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Effect of Peak Runoff Control Method on Growth of Scots Pine Stands on Drained Peatlands in Central Finland

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In drained peatland forests ditch networks need regular maintenance operations in order to sustain their drainage capacity. These operations however have a significant impact on the quality of the runoff water from the ditched areas. Peak runoff control (PRC) method has been proposed as a possible method to diminish the load to water courses through retention of the runoff temporarily in the ditch network during maximum runoff events using dams with a plastic control pipe. However, blocking water into the ditched area for periods of varying length during the growing season may have a negative impact on the growth of the tree stands. In this study past stand growth was investigated in Central Finland in altogether 10 sample Scots pine thinning stands in which the PRC method has been applied 5 growing seasons earlier. In each stand, a pair of sample plots was established: one plot next to the dam within the influence of periodic flooding and the other one outside the effect of periodic flooding. For determining stand growth, field measurements were made in August 2009. Stand growth near the dam was on average 0.54 $m^3ha^{-1}a^{-1}$ lower than farther away from the dam but the analysis of covariance showed that the dam effect was not significant. The results of this study suggest that the PCR method does not decrease Scots pine stand growth during the first five year growth period after ditch cleaning.

Keywords forest drainage, stand growth, peatland, runoff control, water quality
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1 Introduction

Peatlands drained for timber production constitute one fourth (5.5 mill. ha) of the productive forest land area and one fifth (289 mill. m^3) of the growing stock in Finland (Hökkä et al. 2002). Since the drainage networks gradually loose their water transportation capacity, they should be maintained in order to prevent retarded tree growth due to rising water table levels. Ditch network maintenance (DNM) operations cause significant load to the receiving water courses, mainly in a form of increased amount of suspended solids (Nieminen et al. 2010). Non-point suspended solids transport and erosion are the key water quality problems in ditch network maintenance (DNM) operations. The load is generated during the ditch digging work or during the following years as a result erosion of ditch walls or beds during high flow events (Marttila and Kløve 2010a).

Peak runoff control (PRC) method has been used in peatland drainage areas to reduce high peak flows (Kløve 2000, Amatya et al. 2003, Marttila and Kløve 2009, Marttila and Kløve 2010b). The PRC idea is based on a concept in which runoff is temporally stored in ditch network during high runoff events. Detention is achieved by a dam and a set of control pipes that regulate the flow (Marttila et al. 2010). It has been shown in several previous studies that the method reduces peak flow and flow velocity, prevents ditch-bed erosion, settles suspended solids and particle bound nutrients in the peat harvesting sites (Kløve 2000, Marttila and Kløve 2009) in forested peatlands in temperate (Amatya et al. 2003) and boreal forestry conditions (Marttila and Kløve 2010b).

Because the PRC method temporarily stores water into the ditch network, it may lead to reduced drainage which is basically opposite to the aim of the DNM operation: instead of lower water table in the soil, higher water table levels may occur. With elongated flooding, tree roots may suffer lack of oxygen, which may turn out as continuing retarded growth or negligible growth response to DNM. In order to improve runoff water quality, PRC must retain runoff during high flow events. The design should balance between runoff retention and sufficient drainage after ditch network maintenance to provide better conditions for improved tree growth.

The influence of flooding on trees is controlled by the duration, repetition, and timing of the flooding event, as well as the depth and quality of flooding water (Glenz et al. 2006, Kozlowski 1982, Tuononen et al. 1981). Also the tree species, tree age, and individual properties of the tree influence how trees respond to flooding (Glenz et al. 2006, Kozlowski 1982). Generally, the flooding effects are realized in declined shoot and root growth (Glenz et al. 2006). Flooding during the growing season is clearly more harmful for trees, because during dormant season, need of oxygen by the roots is minimal. Glenz et al. (2006) have classified Scots pine as a low-tolerant species in terms of flooding. Späth (1988, 2002) has proposed that Scots pine would maintain its vitality if the duration of flooding does not exceed 30–40% of the growing season.

Based on results from field experiments in central Finland, Pelkonen (1975) and Päivänen (1984) have shown that if water table levels are adjusted near the soil surface in drained peatland stands during late growing season (July–August), Scots pine height growth will decrease by 60% and circumference growth by 35% (Pelkonen 1975). Contrary to this, no harmful effects due to high water table levels in early growing season were noticed. Pelkonen (1975) concluded that flooding before mid-June did not cause any impact on growth of peatland pine trees. Since the PCR structure does not adjust the water table to any specific level, great variations in severity and duration of flooding events among growing seasons may exist, depending on spring and summer weather conditions.

The aim of this study was to find out if the repeated storing of peak flow water in the ditch network during growing season influence negatively on the growth of peatland Scots pine (*Pinus sylvestris* L.) stand in the proximity of the PRC control dam. On the basis of the results of previous studies, we hypothesized that flooding does not decrease stand growth near the PRC dam. The data was collected from practical ditch network maintenance areas from Viitasaari and Pihtipudas, central Finland.

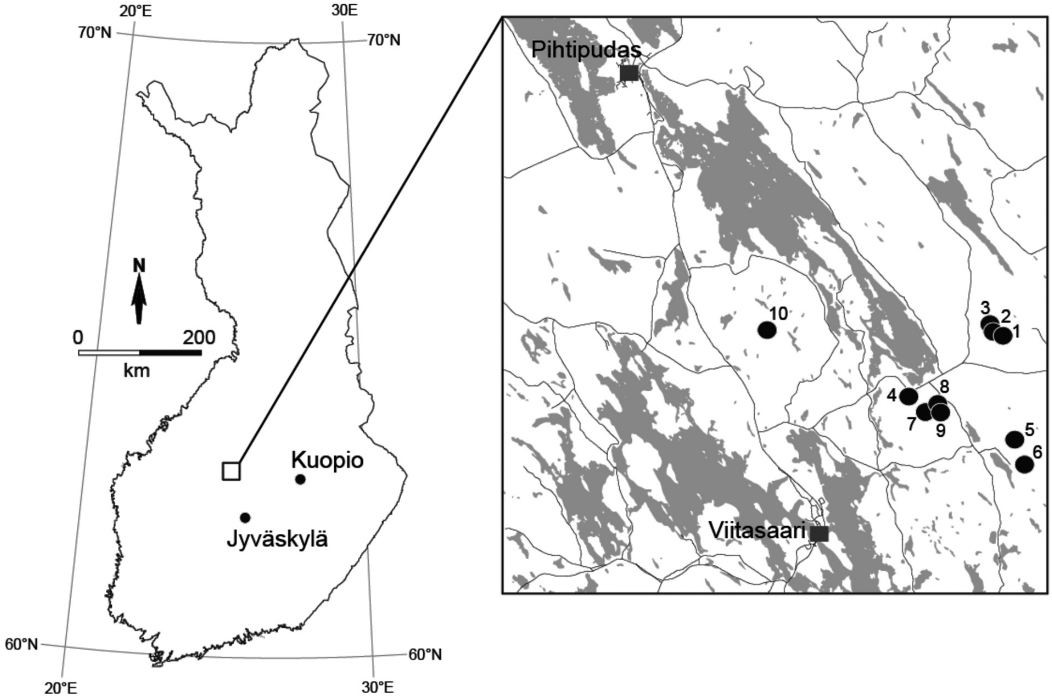

Fig. 1. Map of Finland and the location of the study sites.

2 Materials and Methods

2.1 Data Sampling

In Viitasaari and Pihtipudas, north central Finland, the PRC dams have been applied for several years in practical forest management in connection with DNM operations. Since the method is rather new even there, the longest operating time period found in the potential areas was six growing seasons. In order to get sufficient number of study sites, five post-treatment growth years was chosen as the minimum necessary time for this analysis. Altogether ten areas were selected based on following criteria: 1) the PRC structure is still working as planned , 2) two sample plots – one representing an area affected by flooding (plot 1) and another one representing intact area (plot 2) – could be established within one stand. Further selection was made to obtain stands that were more or less homogeneous, Scots pine dominant, and of similar drained peatland site type. Seven stands represented advanced thinning stands, and three were young thinning stands. Stand volumes ranged from 86 to 154 m^3ha^{-1} (Table 1). The site quality in the data ranged from very good to poor pine sites (Laine and Vasander 2005) (Table 2). All sites were located within a rather small geographical area (Fig. 1).

After marking of the location of the sample plot pairs, their center point elevations and PRC dam top elevations were determined using a precision GPS and a tachymeter in summer 2007 and 2008 (Table 2). The mean distance of the plots was 129 m with range from 62 m to 299 m. The mean distance from the PRC dam to closest plots was 43.5m, ranging from 18 m to 96 m.

2.2 Stand Measurements

The field measurements included measurement of the tree attributes from a variable size sample plots delineated in a way that the total number of trees included in a sample plot was approximately 30 (Gustavsen et al. 1988, Penttilä and Honkanen 1986). All living trees over 4.5 cm in diameter at

1.3 m height above ground (dbh) were inventoried in 0.1 cm accuracy. A smaller sub plot (area 1/3 of that of the sample plot) was superimposed on the larger plot and several sample tree characteristics (e.g., tree height, height growth, crown length, possible diseases) were determined from those trees (n ≥ 10). In order to determine diameter growth, an increment core sample was taken from every Scots pine sample tree to cover the past 15 years' growth. The width of the annual tree rings was measured with accuracy of 0.01 mm using a microscope in the tree ring laboratory of Finnish Forest Research Institute Rovaniemi unit.

The volume (m^3 ha^{-1}) of living trees was calculated in both plots (plot 1 and plot 2) at the time of sampling in August 2009 using the KPL software (Heinonen 1994). Based on tree growth measurements, annual volume growth in each sample plot was calculated to cover a full five-year period after construction of the PCR dam and another five-year period preceding the construction. In the comparison, average growth of both periods was used. The used calendar year periods were 2000–2009 in three stands and 1999–2008 in seven stands (Table 1).

Table 1. Mean, minimum, maximum, and standard deviation of stand characteristics in the data (Plots 1 and 2 combined, n = 10).

Stand characteristic	Mean	Minimum	Maximum	St.dev.
N	858	495	1297	289
G	16.5	13.8	19.8	1.6
H_{Dom}	17.0	14.6	20.3	2.3
V	114.5	86.2	153.7	21.7

N = number of stems (ha^{-1}), G = stand basal area (m^2 ha^{-1}), H_{Dom} = average height of 100 thickest trees per hectare (m), V = stand volume (m^3 ha^{-1})

2.3 Other Measurements

Precipitation was obtained from the Finnish Meteorological Institute's Kolimajärvi-Kellankoski weather station. The mean annual precipitation during the study period (1999–2009) was 609.5 mm. The minimum and maximum values were observed in 2009 (460 mm) and 2008 (789 mm).

To find out the water table level fluctuations during the growing season, water table level (WT) was monitored in the center of plot 1 using water level data logger (TruTrack WT1000) in all sites in 2009. In 2008 eight sites were monitored and in 2007 four sites. Runoff was continuously monitored in four sites (Kivisuo, Kiviselkämä, Ulppaa, and Keuhkosenneva) during growing seasons 2007 and 2008 except in Ulppaa, where monitoring was done only in 2007 (Marttila et al. 2010).

Table 2. Basic information of the study sites and elevation differences between Plot 1 (locating next to the PRC dam) and Plot2 (locating far from the dam) and Plot 1 and the PRC dam top.

Site	North coordinate	East coordinate	Elevation m a.s.l.	Drained peatland site type [1]	Year of PRC dam constr.	Peat thickness, cm	Elevation difference, m	
							Plot2 – Plot1	Plot1 – PRC
dam top								
1 Varissuo1	7011494	3455398	189	PtkgI	2005	115	0.85	0.08
2 Varissuo2	7011621	3455090	187	PtkgII	2005	95	0.15	0.34
3 Pentinniemi	7012202	3454563	177	PtkgII	2005	>150	0.44	0.29
4 Kivisuo	7007377	3448981	120	PtkgII	2005	130	0.07	0.05
5 Kiviselkämä	7003982	3456511	139	PtkgII	2004	90	0.11	–0.23
6 Ulppaa	7002510	3457152	136	PtkgII	2004	108	1.23	–0.06
7 Toivola	7006330	3450124	118	MtkgII	2004	>150	0.08	0.37
8 Toulatsuo1	7006578	3450888	113	Rhtkg	2004	105	0.21	0.38
9 Toulatsuo2	7006307	3451192	113	MtkgII	2004	113	0.29	0.20
10 Keuhkosenneva	7011795	3439174	129	MtkgII	2005	>150	0.00	–0.1

[1] according to Laine and Vasander (2005)

2.4 Methods

In the growth analysis, average five year stand growth after the construction of the dam was used as the response variable. Average growth on plots 1 and 2 was calculated and group means were compared. Then analysis of covariance was made in which the 5-year post-treatment growth was explained by the treatment effect (plot location) and stand volume at the time of PRC dam construction (in the beginning of the five-year period) and the average pre-treatment volume growth. The analysis was carried out with SAS glm procedure (SAS Institute Inc. 2003).

Because the vertical difference of sample plot midpoint elevations was less than 0.1 m in three sites (sites 4, 7 and 10, Table 1), possibility of flooding also on plot 2 existed in these sites. Due to this the statistical analyses were carried out first for all data and then for data where these three sites were omitted.

3 Results

3.1 Growth Analysis

The PRC dam did not have a significant negative effect on tree growth. When all ten sample sites were included in the analysis, the mean five year growth in plots 1 and 2 were on average 4.19 and 4.73 m^3 $ha^{-1}a^{-1}$, i.e., slightly lower growth in stands which were located near the PRC dam (Fig. 2). This difference was non-significant ($p = 0.4854$) due to the relatively large standard error.

The covariance analysis showed that the pre-treatment growth ($p < 0.0001$) and the stand volume at the time of PRC dam construction ($p = 0.0171$) were significant predictors of the post-treatment growth (Table 3). The location effect, in turn, was non-significant ($p = 0.5222$). Based on the covariance model in Table 3, the covariance corrected average growth in plot 1 next to the PRC dam was 4.36 m^3 $ha^{-1}a^{-1}$ and that in plot 2 was 4.56 m^3 ha^{-1} a^{-1}. Consequently, only minor part of growth differences were due to differences in the pre-treatment growth. In these data the used covariates were similarly related to growth in both groups (plots 1 and 2) and use of covariates did not reveal any further differences among the groups in terms of the PRC treatment. Omitting sites 4, 7 and 10 from the data slightly decreased the mean observed differences but re-calculation of the analysis did not change the results.

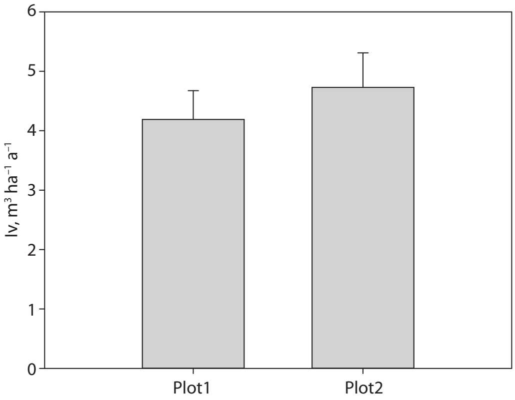

Fig. 2. Mean annual volume growth during the 5-year period after PRC dam construction and the respective standard errors on plots locating next to the PRC dam (Plot 1) and plots locating far from the dam (Plot 2). Differences are statistically non-significant.

Table 3. Estimated coefficients and their standard errors in the Analysis of covariance model for 5-year volume growth of the study stands (n = 10).

Variable	Estimate	s.e.	p
Intercept	2.1435	0.7395	0.0105
I_{v-5}	1.2975	0.1380	<0.0001
V_0	–0.0176	0.0066	0.0616
Location 1	–0.2047	0.3129	0.5222

I_{v-5} = average volume growth of during the five years preceding the PRC-dam construction.
V_0 = stand volume at the time of PRC dam construction.
Location 1 = dummy variable indicating whether the sample plot is located near the PRC dam (value = 1, otherwise = 0)

3.2 Water Table Variations

The water table (WT) measurements showed that in July–August 2009 median WT depth varied from 26 cm to 55 cm below peat surface (average 39.8 cm) (Table 4). In June the WT levels were higher, but even the maximum June mean WT was 24 cm below peat surface (data not shown). In sites 4, 5, 6, and 10 where WT measurements were available starting from late summer 2006, maximum late summer WT levels were observed in 2008. In these sites median WT was on average 16 cm deeper in 2009 than in 2008. In sites 1–3 and 7, water table measurements from July–August 2008 showed that the highest median WT was in site 7 (14 cm).When 2009 median late summer WT levels were plotted against tree stand volumes, no relationship was found (data not shown).

Table 4. The median observed depth of ground water table levels in the study sites in June–August 2006–2009.

Site	Median WT level in June–August, cm below peat surface			
	2009	2008	2007	2006
1 Varissuo1	27	41*		
2 Varissuo2	37	25*		
3 Pentinniemi	26	21*		
4 Kivisuo	51	36	48	54
5 Kiviselkämä	55	37	41	55
6 Ulppaa	37	32	39	37
7 Toivola	30	14*		
8 Toulatsuo1	33			
9 Toulatsuo2	52			
10 Keuhkosenneva	50	23	45	51

* July–August 2008

3.3 Flooding Events

In sites 4, 5, 6, and 10, where runoff and ditch slope measurements had been made, flooding events during spring snow-melt season and also during growing season in 2007–2008 were observed and the corresponding uppermost water levels were calculated (Fig. 3). During spring floods detention volume filled and water level in ditches approached the dam surface. Highest water level during summer seasons (June–August) was noted during extreme rainfall (65

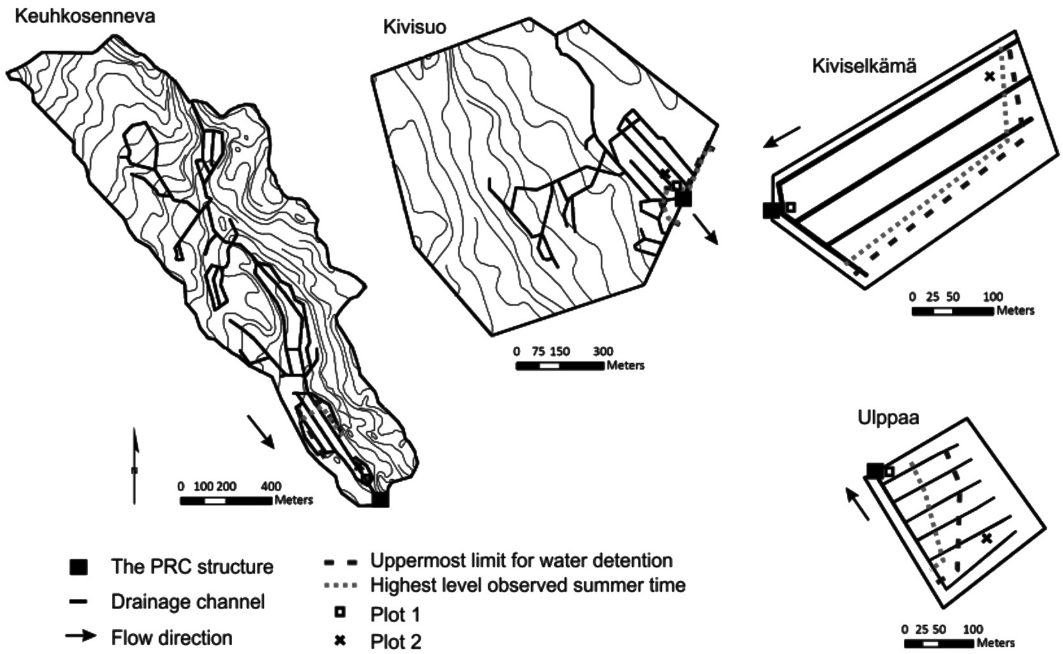

Fig. 3. The uppermost limit for water detention during spring flood conditions (dashed line) and during summer (June–August, dotted line) in Keuhkosenneva, Kivisuo, Kiviselkämä and Ulppaa study areas, where the runoff and ditch slope measurements were available. Location of the sample plots are shown with different symbols.

mm/day on July 21, 2008), when water levels almost reached spring flood conditions. However, a normal high rainfall situation, i.e., 10–20 mm/day caused only water detention at lower part of the ditch network suggesting that damming had only a minor effect on drainage conditions. Since Kiviselkämä area was completely flat, it was the only area, where severe flooding could inundate the whole peatland.

4 Discussion

The analysis indicated no statistical differences in the five-year post treatment growth between the two plots which were at different distances from the PRC dam. In the observed means there was a difference of 0.54 m^3 ha^{-1} a^{-1} in favor of plots locating further away from the dam. Taking into account the covariance correction, the difference was only 0.20 m^3 ha^{-1} a^{-1}. These differences (observed and corrected) were statistically non-significant because of the variability in the data. Omitting sites where the vertical differences between plot 1 and 2 were marginal did not change the results.

The results of this study are in line with those of previous studies which have shown that the early summer high water table levels did not affect tree growth in drained peatland Scots pine forests (Pelkonen 1975, Päivänen 1984). The PRC structure evidently caused spring and summertime flooding, but the events appeared to be short in time. In part of the study areas (sites 4, 5, 6 and 10) also runoff and detention times were monitored (Marttila et al. 2010). According to Marttila et al. (2010), maximum detention time during early summer was 10 days. Some flooding events took place also during later parts of the growing season in the monitored years (2007–2008), but according to Marttila et al. (2010), summertime extreme rainfalls caused a maximum of 2 days detention.

Effects of flooding on trees are mediated through the root system, the suffering of which is most commonly seen in declined shoot and root growth (Glentz et al. 2006). Inundation of the root layer causes a drastic decrease in exchange of oxygen in the soil with consequent changes in vegetative growth and plant anatomy as well as promotion of mortality (Kozlowski 1982, 1997). Most of Scots pine roots in drained peatlands are located within the topmost 20 cm peat layer (Paavilainen 1966). Pelkonen (1975) showed that flooding in early summer does not harm growth of Scots pine. According to Pelkonen (1975) flooding should start in early August and inundate the topmost peat layer for several weeks in late summer in order to cause decreased growth of Scots pine. In the sites where runoff measurements were made, the observed flooding occasions were a way too short to form a threat to tree growth.

Based on results from water table monitoring in plots that were located within the influence of the PCR dam, at least the monthly median water table levels did not reach a level detrimental for tree growth during late growing season (July and August). In 2008 water level was within 20 cm depth in site 7 (Table 5) and near 20 cm depth in sites 3 and 10. Summer 2008 was the coolest and wettest during the study period, which suggests that soil drainage conditions were generally good. In general, tree growth and water table depth of the current year are not closely correlated (e.g., Pelkonen 1975). Instead, long-term mean water table level is correlated with long-term growth (Hökkä et al. 2008). In this study, the water table level measurements were not sufficient to investigate real causalities merely they indicated if there were sites where water table could reach critically high levels.

Recent studies have pointed out that evapotranspiration of tree stand itself has a remarkable influence on soil water table levels in drained peatlands (Sarkkola et al. 2010). Water use of a stocked tree stand may compensate for poor drainage and keep late summer water table levels generally low. No such relationship could be found in this study, possibly due to the narrow range of stand volumes. It is however possible that in most stands there was additional storage capacity in the soil in late summer, making the potential water storage volume essentially larger than that of the volume of the ditches.

All the results from growth differences, water table, and flooding support the hypothesis that water detention in drainage network was short in time and could not cause the PRC method to affect tree growth. This is also the fundamental assumption in the PRC method dimensioning; excessive water detention is avoided using suitable control pipe dimensioning in the dam structure (Marttila et al. 2010). The PRC method is most ideal in conditions with slight surface slope: possible flooding is limited within a small area surrounding the dam. In this study only Kiviselkämä area was completely flat with likelihood to inundate larger areas.

Some reservations on the results can be made. Generally, the five years study period is a short time for trees to respond to ditch network maintenance. Hökkä and Kojola (2002) have shown that the growth response to ditch network maintenance operations peaks within 6–10 years time. It is thus possible that significant growth differences may appear within the next five-year period. Although the observed growth difference (0.54 $m^3ha^{-1}a^{-1}$) is low, it is comparable to the growth response to DNM operation in southern Finland (Ahti 2005) and may be of importance with time. Another point is that the sample size was somewhat limited, and despite the attempts to obtain a homogeneous sample, the random variations in stand and site conditions may have masked differences in growth. In further studies, a larger sample covering a longer post-treatment study period (up to 10 years) is recommended to verify the results.

5 Conclusions

The peak runoff control (PRC) structure can be used to store peak flow water in the ditch network in drained peatland forestry areas. Based on findings of this study, no significant decrease of growth of peatland Scots pine stands in the proximity of the PRC control dam was observed.

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References

Ahti, E. 2005. Kunnostusojitus. In: Ahti, E., Kaunisto, S., Moilanen, M. & Murtovaara, I. (toim.). Suosta suometsäksi. Suometsien ekologisesti ja taloudellisesti kestävä käyttö. Tutkimusohjelman loppuraportti. Metsäntutkimuslaitoksen tiedonantoja 947: 114–120. (In Finnish)

Amatya, D., Skaggs, R., Gilliam, J. & Hughes, J. 2003. Effects of orifice-weir outlet on hydrology and water quality of a drained forested watershed. Southern Journal of Applied Forestry, 27(2): 130–142.

Glenz, C., Schlaepfer, R., Iorgulescu, I. & Kienast, F. 2006. Flooding tolerance of Central European tree and shrub species. Forest Ecology and Management 235: 1–13.

Gustavsen, H.G., Roiko-Jokela, P. & Varmola, M. 1988. Kivennäismaiden talousmetsien pysyvät (INKA ja TINKA) kokeet. Suunnitelmat, mittausmenetelmät ja aineistojen rakenteet. Metsäntutkimuslaitoksen tiedonantoja 292. 212 p. (In Finnish).

Heinonen, J. 1994. Koealojen puu- ja puustotunnusten laskentaohjelma KPL: Käyttöohje. Metsäntutkimuslaitoksen tiedonantoja 504. (In Finnish).

Hökkä, H. & Kojola, S. 2002. Kunnostusojituksen kasvureaktioon vaikuttavat tekijät. In: Hiltunen, A. & Kaunisto, S. (toim.). Suometsien kasvatuksen ja käytön teemapäivät 26.–27.9.2001 Joensuu. Metsäntutkimuslaitoksen tiedonantoja 832: 30–36. (In Finnish)

— , Kaunisto, S., Korhonen, K.T., Päivänen, J., Reinikainen, A. & Tomppo, E. 2002. Suomen suometsät 1951–1994. Metsätieteen aikakauskirja 2B/2002: 1–357. (In Finnish).

— , Repola, J. & Laine, J. 2008. Quantifying the interrelationship between tree stand growth rate and water table level in drained peatland sites within Central Finland. Canadian Journal of Forest Research 38: 1775–1783.

Kløve, B., 2000. Retention of suspended solids and sediment bound nutrients from peat harvesting sites with peak runoff control, constructed floodplains and sedimentation ponds. Boreal Environmental Research 5(1): 81–94.

Kozlowski, T.T. 1982. Water supply and tree growth. Part II Flooding. Forest Abstracts 43(3): 145–161.

— 1997. Response of woody plants to flooding and salinity. Tree Physiology Monograph 1: 1–29.

Laine, J. & Vasander, H. 2005. Suotyypit ja niiden tunnistaminen. Metsäkustanus Oy. 110 p. (In Finnish)

Marttila, H. & Kløve. B. 2009. Retention of sediment and nutrient loads with peak runoff control. Journal of Irrigation and Drainage Engineering 135(2): 210–216.

— & Kløve, B. 2010a. Dynamics of suspended sediment transport and erosion in a drained peatland forestry catchment. Journal of Hydrology 388(34): 414–425.

— & Kløve, B. 2010b. Managing runoff, water quality and erosion in peatland forestry by peak runoff control. Ecological Engineering 36(7): 900–911.

— , Vuori, K.-M., Hökkä, H., Jämsen, J. & Kløve. B. 2010. Framework for designing and applying peak runoff control structures for peatland forestry conditions. Forest Ecology and Management, doi:10.1016/j.foreco.210.06.23.

Nieminen, M., Ahti, E., Koivusalo, H., Mattsson, T., Sarkkola, S. & Lauren, A. 2010. Export of suspended solids and dissolved elements from peatland areas after ditch network maintenance in South-Central Finland. Silva Fennica 44(1): 39–49.

Paavilainen, E. 1966. Maan vesitalouden järjestelyn vaikutuksesta rämemännikön juurisuhteisiin. Summary: On the effect of drainage on root systems of Scots pine on peat soils. Communicationes Instituti Forestalis Fenniaea 61(1). 110 p.

Päivänen, J. 1984. The effect of runoff regulation on tree growth on a forest drainage area. Proc. 17th Int. Peat Congr., Irish Nat. Peat Comm., Dublin 3: 476–488.

Pelkonen, E. 1975. Vuoden eri aikoina korkealla olevan pohjaveden vaikutus männyn kasvuun. Effects of Scots pine growth of ground water adjusted to the ground surface for periods of varying length during different seasons of the year. Suo 26(2): 25–32. (In Finnish, summary in English)

Penttilä, T. & Honkanen, M. 1986. Suometsien pysyvien kasvukoealojen (SINKA) maastotyöohjeet. Metsäntutkimuslaitoksen tiedonantoja 226. 98 p. (in Finnish)

Sarkkola, S., Hökkä, H., Koivusalo, H., Nieminen, M., Ahti, E., Päivänen, J. & Laine, J. 2010. Role of tree stand evapotranspiration in maintaining satisfactory drainage conditions in drained peatlands. Canadian Journal of Forest Research 40: 1485–1496.

SAS Institute Inc. 2003. SAS OnlineDoc. SAS Institute Inc., Cary, NC, USA (version 9.1).

Späth, V. 1988. Zur Hochwassertoleranz von Auenwaldbäumen. Natur und Landschaft 63(6): 312–314.

— 2002. Hochenwassertoleranz von Waldbäumen in der Rheinaue. AFZ-Der Wald 15: 807–810.

Tuononen, E., Vähäsöyrinki, E. & Österlund, P. 1981. Vedenkorkeusvaihteluiden vaikutus rantamaiden viljelyyn ja puustoon. English summary: Effects of water level fluctuations on land cultivation and on the stand of trees on lake shores. Vesihallitus. Tiedotus 206. (In Finnish)

Total of 26 references