Influence of Ground Water Table Depth, Ground Vegetation Coverage and Soil Chemical Properties on Forest Regeneration in Cutovers on Drained Fen Habitats

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Abstract

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The objective of this study was to evaluate natural forest regeneration in cutovers on drained fens (eutrophic and mesotrophic low moor peat soils) depending on intensity of drainage characterised by depth of the ground water table, coverage of ground by vegetation and soil chemical properties (soil acidity and saturation with bases). The data were collected in 172 sample plots established in transects located perpendicular to drainage ditches at different distance to it. The assessments were carried out in 2003-2007 in the Panevėžys and Biržai state forest enterprises.

It was found that downy birch (*Betula pubescens*) seedlings dominated in cutovers on eutrophic and mesotrophic fens. The density of seedlings was greatest (3,700-5,300 trees per ha) on undrained and extensively drained cutovers where ground water table depth (h_5) at the beginning of growth period was 1-20 cm. Black alder (*Alnus glutinosa*) seedlings were most abundant (1,000-1,300 trees per ha) in undrained and extensively drained cutovers on eutrophic peatlands where ground water level at the beginning of growth period is above the soil surface (10 cm) or near it (in the depth of 1-10 cm). Spruce (*Picea abies*) seedlings were not abundant (averaged 300±101 trees per ha) in these sites. The higher density of spruce seedlings was found (more than 300 trees per ha) in drained cutovers (h_5 = 10-80 cm) on mesotrophic peatlands.

It was found that the average density of seedlings of trees in cutovers on fens (eutrophic peatlands) depended significantly on the depth of the ground water table, coverage of ground vegetation and acidity of soils.It was concluded that overly intensive drainage of fens (lowering ground water table at the beginning of the growth period of trees by more than 30-40 cm) created unfavourable conditions for regeneration of trees, decreased the base saturation of soil, increased soil acidity and reduced soil fertility.

Keywords: forest regeneration, cutovers, fens, ground water, chemical properties of soils

Introduction

Peatlands have been widely drained for forestry in northern Europe, in the British Isles and in parts of the USA and Canada (Minkkinen et al. 2008). Drainage of paludal forests and clear cuttings alter the physical, chemical and biological properties of their soils as well as soil water regime. In addition, forest floor vegetation, especially dwarf shrubs, may grow rapidly in the initial years following drainage (Laiho et al. 2003). This creates specific conditions for the forest regeneration and development in fens (Berry and Jeglum 1988, Braekke 1990, Dube et al. 1995, Paavilainen and Päivänen 1995, Roy 1998). In recently drained fens, the two- and three-year-old black alder saplings established just before the drainage on a thin layer of peat above the roots of trees or the decaying remainders of trees, rapidly desiccates without being able to root any deeper (Kapustinskaitė 1983). On the clear cutting sites of fens within the intensive drainage zone (up to 65 m wide along the ditch) the roots of felled trees get exposed as a result of a much lowered water table and settling of peat. Therefore, a part or even all of the one- and two-year-old sprouts of stumps dried out (Kapustinskaitė 1960). Thus, the intensive drainage could damage seedlings and saplings in the black alder stands, particularly, in the second year after cutting. Moreover, after clearcut the fluctuations of moisture in forest litter and upper soil layers of fen achieve critical values for the seedlings in summer time and reduce regeneration in cutting sites (Острошенко 2003). On strongly drained peat soils, despite high yield of black alder seeds in favourable years for seed production (up to 40 million ha^{-1}), fewer seedlings appear and survival is poorer compared to undrained paludal soils (Поджаров and Степанчик 1988). These authors report the best regeneration in undrained black alder stands of the type *Urtico-Alnetum*, where the surface water retains until the middle of May.

The optimal peat soil drainage level (-7 cm) established by us (Русецкас 1991) is oriented, with 50% probability, at the natural water regime of the most productive undrained black alder stands of *Urtico-Alnetum* type. However, strong drainage of peat soils in Lithuania is common. As reported by Volskis et al. (1999), a fen ecotope is lost when ground water table drops below 60 cm, and only plant communities of low economic value are able then to develop in a new ecotope.

Meanwhile, some Belarusian researchers (Стерин 1989) consider that in order to get productive black alder stands on a fen peat soil, the level of ground water should fluctuate within 30-110 cm during the growth season, while aiming at productive birch stands, that level should be 55-110 cm. According to Finnish, Swedish and Canadian researchers (Heikureinen 1967, Braekke 1990, Toth and Gillard 1988, Lieffers and Macdonald 1990) the aim of drainage or ditching of undecomposed ombrotrophic peat soil is to lower ground water level by 35 cm and more, while in the case of the decomposed minerotrophic peat soil the aim is to lower by 55 cm and more.

According to Podjarov and Stepanchik (Поджаров и Степанчик 1988) the natural regeneration of black alder is very poor even in good seed years when soil is totally waterlogged by melt-water, which often is observed in undrained sedge, swampy-fern and other lowland stands of black alder. In such stands and their clearcuts a drainage by shallow ditches spaced at 400-500 m apart from each other is recommended.

The drainage of forest swamps and clearcut also influence the physical and chemical properties of soils, changing conditions for tree recruitment and growth. As some researchers report (Котрушенко 1967, Кошельков 1982, Vaičys and Oniūnas 1992, Saarinen 1996, Saarinen and Sarjala 1999), after the drainage of forest swamps and clearcuts, peat density, water penetration, ash content, basicity, acidity, and thereof, fertility of soil is changing. For example, it is found that the contents of nutrients, deposited on a soil surface with precipitation is higher under the crowns of trees than on a clearcut site (Päivänen 1974, Helmisaari and Mälkonen 1989, Hyvärinen 1990). Moreover, the influx of nutrients from neighbouring mineral soils to peat soil is impeded heavily by the drainage ditches (Paavilainen and Päivänen 1995). On the other hand, peat of the drained swamp decomposes more rapidly and shrinks, resulting in increased ash content, saturation with bases, and overall change of conditions for the regeneration and growth of forest. However, the interactions between ground water table, vegetation and soil acidity on the success of tree regeneration on drained fen habitats have not been studied sufficiently in Lithuania and other Northern temperate and hemiboreal forest regions. Therefore, the aim of the present study was to evaluate the influence of intensity of drainage (characterised by ground water table depth), ground vegetation coverage and soil chemical properties on forest regeneration in clearcut sites on drained fen habitats.

Material and Methods

The study was carried out in Biržai and Panevėžys Forest Enterprises (Northern Lithuania). These enterprises are distinguished by the largest areas of paludal forests in Lithuania (28-35% of forests grow on peat soils there). About 56% of peat soils are drained in Biržai Forestry Enterprise, while 36% of those are drained in Panevėžys Forest Enterprise. The most intensively drained are fen peat soils (ca. 70%), where sedge and sedge-orris forest types of black alder and birch stands prevail. Most of the chosen cutting sites (ca. 96%), as well as stands, were drained 20-30 years ago by ditches dug along the forest block lines at 1.2-1.9 m depth.

The studies were performed in forest cutovers on drained mesotrophic (Pc habitat type) and eutrophic (Pd habitat type) fen habitats. The influence of drainage intensity, characterised by the depth of ground water table, on regeneration of cutting sites was studied in 37 transects of 100-300 m in length located perpendicular to drainage ditches, where 172 research plots were established at every 20-50 m at different distances to ditches depending on the width of cutting site (Figure 1). In total, 19 transects with 88 research plots represented mesotrophic fen habitat (Pc habitat type) and 18 transects with 84 research plots represented eutrophic fen habitat (Pd habitat type).

At the centre of each research plot a one metre deep hole was dug and a soil borer was applied at its bottom to reach parent rock. Then soil probe was hammered in to the depth of 2 m from the ground surface. At each hole the thickness of peat layer was measured as well as thickness of each soil horizon determined. At every fifth hole, soil samples with 5 replicates were collected from the upper 2-20 cm peat layer for chemical analysis. Nearby the holes, 1.5 m

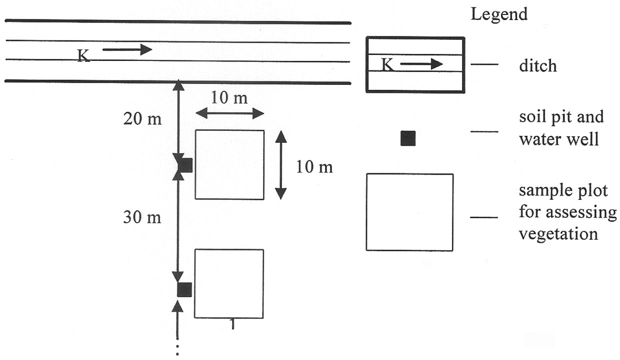

Figure 1. Scheme of establishment of sample plots in naturally regenerating cutovers. Sample plots were arranged every 20-50 m in transects that are located perpendicularly to drainage ditches. K stands for water flow in ditch

deep wells were established for the measurement of ground water level (h). The level of ground water was measured in the wells regularly during the study period (2003-2007) in the beginning of May (h_5) as well as in dry and wet periods during the growing season.

Chemical properties of soil samples were analysed in the Agrochemical Research Centre of the Lithuanian Centre of Agricultural and Forest Sciences as follows: pH_{KCl} in the 0.1 N KCl suspension by potentiometric method; hydrolytic acidity by alkaline titration of acetic acid which was obtained by the reaction between soil and sodium acetate; the sum of sorbed bases was established by treating the soil with 0.1 M hydrochloric acid, the H^+ ions of which substitute cations of sorbed bases. The surplus of hydrochloric acid was established by titration with 0.1 M NaOH solution.

Regeneration inventory in cutting sites was carried out in the plant inventory plots of 10×10 m size established near the hydrological wells (Figure 1). Tree recruitment was counted in the whole inventory plot. Extremely abundant regeneration was evaluated by the data collected from 5 squares (2×2 m size), each of them located in the centre and four corners of the inventory plot, and then recalculated for the whole inventory plot. The density of regeneration was estimated in the whole plant inventory plot. The numbers of viable, non-viable and dead individuals of tree species, age, origin, height, and growth place were evaluated. For the evaluation of vegetative regeneration of broadleaved tree species the stump sprouts were counted and stump condition was described in the plots.

The species composition, mean height and cover (%) were estimated for the undergrowth, subshrubs, shrublets, vascular cryptogams, herbaceous dominants. Their abundance and distribution in a plot were evaluated according to the Braun-Blanquet scale. The horizontal and vertical structure of vegetation of the inventory plots was described.

Data analysis

Aggregated values of seedlings number from each plot (plot means) were used in statistical analysis. Linear regression analysis was used for approximation of the dependence of coverage of tall grasses and subshrubs shading the naturally regenerating seedlings upon the ground water level at the beginning of growing period, the dependence of density of naturally regenerating seedlings upon the coverage of grasses and subshrubs, and the dependence of density of naturally regenerating seedlings capable of forming forest upon the pH_{KCl} of the upper (0-20 cm) layer of soil. Regression analysis was done using the REG procedure of the SAS software (SAS® Analytics Pro 12.1 2012).

RSQUARE procedure of the SAS software was used to construct best fitted (with highest R^2) models of multiple linear regression to characterize integrated impact of different factors (depth of ground water table, hydrolytic acidity of peat, plant vegetation cover, etc.) on forest regeneration. REG procedure of the SAS software (SAS® Analytics Pro 12.1 2012) was used to establish multiple regression equations and to characterize significance of contribution of individual factors (with *t*-test). Only factors with $t > 2.5$ have been included into equations of multiple linear regression.

The correlation analysis was performed to relate the soil properties (the ground water level at the beginning of growth period) and the parameters of naturally regenerating forest. CORR procedure of the SAS software was used (SAS® Analytics Pro 12.1 2012).

Means, standard errors, standard deviations, and the 95 % level confidence intervals for the means were calculated for each regeneration characteristic (Explore procedure of SPSS 16.0 for Windows). Statistical significance was evaluated with *t*-test.

One-way analysis of variance (ANOVA) was used to assess the significance of impact of ground water level and percentage of area covered by tall grass on seed-derived saplings density. The ground water level was considered as fixed factor with 7 discrete groups. The percentage of area covered by tall grass was of random continuous distribution. The variance analysis was done with the MIXED procedure of the SAS Software (SAS® Analytics Pro 12.1 2012).

Clustering of sample plots groups with same depth of ground water table based on the density of seed-derived saplings significantly influencing differences of forests density in fen peat soils was performed by applying CLUSTER procedure (Average method) of the SAS software (SAS® Analytics Pro 12.1 2012).

Results and Discussion

Regeneration is key to the existence of species in a community. It is also a critical component of forest management because regeneration maintains the desired species composition and stocking after biotic and abiotic disturbances. Present study showed, that the natural regeneration of the peat swamp forest ecosystem is influenced by the interrelationships between peat subsidence, surface flooding during the wet season, and vegetation succession.

Effects of ground water level on forest regeneration on fen peat soils

It was established that in mesotrophic (Pc habitat type) as well as in eutrophic (Pd habitat type) fens the regeneration by downy birch (*Betula pubescens* Ehrh.) predominated comprising ca. 74% of the total number of all tree species regeneration (Figures 2 and 3). On sites where ground water table was below the soil surface in the beginning of growth season, the number of these individuals depended significantly on the ground water level (r = 0.43; p = 0.001). The densest regeneration (3,700-5,300 ha^{-1}) occurred in the cutting sites, where ground water depth was 1-20 cm in the beginning of growth season. In the case of very intensive drainage of peat soils, i.e., when ground water table is at the depth of 60-80 cm in spring time, only a very sparse regeneration of downy birch (up to 700 ha^{-1}) took place (Figures 2 and 3). When ground water level retained up to 20 cm above the soil level in spring time (Figures 2 and 3), then downy birch and black alder (*Alnus glutinosa* (L.) Gaertn.) exhibited relatively good regeneration (up to 2,500 ha^{-1}) on various humps and other micro elevations.

The density of black alder regeneration and the depth of ground water level were also interrelated by the positive regression (r = 0.48; p < 0.001), when the latter occurred below the soil surface (Table 1). This proves that black alder is intolerant to the intensive

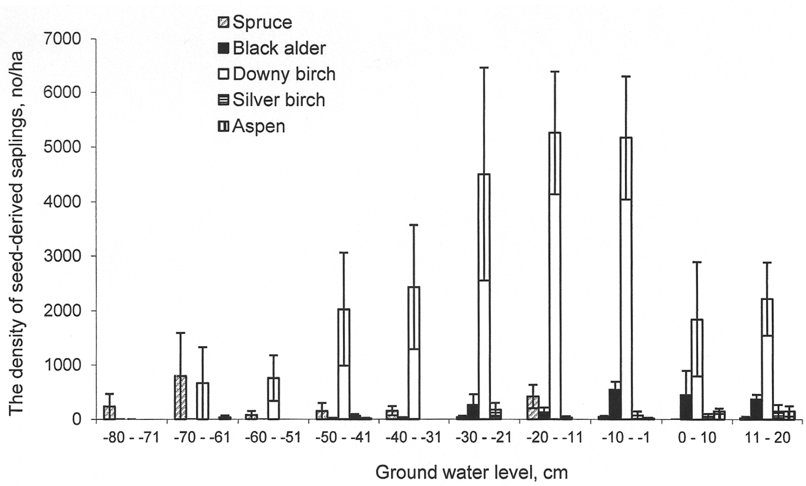

Figure 2. Mean density of seed-derived saplings under different ground water levels at the beginning of the growth period on fertile fen peat soils (Pc forest site). The pins indicate standard errors

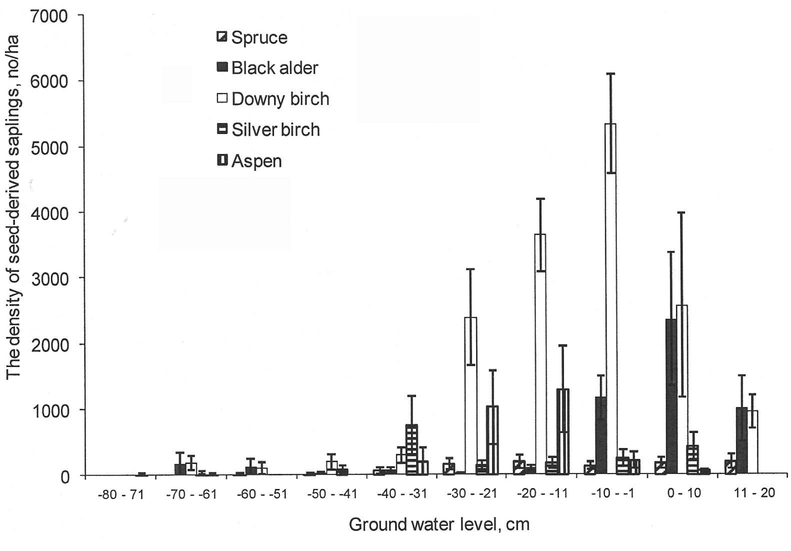

Figure 3. Mean density of seed-derived saplings under different ground water levels at the beginning of the growth period on very fertile fen peat soils (Pd forest site). The pins indicate standard errors

drainage. For instance, in the cutting sites, where ground water table occurs at the depth of 71–80 cm, no viable seedlings of black alder are found (Fig. 2 and Fig. 3). However, black alder seedlings were more abundant on those sites where ground water level in the beginning of growth season is retained up to 10 cm above the soil surface or up 10 cm below it. On very fertile paludal habitats (Pd type) the density of regeneration reached 1,200-2,350 ha^{-1}, while on medium fertile low moor habitats (Pc type) it was only 475–543 ha^{-1} (Figures 2 and 3).

Trembling aspen (*Populus tremula* L.) regeneration (both generative and vegetative) occurred some more abundantly (up to 1,000-1,300 ha^{-1}) only on cutting sites of eutrophic fens (Pd type habitat) (Figure 3), where ground water retained at the depth of 11-30 cm in spring time. On the sites where ground water occurred deeper than 30 cm in spring time, only single seedlings of poplars were found (Figure 3).

Among forest tree species in fens, Norway spruce (*Picea abies* (L.) Karst) was relatively sparsely regenerating (300±101 ha^{-1} on average) (Figures 2 and 3). Greater abundance (over 300 ha^{-1}) was found on drained mesotrophic fens (Pc habitat type), where ground water occurred deeper than 10 cm in the beginning of the growth season (i.e., h_5 (ground water depth in first decade of May) = -10 to -80 cm) (Figure 2).

In fens (both drained and undrained), silver birch (*Betula pendula* Roth) was not abundant (Figures 2 and 3). Greater abundance (up to 750 ha^{-1}) was on moderately drained (h_5 = -30 to -40 cm) very fertile marshy habitats (Pd type). This corresponds to the conclusion made by Finnish researchers, Paavilainen and Päivänen (1995) that silver birch is infrequent on paludal soils and it prefers dryer soils.

As indicated in the Table 1, in fens, where ground water retains above the soil surface in spring time, no reliable relations were established between the density of viable regeneration of both seed and vegetative origin and h_5 values. Only a trend was established showing the higher is ground water level in spring the lower density of seedlings occurs (r = -0.35; p = 0.192).

The fact that high and low levels of ground water affect the establishment of seedlings on peat soils differently was confirmed by the results of the cluster analysis. As seen in Figure 4, the research plots were combined into one group by the density of regenerating seedlings on those peat soils, where ground water occurred at the depth of 11–30 cm, and combined with the plots, where ground water occurred up to 10 cm below the soil surface. Thus, the larger group contained all the research plots, where ground water level in the beginning of growth season occurred within the range of our formerly established norms (Ruseckas 2000) (those norms recommend lowering of ground water level in fens up to -7 to -28 cm). More intensively drained sites were combined into another big group. This confirms the facts that drainage norms for fens are established properly.

Table 1. Pearson correlation coefficients between the ground water level at the beginning of growth period (h5) and the parameters of forest natural regeneration, and its *t*-est values and probabilities

Range of the ground water level (h_5), cm	Density of regeneration by saplings	*r*	Student *t-test* value	Probability (*p*)
-80-0	seed-derived black alder	0.48	7.16	<0.001
-80-0	seed-derived downy birch	0.43	6.15	0.001
-80-0	seed-derived saplings (all species)	0.57	6.20	0.001
0-30	seed-derived saplings (all species)	-0.35	0.31	0.192
0-30	sprout-derived saplings (all species)	-0.03	0.64	0.916

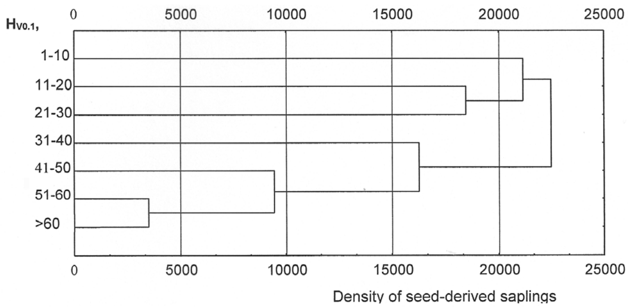

Figure 4. Dendrogram of distribution of sample plots groups with the same depth of ground water table according to the density of seed-derived saplings on fen peat soils

Judging of the results of cluster analysis the research plots with ground water depth of 1–30 cm exhibited a sufficient density of regeneration and could not be combined into one cluster with those, where ground water level occurred at the depth of 31–60 cm and deeper, and which regenerated with insufficient density as shown in the Figures 2 and 3.

The researchers from other countries (Laine et al. 2007) refer that the surface of bogs is commonly patterned and composed of different vegetation communities, defined by water level. According Laine et al. (2007), vegetation structure is strongly controlled by water level, the number of species and leaf area is the highest in the intermediate water level range and photosynthesis is the highest when the water level is 11 cm below the surface.

Effects of herbaceous vegetation on tree regeneration in cutting sites

In boreal peatlands (both natural and drained) there is a continuum from open treeless peatlands to densely forested sites. Drained peatlands are hydrologically less variable ecosystems than undisturbed mires; they are far from being homogenous in this sense. Depending on the original site type, slope of the terrain and intensity of the drainage, some mire plant species, may remain vigorous in the moist patches of the peatland decades after drainage (Laine et al. 2007).

The drainage intensity of peat soils, indicated by the depth of ground water level, affects also the distribution of herbaceous vegetation. The distribution of the tall grasses and shrubs shading the regenerating seedlings, and the level of ground water, were negatively correlated (r = -0.64; p < 0.001) (Figure 5), that means the deeper the ground water in spring time is, the higher is the density of tall grasses and shrubs (*Rubus idaeus, Urtica dioica, Galeopsis tertahit, Anthriscus sylvestris, Calamagrostis canescens*), and the more shading takes place of regenerating seedlings of forest tree species. Moreover, the herbaceous vegetation evaporates a significant portion of soil moisture, thus competing for this resource with the forest regrowth (Ruseckas 2002, Gradeckas and Malinauskas 2005).

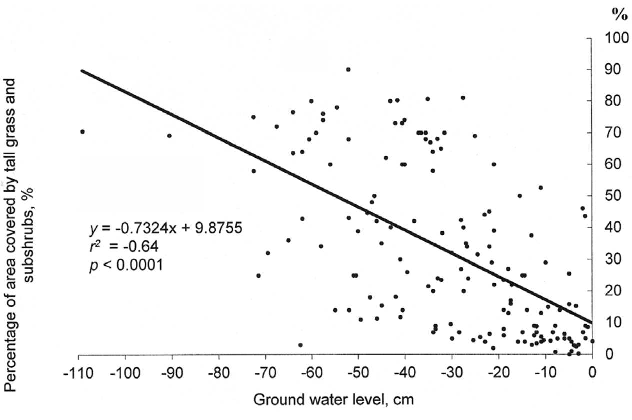

Figure 5. The linear dependence of relative coverage of site by tall grasses and subshrubs (which are shading the naturally regenerating seedlings) upon the ground water level in fens (eutrophic peatlands) at the beginning of growth period

It was established that the number of viable regenerating individuals was conversely proportionate to the cover of grasses and subshrubs in cutting sites (r = –0.41; p < 0.05) (Figure 6). As shown earlier, the level of ground water conditions significantly affects the density of regenerating seedlings as well as the cover of herbaceous vegetation. Therefore, we will try to assess if the effects of herbaceous cover on the density of the regeneration is not random.

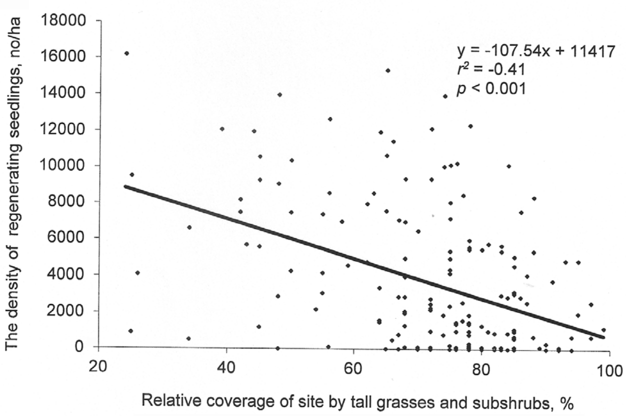

Figure 6. The linear dependence of density of viable naturally regenerating seedlings upon the relative coverage of site by tall grasses and subshrubs in the cutovers on fen sites

Referring to the results of the two-way analysis of variance (Table 2) we can state, that in the case of fen peat soils the density of regenerating seedlings substantially depended on the depth of ground water level in the beginning of growth season (F = 5.42; p = 0.021) and tall grass cover (F = 8.27; p < 0.001) as well as on the interaction of the both factors (F = 4.56; p = 0.012).

Table 2. Results of ANOVA of seed-derived young trees density: significance of impact of ground water level and percentage of area covered by tall grass and its interaction

Factor	Sum of square	df	Mean square	F	p
The ground water level	156194504	6	56194504	5.42	0.0213
The percentage of area covered by tall grass and subshrubs	171551360	2	85775680	8.27	0.0004
The interaction of ground water level and percentage of area covered by tall grass and subshrubs	94611176	151	47305588	4.56	0.0119

It should be noted that the researchers from other countries (Kaunisto and Paavilainen 1988, Groot and Adams 1994, Saarinen and Hotanen 2000, Saarinen et al. 2004) who studied plant successions after drainage, also refer to the plant cover of soil as one of the most significant factors conditioning tree seed germination and seedling development.

Effects of soil acidity on forest regeneration

As indicated in Table 3, the deeper the ground water in fen peat soils, the more acid it is. For instance, the differences between pH_{KCl} values on undrained sites (h_5 = -10 to +10 cm) and in intensively drained

Table 3. The potential mean exchangeable acidity of the upper fen peat soil (HSs) layers (2-20 cm) under the conditions of the different intensity of drainage evaluated by ground water level at the beginning of the growth period (h_5)

Ground water level, cm (h_5)	pH_{KCl}	Differences of pH_{KCl} between sites of relatively undrained (h_5= -10 ... +10 cm) and drained by different intensity soils	*p* (*t*-test)
-10 ... +10	5.79±0.11	0.00±0.00	-
-20 ... -11	5.73±0.09	0.06±0.14	>0.05
-30 ... -21	5.58±0.16	0.21±0.19	>0.05
-40 ... -31	5.25±0.13	0.54±0.17	<0.01
-50 ... -41	5.23±0.15	0.56±0.19	<0.05
-60 ... -51	5.00±0.18	0.79±0.21	<0.01
-70 ... -61	4.29±0.21	1.50±0.24	<0.01

ones (h_5 = -51 to -70) cm and deeper) were significant ($p < 0.01$) and made up 0.79-1.50 ± 0.21-0.24. On less acid soils the density of viable seedlings was higher if compared to more acid soils. A significant positive correlation was found ($r = 0.37$; $p = 0.018$) between the pH_{KCl} values of the upper soil layers and viable seedlings without their differentiation into separate species (Figure 7).

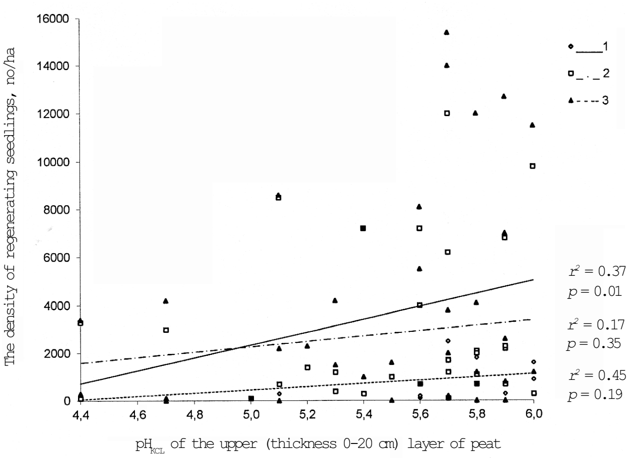

Figure 7. The linear dependence of density of naturally regenerating seedlings upon the pH_{KCl} of the upper (0-20 cm) layer of soil (1 – total of all species, 2 – downy birch, 3 – black alder)

However, different tree species are differently adapted to the variety of soil conditions. A trend was found of an existing weak relation (Figure 7) between pH_{KCl} of the upper soil layers and the density of viable black alder regeneration ($r = 0.45$, $p < 0.01$). A similar trend was observed also in case of downy birch regeneration, although the latter is more tolerant to acid soils than black alder (Vaičys and Oniūnas 1992). Therefore, there are enough cases of birch regeneration on more acid soils. Meanwhile, black alder occurred more abundantly (400-500 ha^{-1}) on less acid soils with pH_{KCl} of the upper peat layers over 5. The fact that broadleaved species grow better on less acid and neutral soils (pH = 4.7-7.0) is also reported by the other researchers (Vaičys et al. 1979, Witt 1997). As reported by Russel (1961), the most favourable pH for uptake of macro- and microelements by plants is 5.8–6.8. Under more acid soil conditions a nutrients are washed out into deeper soil layers, accumulation of aluminium, which is harmful to plants, increases and microorganism activity decreases (Russel 1961).

Additionally we assessed the cutting sites of marshy forests for the regeneration of various tree species estimating the potential hydrolytic acidity (HA). In previous study (Grigaliūnas and Ruseckas 2005) we established a reliable conversely proportionate relation between the density of viable regenerating seedlings on intensively and extensively drained (h_5 = "80 to +20 cm) fen peat soils and hydrolytic acidity of an upper soil layer (2-20 cm) ($r^2 = 0.37$; $p = 0.036$). A similar regularity was also found in the re-analysis of those research plots, where ground water in the beginning of growth season remained within the favourable range for forest regeneration, established by this work, or insignificantly exceeded it, i.e., occurred at the depth up to 40 cm ($r = -0.35$; $p = 0.0470$). Thus, it is likely, that too high exchange (Figure 7) and hydrolytic soil acidity affect negatively the regeneration of major tree species in fens. In order to improve the growth of tree recruitment on acid peat soils, several researchers (Паавилайнен 1983, Корчагина and Ионин 1984, Ипатьев 1990) suggest liming.

Effects of soil saturation with bases on forest egeneration

The degree of saturation with bases is one of the ıain properties of soil fertility which affects growth and development of plants (Вайчис 1975, Buivydaitė and Motuzas 2000). Present study shows, that this soil property affects the density of regeneration as well: a significant positive correlation was found ($r = 0.33$; $p = 0.0254$) between the saturation with bases of the upper peat layers and the density of viable regenerating seedlings (Figure 8). In the research plots, where soil saturation with bases reached less than 50%, only single tree seedlings (Fig. 9) and sparse vegetative ones occurred (the density of all regenerating species was about 880 ha^{-1}). In the plots, where soil saturation with bases was 60-70%, birch species (downy and silver), spruce and black alder all grew more abundantly (the average density of saplings was 2,480±796 ha^{-1}) (Figure 9). On sites where soil saturation with bases exceeded 70%, the seedlings of downy birch dominated, making up about 66% of total amount of regenerating saplings with mean density of 2,700±840 ha^{-1}) (Figure 9). The total density of regeneration on such well-saturated with bases soils made up

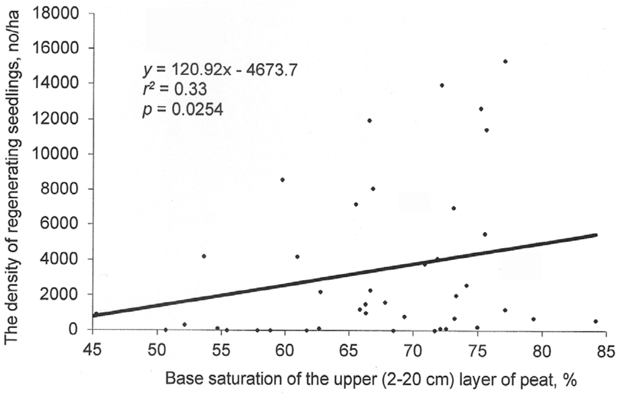

Figure 8. The linear dependence of density of naturally regenerating seedlings upon the base saturation of the upper (0-20 cm) layers of peat soils in fens

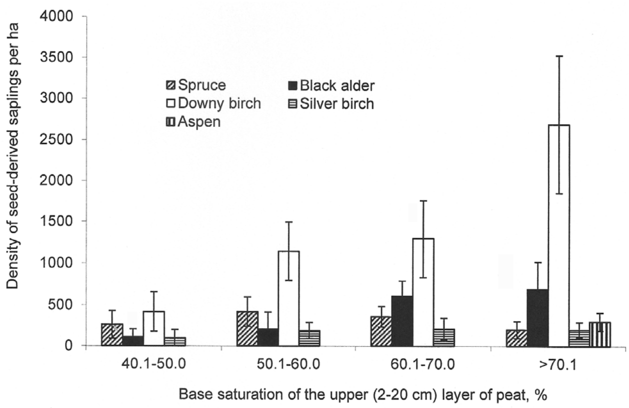

Figure 9. The mean density of seed-derived saplings at different levels of base saturation of the upper (2-20 cm) layer of low moor soil. The pins indicate standard errors

4,100±1,299 ha^{-1}. Thus, it is likely, that the favourable conditions for the regeneration of target tree species occur on drained fen paludal soils when soil saturation with bases reaches 70% and more. That high degree of peat soil saturation with bases was observed only in sites where ground water occurs in the beginning of growth season at a depth of up to 30 cm (Table 3), i.e., in extensively drained sites. In very intensively drained sites, where ground water occurs deeper than 70 cm in the beginning of growth season, a saturation with bases less by 31.9±5.8% was established if compared with soils where water retains within the limits of drainage norm, i.e., at the depth of 11–30 cm. Thus, the over-drainage of fen peat soils not only creates unfavourable conditions for natural forest regeneration, but also reduces soil fertility.

Multifactorial linear regression analysis of factors affecting forest regeneration on cutting sites

As mentioned above, the regeneration of trees on fen peat soils is conditioned by a series of factors: depth of ground water, pH of peat and hydrolytic acidity, saturation with bases, plant cover of soil, etc. Most of the factors affecting regeneration of trees on cutting sites correlated between each other significantly (Table 5). For instance, the correlation coefficients between the saturation with bases and hydrolytic potential acidity and pH_{KCl} of the upper soil layer (2-20 cm) were -0.98 and 0.94 (p < 0.05), respectively.

Table 4. The mean saturation of the bases of the upper fen peat soil (HSs) layers (2-20 cm) under different conditions of drainage intensity characterised by the ground water level (h_5) at the beginning of the growth period

Ground water level, cm (h)	Saturation of bases, %	Differences of saturation of the bases between sites of relative undrained (h= -10 ... +10 cm) and drained by different intensity soils, %	p (t-test)
-10 ... +10	70.2±2.2	0.0±0.0	-
-20 ... -11	71.2±2.2	-1.0±3.9	>0.05
-30 ... -21	70.0±4.5	0.2±5.5	>0.05
-40 ... -31	63.8±2.9	6.4±4.4	>0.05
-50 ... -41	62.6±2.1	7.6±3.04	<0.05
-60 ... -51	62.0±2.6	8.2±3.40	<0.05
-70 ... -61	48.6±4.8	21.6±5.8	<0.01
-80 ... -71	38.3±4.9	31.9±5.8	<0.01

Table 5. Correlation coefficients among the soil properties affecting the natural regeneration of forest tree species. Significant (p <0.05) correlations are indicated in bold

Indices*	h_5	Z	pH_{KCl}	HA	BS
Z	-0.19	-	-	-	-
pH_{KCl}	**-0.51**	-0.10	-	-	-
HA	**-0.51**	0.02	**-0.95**	-	-
BS	**0.47**	0.01	**0.94**	**-0.98**	-
N	**0.53**	**-0.60**	**0.33**	**-0.34**	0.30

* h_5 – the depth of ground water table at the beginning of growth period (cm), pH_{KCl} – the potential exchangeable soil acidity (mekv kg^{-1}), HA – the potential hydrolytic acidity of the peat soil (mekv kg^{-1}), BS – the base saturation of the peat soil (%), Z – the projectional coverage of ground vegetation, N – number of viable regenerating young trees per ha

Multiple regression analysis revealed that forest regeneration on fens is affected by three major components: the depth of ground water table in the beginning of growth season (h_5), hydrolytic acidity of peat (HA) and plant vegetation cover (liverworts, mosses, vascular cryptogams, grasses, shrublets, subshrubs) (Z).

The equation of linear multiple regression between the density of forest regeneration (N) and values $H_{V.1}$, Z and HA was as follows:

$$N = 123857.55 + 453.69\,h_5 - 10.23 \cdot HA - 1050.21 \cdot Z$$
$$R^2 = 0.56;\ F = 16.453;\ p < 0.001;$$

This equation confirms the premises provided in the present paper that the major factors conditioning regeneration of trees in cutting sites on drained fen soils are the depth of ground water, the hydrolytic acidity and the plant cover of sites.

Conclusions

On the clearcut sites as with eutrophic as well as mesotrophic fen peat soils the regeneration by downy birch (*Betula pubescens*) predominates. It occurs most densely (3,700-5,300 ha^{-1}) on undrained and extensively drained cutting sites, where ground water in the beginning of growth season is at a depth of 1-20 cm.

Regeneration by seedlings of black alder (*Alnus glutinosa*) occurs most abundantly (1,000-1,300 ha^{-1}) on undrained and extensively drained cutting sites on eutrophic fen peat soils, where ground water table in the beginning of growth season is just above or below soil surface (h_5 = -10 to +10 cm).

In cutting sites on fen peat soils, the regeneration by spruce (*Picea abies*) is, comparatively, sparse (300±101 ha^{-1}). It occurs more abundantly only on drained (h_5 = -10 to -80 cm) cutting sites on mesotrophic fen peat soils.

The density of seedlings of target tree species in cutting sites on fen peat soils depends substantially on ground water depth, plant cover of soil and soil acidity combined.

The strong drainage of fen peat soils (i.e., lowering the level of ground water in the beginning of tree growth season by more than 30-40 cm) not only creates unfavourable conditions for natural forest regeneration, but also stimulates soil acidification and decreases soil saturation with bases and, thereof, reduces soil fertility.

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