australia (Europe, Canada, USA, South America, Kenya, South Africa, Nepal, India, Japan, New Zealand, and Australia) came to the Congress. The Congress based upon submitted contributions offered by registered participants and included Opening and Closing Ceremonies, parallel Sessions, Workshops, Poster sessions, and Field Trips and Post Congress Tours.

Prof. Dr. Dr. Klaus Pohlmeyer, President of the *IUGB* 2003-2005, has opened the Congress. G. Lindemann, State Secretary of the Ministry of Rural Areas, Food and Agriculture and Consumer Protection of Lower Saxony, and G. Greif, President of the main hosted institution, the University of Veterinary Medicine in Hannover, have given introduction speeches at the Opening Session.

The Congress programme encompassed nearly 120 keynote reports and 131 poster presentations in the several parallel sessions under leadership of the Scientific Committee members, and workshops coordinated and organized by participants. Congress sessions were organized corresponding to the main topics as follows: Habitat Networks for Large Wildlife and Habitat Fragmentation (Chairperson Dr. Michael Petrak, Germany, 9 oral presentations), Sustainable Use, Population Assessment and Biomonitoring (Chairperson Prof. Dr. Reinhold R. Hofmann, Germany, 15 oral presentations), Wildlife Toxicology (Chairpersons Dr. Ralf Barfknecht, Germany, and PD Dr. Uwe Kierdorf, Germany, 9 oral presentations), Small Game and Predation/ Large Carnivores (Chairperson Dr. Ingrid Hutch-Ciorga, Germany, 13 oral presentations), Wildlife Diseases (Chairperson PD Dr. Kai Frölich, Germany, 9 oral presentations), Wildlife in Urban Areas (Chairperson Dr. Ulf Hohmann, Germany, 7 oral presentations), and two sessions of Free topics (Chairpersons Dr. Walburga Lutz and Prof. Dr. Dr. Sven Herzog, Germany, 13 oral presentations). The parallel workshops deal with the key discussion topics such as Predation Pressure on Capercaillie in Different Parts of Europe (organized and coordinated by Prof. Kjell Sjöberg, Sweden), Impacts of Set-Aside on Wildlife (organized and coordinated in cooperation with the International Council for Game and Wildlife Conservation *CIC* and *Deutche Wildtier Stiftung*, Institute of Wildlife Research at the University of Veterinary Medicine Hannover), Emerging Diseases in Wildlife (organized and coordinated by Prof. Franz-Josef Kaup, Germany), Reproduction of Wild Animal Species (organized and coordinated by Prof. Zygmunt Gizejewski, Poland), Pathways for Migrating Mammals in Germany and Central Europe – Illusion or Real Chance? (organized and coordinated by Dr. Mathias Herrmann, Germany), GIS Mapping and Modelling Wildlife-Habitat Relationships: Spatial Data for the Past, Present and Future (organized and coordinated by Prof. Falk Heuttmann, USA). The Federation of Associations for Hunting and Conservation of the E.U. *FACE* organized and presented an E.U. Workshop on sustainable bird hunting and bag records "Monitoring of Population Levels and Trends Huntable Bird Species in Europe, Hunting Bag Statistics and Population Dynamics" including sessions as Opening Session, Session A "The Current Situation" (Chairs Dr. Walburga Lutz, *IUGB*; G.-N. Oliver, *OMPO*; K. Kreiser, *Birdlife International*); Session B "Towards a Pan-European Monitoring Scheme for Birds" chaired by A. Teller, *European Commission*, and D.G. Env.

Plenary lectures were given by Dr. Deborah .J. Pain *et al*. (United Kingdom; Gyps Species Vulture Declines Across South Asia: The Role of the Veterinary Drug Diclofenac), Dr. Christian Gortįzar (Spain; Disease Risks and Overabundance of Game Species), Prof. Stanley D. Gehrt (USA; Mesocarnivores in the City: Lessons for Conservation and Conflict), Prof. Dr. John A. Bissonette (USA, Restoring Habitat Network: The Role of Allometrically–Scaled Wildlife Crossings), Dr. Richard Potts (UK; Avoiding High Predation Rates on Small Game in a "Politically Correct" World), and Prof. Dr. Falk Huettmann (USA, Alaska, Habitat Resource Selection, Free Internet Data Bases and Progressive GIS Modelling of the Globe: Towards a Digital Culture of Wildlife Research and Sustainable Management).

Participants of the congress had possibilities not only to advance their knowledge and give benefits of their experience to colleagues but also to know more about the location of Congress. The Congress Programme includes scientific trips in the midst of Congress in Hannover Adventure Zoo – Safari, and several Field Trips as "*Autostadt Wolfsburg*", "*Steinhud-*

er Meer", "*Wisentgehege und Jagdschloss Springe*", and "*Wolfenbüttel/ Jägermeister*", as well as two Post Conference Tours in the Harz National Park and Wadden Sea National Park.

Figure 1. IUGB Congress scientific trip: Hannover Adventure Zoo – Safari

The participants of the IUGB Congress appreciated the value of regular meetings, growing importance of the continuous game research inseparably from their habitats, positively noted the crescent potential of game biologists. The next meeting is supposed to be held in Uppsala, Sweden in 2007, 34 years since Sweden hosted the XIth IUGB Congress in 1973. It is momentous that it will be 300 years after the birth of famous Carl von Linné. The further Congress will intend to forge links between scientists, game managers and authorities, and to consider game communities in a societal and international context.

Olgirda Belova
Lithuanian Forest Research Institute

NOLTFOX – Nordic and database of long-term forest experiments now includes also the Baltic countries

SNS - the Nordic Forest Research Co-operation Committee had for some years noticed that long-term field experiments in forest faced many of the same challenges in all Nordic countries. This was mainly a problem in raising sufficient financial support for maintaining high quality experiments and thereby to assure collection of data and achieve valuable scientific results also in the future. It was supposed that possible benefits for the maintenance of existing and the establishment of new high quality experiments, could be achieved by a closer Nordic co-operation within this field. One important prerequisite and the first step for increased scientific co-operation is to have a common database showing all experiments in the Nordic countries with a common classification standard. NOLTFOX is the result of the attempt to make such a database, easily accessible for everybody (**http://noltfox.metla.fi**).

The board of SNS initiated this work in June 1999. The main forest research organisations dealing with long-term forest experiments in the Nordic countries were asked to participate in the work. In January 2000 the NOLTFOX project started according to a proposal from a working group. The objectives were at first hand:

- Harmonising data from existing (and new) national databases in the form of common descriptive variables for the experiments.
- Conversion of all national databases to a common data format in order to create one common Nordic database.
- Creating a Nordic website where the basic information about all the field experiments would be available through a flexible search module; e.g. country, research organisation, subject field, objective, keyword, geographical location, etc.

In 2001, the first version of NOLTFOX was launched to the public. Two years later, in 2003, NOLTFOX was evaluated by an international group and they recommended SNS to continue the development of NOLTFOX on a project basis and to participate on the funding. In accordance with the evaluation outcome the work on including the Baltic countries - **Estonia, Latvia and Lithuania -** in NOLTFOX was initiated in 2004. A further development of NOLTFOX was also proposed with expansion of the database with references to published literature relevant to the long-term field experiments. The project has been granted 300,000 NOK for each of the years 2004, 2005 and 2006.

SNS expects that the NOLTFOX database will stimulate to:

- Promotion of the scientific co-operation, advance knowledge and awareness about existing research, facilities and long-term forest field experiments within and between the Nordic and Baltic countries, and in an international context.

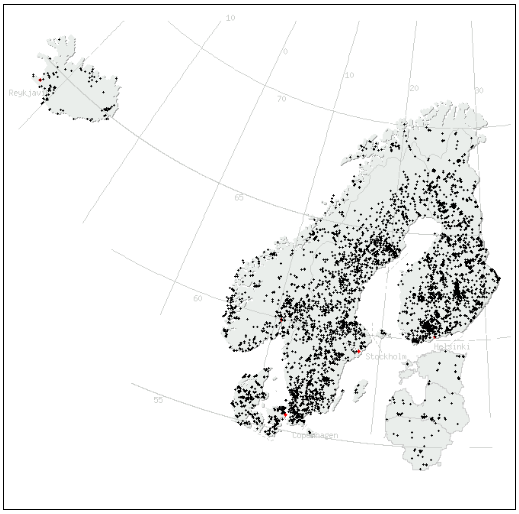


Figure 1. Map showing Nordic and Baltic forest field experiments (interactive map at the web-page)

- Expanding and further development of the high quality database for long-term forest experiments in order to promote evaluation, maintenance and establishment of forest field experiments as an important fundament for sustainable forestry guidelines.

- Reduction in the use of resources by concentrating the activities on high quality field experiments and the promotion of effective use of existing experimental data.

In May 2005 the annual working meeting took place at the Lithuanian Forest Research Institute, Kaunas. 13 representatives from 7 countries were participating at this meeting. The new version of NOLTFOX with field experiments from the Nordic and the Baltic countries is now launched (Fig. 1) and the work on including references to the literature has been initiated.

The project group consists of researchers from all Nordic and Baltic countries. The database is constructed by Jukka Pöntinen (METLA, Finland) and the visual layout is designed by Jouni Hyvärinen (METLA, Finland). The project manager is Fredrika von Sydow at SLU in Sweden.

Virgilijus Baliuckas
Lithuanian Forest Research Institute

International workshop "The scale of natural disturbances from tree to stand"

International workshop "*The Scale of Natural Disturbances from Tree to Stand*" was held in Palanga, Lithuania, on 28 – 30th September 2005. The workshop was an integral part of *SNS* (Nordic Forest Research Cooperation Committee) Network "Natural Disturbance Dynamics Analysis for Forest Ecosystem Management". SNS granted the financing of the workshop. The Lithuanian Forest Research Institute hosted the workshop.

Totally 30 participants from 9 different countries (Estonia, Norway, Latvia, Finland, Lithuania, Russia, Belarus, The Netherlands, USA) attended the meeting.

Pre-workshop excursion concentrated on the forest disturbances and experiments. Investigations on the influence of the bark beetle and seasonal distribution of the Norway spruce xylofauna as well as drought were presented. The participants have visited the Old-growth forest in the strict forest reserve that is situated on the territory of Dubrava Experimental and Training Forest Enterprise. The total area of this strict nature reserve is 122 hectares including 92 hectares covered by mature and pre-mature stands of *Picea abies* Karst., *Pinus sylvestris* L. and *Betula* spp., and 30 hectares under raised bog. After the drought in 1992, the old-growth Norway spruce stand was damaged by *Ips typographus* L., and further spruces were fallen by stormy winds. Participants observed visual process of the natural regeneration of Norway spruce. Ash and oak decline were observed on study area in the Kėdainiai Forest Enterprise.

Dr. Kalev Jõgiste opened the session of presentations and posters at the workshop. It was stressed at the opening that looking worldwide the importance of disturbances is increasing. There is a strategic need to increase the disturbance management study field.

The topic of the workshop allowed accommodating a wide spectrum of presentations. 12 oral presentations were held during the meeting. A wide array of topics was included. The lively poster session with 9 posters from researchers from different countries was successful.

Dr. Chris Peterson, professor of botany at the University of Georgia (USA), was an invited keynote speaker at the meeting and presented his work on wind disturbances in North America.

Dr. Tuomo Wallenius (University of Helsinki) brought interesting ideas about the fire disturbance into view. Prof. Martin Zobel (University of Tartu) presented exciting results from studies of biodiversity of fungi. Dr John Stanturf (USDA Forest Service) had a presentation on disturbances in the face of climate change. The hurricane *Katrina* influence was a fresh example for preliminary analysis of the damage and the loss of costal forests.

The discussion on further activities was focused on the next meeting and publication procedure. It was stressed that the contacts with other global networks are important. The IUFRO and other global networks should be approached by our initiative. It is an efficient way to use IUFRO web site for communication.

The Network web site will be developed. More information including publication of oral and poster presentations will be organised. The website address should be corrected to avoid misinterpretations by visitors of the site. The presentations and posters are published via net (the website for network activities can be reached: http://www.eau.ee/~ecosyst/

It was agreed that the publication of network papers in peer-reviewed journal is one of the priorities in the network activities.

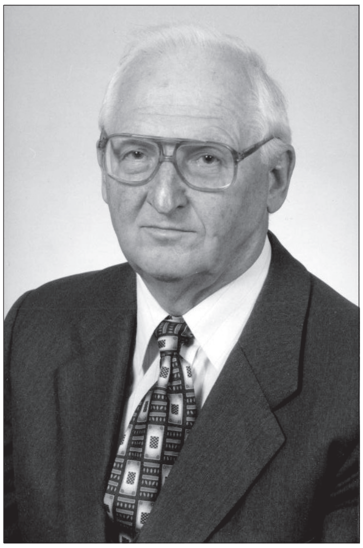
Post-workshop excursion was a highlight of the program. Participants of the workshop got to know of the unique Curonian Spit (55˚30′ N 21˚07′ E). The Kuršių Nerija National Park is situated there on the total area 26,474 hectares including 15.9% under Curonian Lagoon, 47.2% of the Baltic Sea and 36.9% of land. In 2000 this territory was included into UNESCO World Heritage list as a valuable cultural landscape aimed to preserve natural and cultural heritage of the Spit, to control urban and economic development, to perform scientific research and monitoring etc. The visited area is the narrow spit that separates the Curonian Lagoon from the Baltic Sea. The spit is a sandy stretch of land covering an area with the width from 400 m in the northern part to 3.8 kilometres in the widest part at the Bulvikis Horn. The evolution of the spit is short but quite rich. The development of this area had started to the North from the Semba Peninsula some 5-6 thousand years ago. Moving dunes covered the moraine ground and the swamp. Parabolic dunes were formed at the end of the Littorina Sea period. These dunes were overgrown by the forest and did not move any more. Some fragments of the old growth forests are still presented. Up to the 15th century the spit was covered by mixed forests with oak, lime, elm, pine, birch, alder and hazelnut. However, the forest cover was destroyed sometimes because of the fires and that influenced the sand drifting. Further, since the 16th century the forests were destroyed due to negative human impact. That caused the severe sand shifting. Forest disturbances influenced deep changes and moving dunes swallowed nearly 14 villages. In 1825 G.D. Kuvertas started the first reforestation project suppressing the sand. Today the forests protect the spit and cover nearly 7 thousand hectares. The fore dune ridge rises up to 15 metres high and extends from 120 to 130 metres wide. The specific sea sand plain, that is named “*palve*” (it means “yellowish”), lies behind the fore dune ridge. This plain was formed of sand, which had been blown from the sea. Because of specific conditions storms caused the most significant damage to the forest. The greatest storms came in 1497, 1630, 1680, 1706, 1714, 1790-1792. Since World War II, the spit was devastated by seven major storms, which uprooted pine stands of 80 thousand cubic metres, in 1967 about 30 thousand cubic metres, and in 1999 another one damaged 20 thousand cubic metres of timber. The second major disturbances to forests are especially dangerous fires. The most tragic fires were in 1957 (150 hectares of forests had burned), in 1971 (15 hectares burned) and in 1995 (60 hectares burned). In 1966 there were even 84 fires. The fire hazard of forests keeps the management focused on protective issues. Although fires occur often, in most cases foresters control the fire at the early stage. Forest cover today is mostly Austrian and Scots pine (*Pinus mugo* and *P. sylvestris*). As a result of the reforestation, the forest composition has changed in favour of the Scots pine that was planted on the burned areas in place of the mountain pine.

Different disturbance sites were visited including dunes of eroded vegetation and cormorant colony. The debate about the restoration to natural native broadleaved forests (found in the area in the 1600s) starts. During the scientific excursion, Dr. Olgirda Belova elucidated the point of the monitoring system of the interaction between wildlife and forest woody vegetation. The investigations aim to ascertain the role and impact caused by animals to forest and its successional changes considering the animals as a natural indispensable component of the forest biota.

We believe the workshop met our expectations and created good continuation to our further cooperation. Lithuanian colleagues prepared a good meeting. Dr. Kęstutis Armolaitis was heading the organization team. We are very grateful to him.

Olgirda Belova
Lithuanian Forest Reseasch Institute
Ahto Kangur
Estonian University of Life Sciences
Kalev Jõgiste
Estonian University of Life Sciences

Professor Habil. Dr. Member Correspondent of the LAS Stasys Karazija is 75



Prof. Stasys Karazija is one of the most eminent creators of Forestry Science in Lithuania, who has contributed to the biogeocoenotic concept of forest as an ecosystem. His scientific activity is associated with the research on the structure of forest ecosystem of Lithuania, the results of which have served the resolving of fundamental issues of forest biology and ecology as well as the solution of practical tasks of economic activity. The works by Prof. S.Karazija, which analyse the dynamics of forest community structures, protective role of the soil and water, provide the ecological fundamentals for recommendations of different forest economic measures as well as for the protection of the biodiversity and landscape. Creative biography of Prof. S.Karazija harmoniously supplements the ranks of the creators of Forestry Science in post-war years and his contribution to a great deal of trends of Forestry Research is of great importance.

Stasys Karazija was born on December 14, 1930 in Terpeikiai village of the Kupishkis district in the family of farmer–forester of forest guard. He finished the secondary school (1949) in Kupishkis and the Faculty of Forestry of the Agricultural Academy (now Agricultural University of Lithuania) in 1954.

After graduating from the Faculty of Forestry he worked as a forester of a district in the Shimonys Forest. Since 1957 he was senior forester in the Shakiai Forestry Enterprise. Since 1960 S.Karazija was scientific associate at the Lithuanian Forest Research Institute. In 1965 he defended the thesis „Types of the birch stands of Lithuania and their productivity“ and was awarded the degree of Candidate (now Doctor) of sciences.

While working at the Forest Research Institute and at Kaunas Botanic Garden (1969–1970) over 40 years S.Karazija conducted research on forest typology, on the issues of perception of coenotic structure of forest communities, analysed the forming of stands structure and the peculiarities of managing them, protective functions of forests and their role for the ecology of landscapes. He was a supervisor of a great deal of scientific topics and was responsible for their implementation. While following the forest typological regulations by Acad. V.Sukachiov and Prof. P.Matulionis. S.Karazija has created ecologically based classification of all Lithuanian forests and these of Kaliningrad region (Russia). In 1980 on the basis of these works he defended the thesis „Typological classification of forests of the Southern Baltic region as the basis of optimization of their composition and an increase in their productivity“ and was awarded Habilitate Doctor’s Degree.

Later investigations by S.Karazija were assigned for preparation of the systems of economic measures for different types of forests. While carrying out the investigations (1985– 2000) of the ecological role of forests he determined some indexes of protection of forest, water and the soil, prepared practical recommendations. Also he studied the issues of protection of particularly valuable forest complexes and these of the forming of the system of territories being protected. He guided the program „Theoretical fundamentals of protection and regeneration of the oak stands in Lithuania“.

S.Karazija has published over 250 scientific papers and these popularizing science, he is the author of 7 monographs including „Forest Types of Lithuania“, „Forests and Protected Territories“ and co–author of several large scientific works. He has prepared various recommendations for production, two of them have been awarded Bronze Medal at the Exhibition of Economic Achievements of the former USSR. These recommendations have been widely applied in the north western region of Europe.

Prof. S.Karazija also did scientific – organizing work. In 1974–1989 he was Head of the Laboratory of Forest Soils and Forest Typology. In 1988–1992 he was Vice– director of the Forest Research Institute for scientific work. In 1994–1997 he was Director of the Forest Research Institute and from 1998 he is Chairman of Senate of the Institute. In 1993 he was awarded the title of Professor. In 1996 he was elected Member Correspondent of the Lithuanian Academy of Sciences.

Currently prof. S.Karazija is Editor–in–Chief of scientific journal „Mishkininkyste“, Member of Editorial Board of journals „Baltic Forestry“ and „Agricultural Sciences“. He is Member of the Nostrification Commission of Scientific Degrees of the State of Lithuania. Also he is consultant of the agricultural encyclop(a)edia. Professor S.Karazija lectures on Forestry for students and post–graduates (seeking Doctor's Degree) of the Agricultural University of Lithuania, participates in the preparation of scientists. Under his supervision 3 theses have been defended and Doctor's Degrees awarded.

We congratulate Honorable Prof. Dr. Stasys Karazija on the occasion of the Jubilee of 75 years and wish the best health, inexhaustible energy, new achievements in science and happiness in life.

Akad. Leonardas Kairiūkštis

INSTRUCTION TO AUTHORS

Baltic Forestry is open for papers of all major themes in forestry such as Silviculture; Physiology and Genetics; Forest Operation and Techniques; Inventory, Growth, Yield, Quantitative and Management Sciences; Forest Products; Forest Health (including monitoring *etc.*); Forest Environment (including ecosystem, site research and classification, forest hydrology, wildlife and habitat management, biodiversity conservation, *etc.*).

Baltic Forestry publishes original research papers of the results both theoretical and experimental in the Baltic's and elsewhere. Review papers and brief research reports on topics of interest to a wide audience will be considered for publication.

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Manuscripts should be submitted in triplicate. Graphs, photographs (high quality is need) can be submitted in triplicate separately. The data should be saved in the Win Word format. On the diskette you should indicate your name, institution, the word processing programme you have used and the date. Contributions should be in English .

Submission of manuscripts should be accompanied by a cover letter from the author who will be responsible for correspondence regarding the manuscript. The letter should contain a statement that the manuscript has been seen and approved by all authors. The contribution will imply that this paper has not been published elsewhere and, if accepted for publication in the *Baltic Forestry*, it will not by published in any other journal in the same or similar form without our written consent. All papers submitted to *Baltic Forestry* are peer reviewed by at least two independent referees. To ensure fairness, referees are anonymous.

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General: It is recommended that the text of original article (*Research Reports*) should not normally be longer than 20 printed pages, including tables, illustrations, references and summary. The authors should aim to submit their work, as concisely as possible and longer papers will be accepted under exceptional circumstances. The *Brief Reports* and *Chronicle* will be published in addition to submission of the original articles. The *Brief Report* must not exceed 10 pages. The style should be the same as in original papers. These manuscripts will normally be published quickly after receipt of completed manuscripts. The editors may suggest that manuscripts will be resubmitted in this form.