Tree Growth in an Area Subsided due to Mining Activities in Northeast Estonia

ALAR LÄÄNELAID[*1] **AND DIETER ECKSTEIN**[2]

[1*] *Department of Geography, University of Tartu, Estonia, E-mail: alar.laanelaid@ut.ee*

[2] *Department of Wood Science, University of Hamburg, Germany, E-mail: d.eckstein@holz.uni-hamburg.de*

Läänelaid, A. and Eckstein, D. 2010. Tree Growth in an Area Subsided due to Mining Activities in Northeast Estonia. *Baltic Forestry* 16 (1): 180–186.

Abstract

The radial growth of altogether 105 trees of spruce, pine, birch, aspen, black alder and rowan, growing in an area subsided due to mining activities in northeast Estonia, was measured. The tree-ring series were cross-dated and averaged according to tree species, and a possible influence of the surface deformation on tree growth was looked for. For the same reason, the annual basal area increment was calculated. It appeared that the subsiding event in 1998 has mostly resulted in an increase rather than a decrease of tree growth.

Key words: Tree-ring width, basal area increment, surface subsidence, mining, NE Estonia

Introduction

In northeast Estonia, underground mining for oil shale has taken place for decades in an area of about 400 km^2, of which 220 km^2 lie underground (Eesti Põlevkivi… 2007). Approximately one billion tons of oil shale has been extracted over more than 80 years. Oil shale is mined for four large consumers nearby. The earliest power station at Kohtla-Järve has operated on oil shale fuel since 1949. Apart from air pollution due to burning the oil shale in the power stations, oil shale mining has caused changes in the landscape and in its hydrology.

In our study area, the longwall mining method has been applied to extract oil shale from a depth of about 30 m. Longwall mining is a form of underground mining where a long wall of coal or oil shale is mined in a single slice (typically 1-2 m thick). The coal is cut from the coalface by a socalled shearer. As this shearer removes the coal, the powered roof supports move forward into the newly created cavity. As mining and the entire longwall progresses, the roof of the mining gallery is allowed to collapse (Wikipedia); in the following referred to as 'subsiding event'. Collapsed underground cavities have caused a deformed landscape surface of fields and forests with lowered rectangular areas separated by stripes of a higher relief (Reinsalu et al. 2002). The height difference of the land surface due to this subsidence is 1 - 1.5 m. Sometimes the surface subsidence changes the hydrology of the area; some areas become flooded, whereas others become better drained. Some trees on the newly-formed slopes are tilted. It is not clear whether the influence of the surface subsidence is favourable to tree growth or not. A pure visual assessment of the state of forest on a subsided mining area may lead to a controversial picture and to wrong conclusions.

According to Alestalo (1971) and Gärtner (2007) a dendrogeomorphological investigation could help to detect and assess the influence of underground mining to the forest. Dendrogeomorphological methods (Shroder 1980) were applied, for example, in Poland (Krapiec and Margielewski 1991) and in the USA (Yanosky and Kappel 1997). Examples of assessment of geological hazards like landslides and others using tree-ring analysis have been shown by Degraff and Agard (1984).

We studied the growth of trees at a subsided forest area in the Kohtla mining field in northeast Estonia based on tree-ring widths and basal area increments.

Study site and trees

Seven years after closing the underground mine of oil shale at the Kohtla mining field (Figure 1a, b), the relief of the landscape looked as portrayed in Figure 1c. Whereas tilted pines and spruces on the newly-formed slopes were studied previously (Läänelaid et al. 2009), the current study focuses on trees growing in a sunken area. In such a subsided forest, three circular plots with a radius of 10 m each were estab-

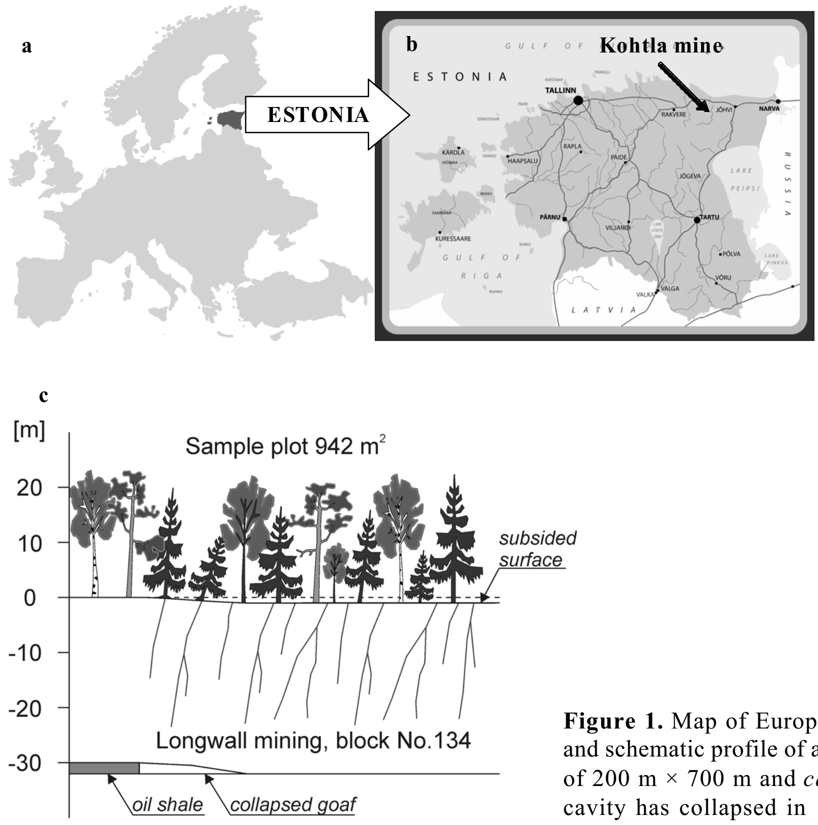

Figure 1. Map of Europe (a), location of the Kohtla mining area (b) and schematic profile of an abandoned longwall mining field (c); blocks of 200 m × 700 m and *ca.* 30 m thick have subsided after the mining cavity has collapsed in 1998

lished. They were located side-by-side in a south-to-north direction and represented uniform growth conditions for the trees. The vegetation is a mixed forest of conifers (pine and spruce – species names given in Table 1) and fine-leaved deciduous tree species (birch and aspen) on moist soil. Field layers (*Vaccinium myrtillus, Rhodococcum vitis-idaea, Pyrola minor, Luzula pilosa, Trientalis europaea, Maianthemum bifolium*) occur only in patches under a thick spruce canopy. The moss layer (mainly consisting of *Hylocomium splendens*) is scarce. In each sample plot, all trees were cored along the northern and southern radii at breast height of the trunk, except those with a perimeter = 25 cm which were only counted. A total of 105 trees of six species were cored during the summer season of 2005 (Table 1).

Table 1. Number of trees on the sample plots within a radius of 10 m; total area of all three plots is 942 m²

Tree species	Plot 1	Plot 2	Plot 3	Total
Norway spruce *Picea abies*	18	18	19	55
Scots pine *Pinus sylvestris*	1	11	3	15
Downy birch *Betula pubescens*	5	4	12	21
Aspen *Populus tremula*	3	4	3	10
Black alder *Alnus glutinosa*	-	2	1	3
Rowan *Sorbus aucuparia*	-	-	1	1
Total	27	39	39	105

Methods

The tree-ring widths of the trees were measured along two radii with a precision of 0.01 mm using a Lintab measuring device and archived by program TSAP (Time Series Analysis and Presentation for Dendrochronology and Related Applications) (Rinn 2003). The ring-width series were plotted as semi-logarithmic graphs and cross-dated on a light table for the detection of possibly missing rings and measurement errors. If necessary, the tree-ring series were re-checked on the cores and corrected. After successful cross-dating, the tree-ring series along two opposite radii were averaged for each tree. Next, all such mean tree-ring series were cross-dated and averaged according to tree species. Beyond that, the basal area increment (BAI) for all trees was calculated and added up for three intervals. As the land subsidence ('subsiding event') very likely took place in 1998, these intervals were 1984-1990, 1991-1997 and 1998-2004.

All relevant results are visually evaluated based on their graphical illustration in Figures 2-5.

Results

The tree-ring series of the sample trees provided the tree ages and the annual radial increment throughout the lifetime of the trees, including the subsiding event in 1998. The oldest trees were birches (the longest tree-ring series begins in 1901). They are followed by pine (since 1910), black alder (since 1914), spruce (since 1923) and aspen (since 1927); the only rowan tree has 62 rings (since 1943). Spruces make up the greatest number of trees, 55.

To evaluate the growth patterns of the individual trees, graphs of their cross-dated tree-ring width series were drawn (Figure 2a); the average tree-ring width series per species are shown in Figure 2b. As the tree-ring widths fluctuated considerably from year to year along a pronounced decreasing age trend, we also used the BAI, which is less dependent on the age trend. The BAI, separated by tree species and by three 7-year intervals (Figure 3), increased notably after the subsiding event, i.e., from 1998-2004, except the rowan tree which grew slowly during all three periods. The main increase of the BAI comes from spruce (165 % in comparison to the previous period) and aspen (126 %).

We also considered the temporal dynamics of the number of trees (with a circumference = 25 cm) growing in the sample plots (Figure 4). Since the beginning of the 20th century when the oldest trees started to sprout, the number of trees has increased until 1961-65 and then stabilized at 105 up to the present. Adding of young trees was most intense from 1941-45 (22 seedlings). These seedlings were mostly spruces. Besides, there are 13 spruces in the sample plots of a perimeter = 25 cm which were not cored; extrapolating their age from the age/perimeter relationship of spruces (Figure 5), these trees are about 50 years old and hence appeared at the site around and after 1955. Thus, regeneration occurred in the middle of the 20th century and ceased afterwards. There were no fresh stumps of cut trees on the sample plots. However, we cannot exclude that some trees may already have died decades ago. The owner of the forest (personal comm.) has logged some of them.

Discussion and conclusions

Much research has been conducted throughout the world regarding the restoration of abandoned open-cast mines (e.g., Reintam and Kaar 2002). Although there are methods for the investigation of forest decline and environmental assessment (e.g., Eckstein 1985, Kairiūkštis et al. 1992, Läänelaid 1994, Schweingruber 1996, Kuzmin and Kuzmina 2000, Stravinskiene 2000), the vegetation on abandoned underground mines has not been studied thoroughly (Rull et al. 2005). This may be due to the assumption that underground mining does not harm the landscape lying above it what may be true for deep underground mines.

In northeast Estonia, however, the oil shale ore layer lies at depths of only a few dozen meters. The exhausting of ore from that depth is followed by a collapse of the underground cavity which in turn is followed by a deformed land surface. In the case of mining in a depth of 30-36 m there will be no surface fissures; the rate of subsidence is 30 mm/h in the first 1.5 hours and reaches nearly zero during three months (Allik 1958, *cit.* Reinsalu et al. 2002). No doubt that such change is also reflected in the water regime and vegetation of the area. The geomorphic disturbances due to ground subsidence in the Kohtla mining area are associated with ground instability and changed water availability. Banks (1991, 1992) has characterised such disturbances according to whether their persistence in the ecosystem is of short- or long-term duration; the effect of most uni-seasonal disturbances, such as soil displacement, is transitory, whereas the influence of water table fluctuations may persist for longer periods. Kaiser and Kaiser-Bernhard (1987) have studied the effect of the Alaska earthquake in 1964 on tree growth. This earthquake caused ground subsidence by 1.37 m with a possible change in the soil-water balance that produced a persistent growth reduction in Sitka spruces. Another study deals with effect on tree growth by movements on the San Andreas Fault in Northern California (LaMarche and Wallace 1972).

Liblik and Punning (2005) carried out geodetic and geologic research on abandoned mining areas with sunken surfaces. The influence of underground mines on agricultural fields has been assessed by Põlevkivi… (2003) and Soovik (2004) and on forests has been shown in expert reports (Soovik 2003, Toim and Velström 2003).

The growth of spruce and pine on an abandoned underground mining area at Kohtla has been studied earlier by Läänelaid et al. (2009); the sample trees were conifers on three types of sites – a slope formed along a subsiding surface, a subsided area above the mine, and unchanged land between subsided areas (as a control). After a short "shock" by the land movement, the spruces on all three types of sites recovered fast and mostly formed tree rings even wider than before, while the radial increment of pines did not change notably after the subsiding event. By the subsiding of the land surface, many trees became tilted which in turn induced

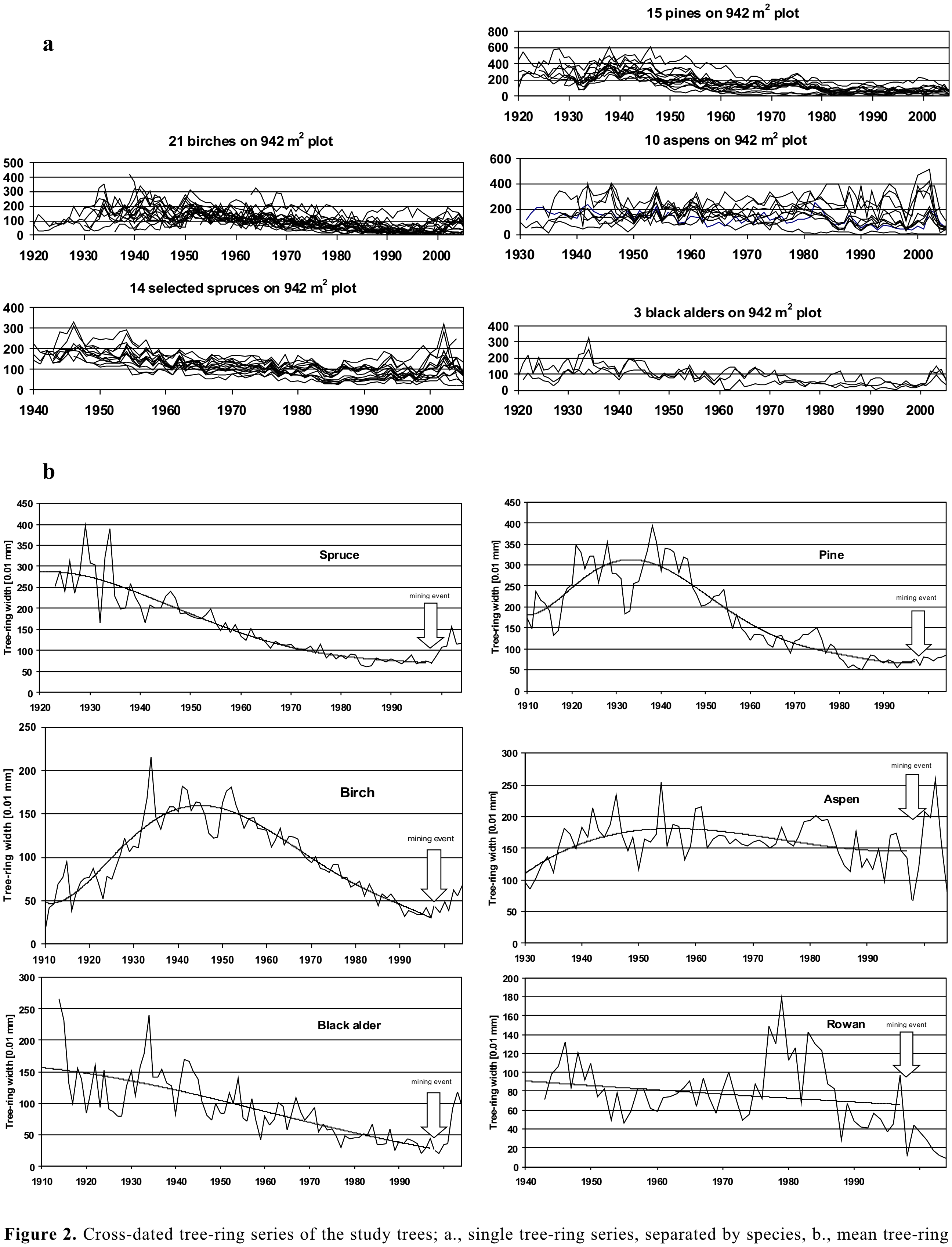

Figure 2. Cross-dated tree-ring series of the study trees; a., single tree-ring series, separated by species, b., mean tree-ring series, averaged by species

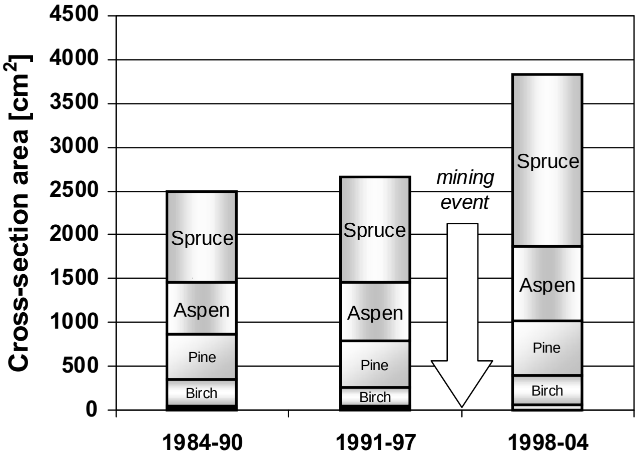

Figure 3. Basal area increment (BAI) of all tree species during three 7-year periods before and after the subsiding event in 1998; alder and rowan as comprising the smallest BAI are not named in the figure

The present study gave us the opportunity to follow the increment history of all trees in a forest throughout their lifetime. After the subsiding event, the annual radial increment of all tree species as well as their BAI increased, but with species-specific different intensities, the strongest increase is with spruce; the sole rowan tree is not considered here.

Due to the known history of mining and the results of our observations, we can hypothetically outline the development of the forest in that area. Before the onset of the mining activities in the beginning of the 20th century, the area was a nearly treeless mire covered with scattered birches (the oldest trees in the sample plot) (Sokman, pers. comm.). The irrigation system established for the mining lowered the water table and hence brought along an intense melioration of the area, so that the regeneration of trees (mostly spruces) actually meant an afforestation of the mire.

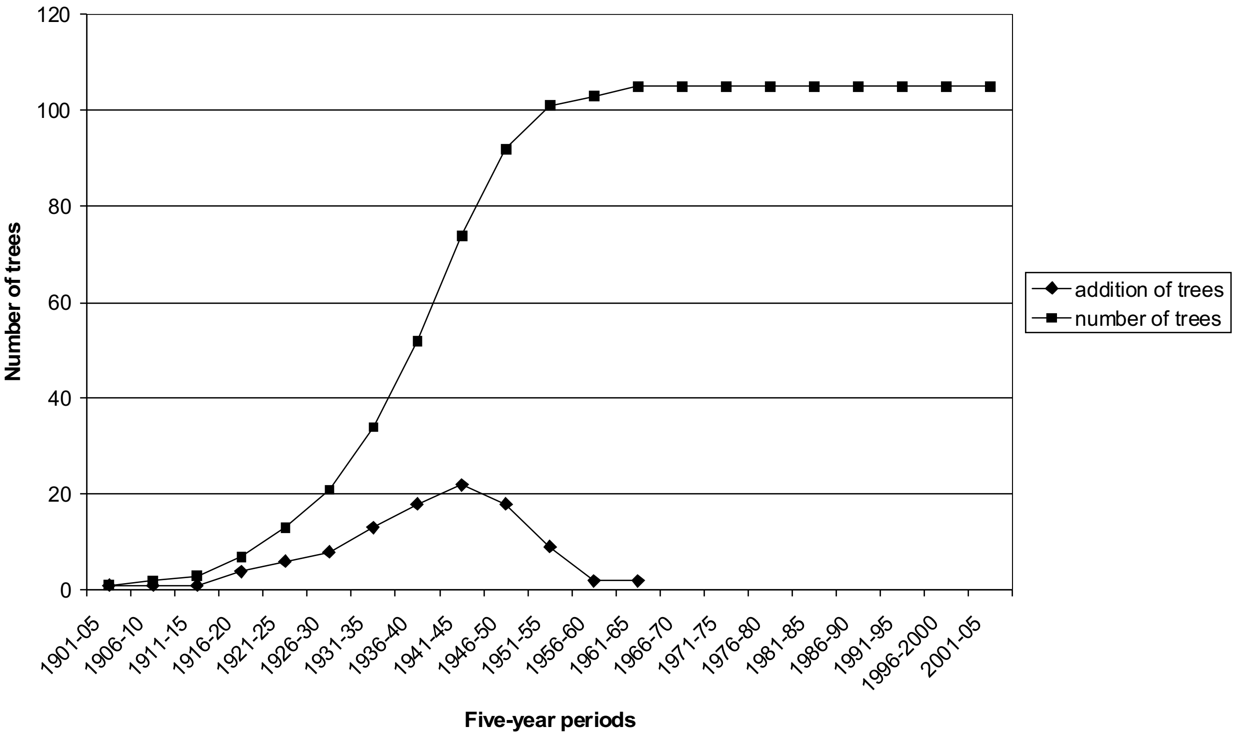

Figure 4. Cumulative number of trees in the sample plots over time (upper curve) and the addition of new tree individuals (lower curve); dead and felled trees could not be taken into account

the formation of compression wood – going along with wider tree rings – on the lower side of the leaning stems; this phenomenon has been repeatedly described earlier (e.g., Haller 1935, Westing 1965, Alestalo 1971, Scurfield 1973, Heikkinen 1994, Gärtner 2007). However, the formation of compression wood does not explain all the increment enhancement of the spruces.

The onset period of most of the present trees, especially spruces, was between 1926 and 1945. The amount of oil-shale mining.increased rigorously after the 2nd World War until the 1970s (Reinsalu 2006). However, since the 1960s, the germination of new trees was seriously hindered because the spruces have meanwhile grown up to a closed canopy forest. After the

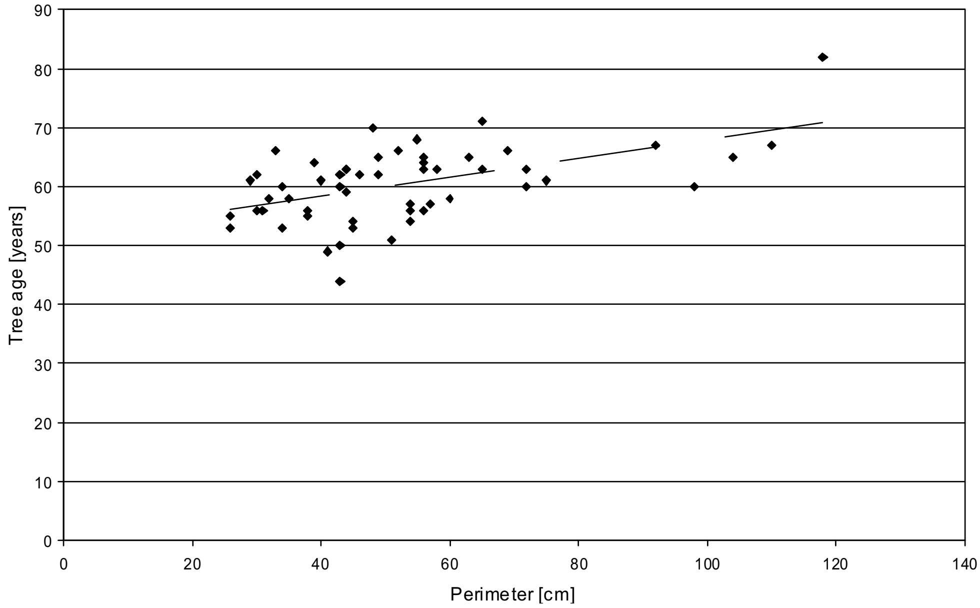

Figure 5. Trunk perimeter *versus* age of spruce trees; the extrapolated approximate age of the spruces with a perimeter = 25 cm is 50 years

subsiding event in 1998, the irrigation system was not maintained any more. This would have meant a deterioration of the growing conditions of the trees unless ground fissures along the fault lines had occurred. Such fissures may have improved the aeration of the soil and also lowered the ground water table. The duration of such a favourable growth period due to improved aeration and lowered ground water is not clear. In any case, the composition of the forest seems to have been left nearly unchanged after the subsiding event.

This consideration does not purport to be forest management research. Our aim rather was to establish whether or not the subsiding event in 1998 damaged forest growth.

Acknowledgements

The authors wish to express their thanks to the head of the Environmental Department of Eesti Põlevkivi Ltd., Kalmer Sokman, for providing information about the history of the mining area; to Vivian Uibo and Vallot Läänelaid for sampling in the subsided forest, to Jeong-Wook Seo and Ivan Sopushynskyy for providing valuable advice. Our research was supported by the mining company Eesti Põlevkivi Ltd.

References

Alestalo, J. 1971. Dendrochronological interpretation of geomorphic processes. *Fennia* 105, 140 pp.

Allik, A. 1958. Eesti põlevkivi leiupaiga mäerõhu nähtuste mõningate uurimistulemuste kasutamisest praktikas [The rock pressure appearances study some results practical use in the Estonian oil shale deposit]. Mäeühingu Tehnika Bülletään, EVTT Mäeühing, Jõhvi, p. 14-26 (in Estonian).

Banks, J.C.G. 1991. A review of the use of tree rings for the quantification of forest disturbances. *Dendrochronologia* 9: 51-70.

Banks, J.C.G. 1992. A Review of the use of tree rings for the quantification of forest disturbances. In: Bartholin, T.S., Berglund, B.E., Eckstein, D., Schweingruber, F.H. and Eggertsson, O. (Editors), Tree Rings and Environment. Proceedings of the International Dendrochronological Symposium, Ystad, South Sweden, 3-9 September, 1990. Lund University, Department of Quaternary Geology, Sweden, Lundqua Report 34: 3-13.

Degraff, J.V. and Agard, S.S. 1984. Defining geologic hazards for natural resources management using tree-ring analysis. Environmental Geology, Springer Berlin/Heidelberg 6, No. 3, 147-155.

Eckstein, D. 1985. On the application of dendrochronology for the evaluation of forest damage. In: Inventorying and Monitoring Endangered Forests. Proc. IUFRO Conf., Zürich, 1985: 287-290.

Eesti Põlevkivi [Estonian oil shale] Ltd. and environment, 2007. Web page at http://www.ep.ee/?id=4306http://www.ep.ee/?id=4306

Gärtner, H. 2007. Dendrogeomorphology. In: Elias, S.A. (Editor), Glacial landforms, tree rings. Encyclopedia of Quaternary Sciences 2, Elsevier, p. 979-988.

Haller, B. 1935. Uurimusi okaspuude ekstsentrilisest jämedusekasvust [Investigations on eccentric radial increment of conifers]. Tartu Ülikooli Metsaosakonna Toimetused Nr. 24. Tartu, 162 pp. + Tables (in Estonian).

Heikkinen, O. 1994. Using dendrochronology for the dating of land surfaces. In: Beck, C. (Editor), Dating in exposed and surface context. University of New Mexico Press, Albuquerque, p. 213-235.

Kairiūkštis, L., Skuodiene, L., Vaičys, M., Ozolinčius, R., Armolaitis, K., Petniūnas, V., Stravinskiene, V., Grigaliūnas, J. and Kilikevičius, G. 1992. Methods of forest decline and environment assessment: application in regional monitoring. Kaunas, Girionys, 62 pp.

Kaiser, K.F. and Kaiser-Bernhard, C. 1987. The Katmal eruption of 1912 and the Alaska earthquake of 1964 as reflected in the annual rings of Sitka spruces on Kodiak Island. *Dendrochronologia* 5: 111-124.

Krapiec, M. and Margielewski, W. 1991. Use of dendrogeomorphological analysis in age determination of surface mass movements. Zeszyty Naukowe AGH, *Geologia* 17: 67-81.

Kuzmin, A.V. and Kuzmina, L.I. 2000. Elaboration of the methodical complex structure and an empirical basis for analysing many years dynamics of developing coniferous stands in the regional scope. In: Kolström, T., Lindholm, M., Viinanen, R. (Editors). Conifer growth variability during the Holocene in Northern Europe. University of Joensuu, Faculty of Forestry, Research Notes 108: 65-77.

Liblik, V. and Punning, J.-M. (Editors) 2005. Keskkond ja põlevkivi kaevandamine Kirde-Eestis [Environment and oil shale mining in north-east Estonia]. Ökoloogia Instituut, Tallinna Ülikool, Publikatsioonid 9. Tallinn, 226 pp. (in Estonian).

Läänelaid, A. 1994. A dendrochronological study of decline of pine stands in South Estonia. *Proceedings of Estonian Academy of Sciences: Biology* 43: 89-97.

Läänelaid, A., Eckstein, D. and Seo, J.-W. 2009. Impact of underground mining of oil shale in Northeastern Estonia on Scots pine and Norway spruce growing thereon. *Oil Shale* 26: 73-83.

LaMarche, V.C. and Wallace, R.E. 1972. Evaluation of effects on trees of past movements on the San Andreas Fault, Northern California. Geological Society of America Bulletin 83: 2665-2676.

Põlevkivi [Oil Shale] allmaakaevandamisest tingitud mõju hindamine põllumajandusmaa viljelusväärtusele [Assessment of impact of underground mining of oil shale on productivity of the agricultural land]. Lepingu nr 1027/EP VI etapi lõpparuanne. Eesti Maaviljeluse Instituut, Saku 2003. 17 pp. (unpubl.) (in Estonian).

Reinsalu, E. 2006. Eesti põlevkivikaevandamise ajaloo säilitamisest ja avalikustamisest [Conservation and publication of the history of the Estonian oil shale mining]. In: Valgma, I. (Comp.) 90 aastat põlevkivi kaevandamist Eestis. Tallinn, p. 7-8 (in Estonian).

Reinsalu, E., Toomik, A. and Valgma, I. 2002. Kaevandatud maa [Mined country]. TTÜ mäeinstituut, 97 pp. (in Estonian).

Reintam, L. and Kaar, E. 2002. Natural and man-made afforestation of sandy-textured quarry detritus of open-cast oil-shale mining. *Baltic Forestry* 8: 57-62.

Rinn, F. 2003. TSAPWin, Software for Tree-Ring Measurement, Analysis and Presentation. Rinntech, Heidelberg. http://www.rinntech.com/Products/Tsap.htm

Rull, E., Liblik, V. and Pensa, M. 2005. Muutused deformeerunud maapinnaga metsaalade taimkattes [Changes in the plant cover of deformed forest areas]. In: Liblik, V. and Punning, J.-M. (Editors), Environment and oil shale mining in north-east Estonia. Publication 9. Tallinn, p. 88-95 (in Estonian).

Shroder, J.F. 1980. Dendrogeomorphology – review and new techniques of tree-ring dating. *Progress in Physical Geography* 4: 161-188.

Schweingruber, F.H. 1996. Tree Rings and Environment. Dendroecology. Birmensdorf, Swiss Federal Institute for Forest, Snow and Landscape Research. Berne, Stuttgart, Vienna, Haupt, 609 pp.

Scurfield, G. 1973. Reaction wood – its structure and function. *Science* 179: 647-655.

Soovik, E. 2003. Kohtla ja Ahtme kaevandusel 13 maaüksuse metsa ja metsamaa inventuur allmaakaevandamise mõju hindamiseks [Inventory of 13 grounds on Kohtla and Ahtme mines for assessment of the effect of underground mining]. AS Kohtla Mining (unpubl.), 10 pp. (in Estonian).

Soovik, E. 2004. Kaevanduste tegelik mõju [The actual impact of mines]. *Eesti Loodus* 7: 39 (in Estonian).

Stravinskiene, V. 2000. Dendrochronological indication of climatic factors and anthropogenic environmental trends in Lithuania. Summary of Dr. Habilitation Dissertation. Biomedical Sciences (000B), Ecology and Environmental Sciences (03B). Kaunas, 43 pp.

Toim, L. and Velström, J. 2003. Eksperdi arvamus [An expert's opinion]. 02.07.2003. AS Kohtla Mining, 3 p. + supplements (unpubl.) (in Estonian).

Westing, A.H. 1965. Formation and function of compression wood in gymnosperms. The *Botanical Review* 31, 3: 381-480.

Yanosky, T.M. and Kappel, W.M. 1997. Effects of solution mining of salt on wetland hydrology as inferred from tree rings. *Water Resources Research* 33: 457-470.

Received 16 December 2009
Accepted 18 June 2010

ПРИРОСТ ДЕРЕВЬЕВ В ЗОНЕ ПРОВАЛА БЫВШЕЙ ШАХТЫ В СЕВЕРО-ВОСТОЧНОЙ ЭСТОНИИ

А. Ляэнелайд и Д. Экштайн

Резюме

В зоне провала бывшей шахты Кохтла в северо-восточной Эстонии было измерен годовой прирост ели, сосны, березы, черной ольхи и рябины, всего 105 деревьев. Ряды ширин годовых колец были перекрестно датированы и усреднены по видам деревьев с целью выявления возможного влияния осадки грунта. Для этого был рассчитан площадной годовой прирост на высоте опробования - 1,3м. В результате установлено, что происшедшая в 1998 году осадка грунта, скорее всего, увеличивала радиальный прирост деревьев, нежели уменьшала.

Ключевые слова: ширина годовых колец, площадной прирост, осадка грунта, разработка месторождений, северо-восточная Эстония