Oil Shale, Vol. 14, No. 3
pp. 409-418

ISSN 0208-189X

https://doi.org/10.3176/oil.1997.3.08

CHANGES IN A FOREST LANDSCAPE AFFECTED BY ALKALINE INDUSTRIAL DUST

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The impact of strongly alkaline dust emitted from the cement industry on the environment was studied in natural forest ecosystems. The accumulation of Ca, K, Mg and trace metals in precipitation (snow, rain) and in upper horizons of forest soil is in good correlation with the total air pollution load. As a result of the alkalization of environment, the mobility and solubility of some contaminants has decreased, and nutrition processes of vegetation have become complicated. This has brought about a decrease in the volume increment of forest stands and changed the initial composition of forest stands with an Oxalis-Myrtillus dominated understorey.

This paper introduces the research conducted over ten years on the general topic of the impact of the pollution from the cement industry to the environment. The investigations have been carried out on a territory influenced by a cement plant in north-east Estonia (Kunda).

Introduction

A number of physical and chemical characteristics of dust are important in considering its impact on the forest ecosystem. Experimental results have shown that the effect of dust may be neutral, stimulating or toxic [1], depending on the type of dust, concentration of its components, the level of its deposition, and meteorological conditions.

Dust emitted by the building material industry is classified as not essentially toxic or only relatively toxic to vegetation. Some earlier authors have recommended the cement-kiln dust as a fertilizer or neutralizer of acid soils [2, 3]. Most researchers have emphasized the deleterious effect of cement-kiln dust on vegetation [4-7].

Study Area and Characteristics of Pollution

The main research area was a territory in north-east Estonia surrounding the cement plant in Kunda. This area is rich in coniferous and mixed forests. Twenty-two sample plots of pine and spruce stands with an *Oxalis-Myrtillus* dominated understorey were chosen for investigation taking into account edaphic, meteorological, structural, and age similarities of sites (Fig. 1).

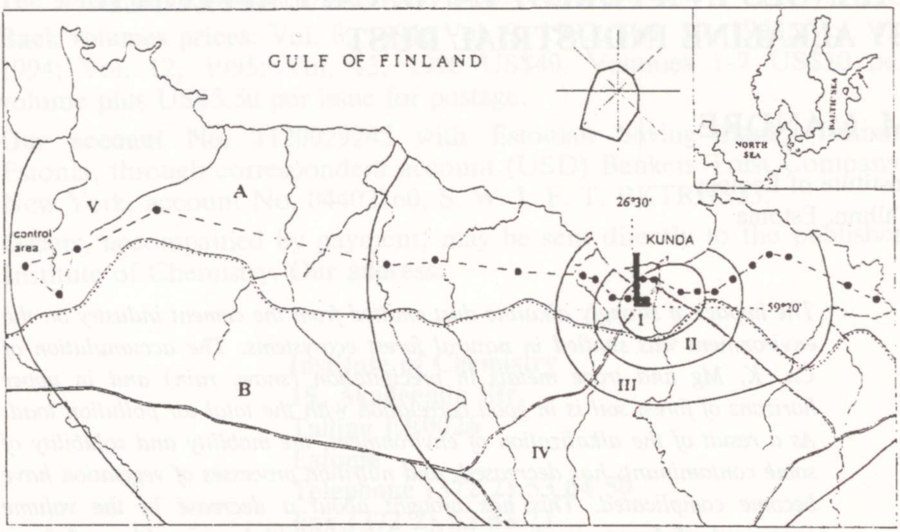

Fig. 1. The study area. Zones based on changes in forest ecosystems depending on the level of air pollution load at different distances from the cement plant: I - strong changes (0-2 km W, 0-3 km E); II - significant changes (2-3 km W, 3-5 km E); III - moderate changes (3-5 km W, 5-10 km E); IV - slight changes (10-15 km W, <10 km E); V - control area (34-38 km W) [8]. Landscape regions [9]: *A* - North-Estonian coastal plain; *B* - Northeast-Estonian plateau. ——— border of landscape regions; •---• sample plots and transect for forest investigation

In order to characterize technogenic changes in the geocomplexes we used relative numbers or parameters to express the qualitative alterations in a certain property of a geocomplex or its components with regard to the respective exponent of the forest ecosystem in a technogenically not influenced area. The field studies were carried out in 1987-94.

The production of cement in Kunda started in 1871. After the last reconstruction in 1960, cement production fluctuated between 0.5-1.2 million t yr^{-1}. The cement production process in Kunda is a standard wet process, except that the fuel is domestic oil shale, instead of coal or fuel oil. Oil shale is well suited to be used as a fuel in cement production because after burning in the kilns, the oil shale ash serves as a raw material for making cement. The main raw materials for cement production are limestone, clay and oil shale. The emission of air pollutants by that plant has been considerable and concrete loads have depended on the production level (Fig. 2).

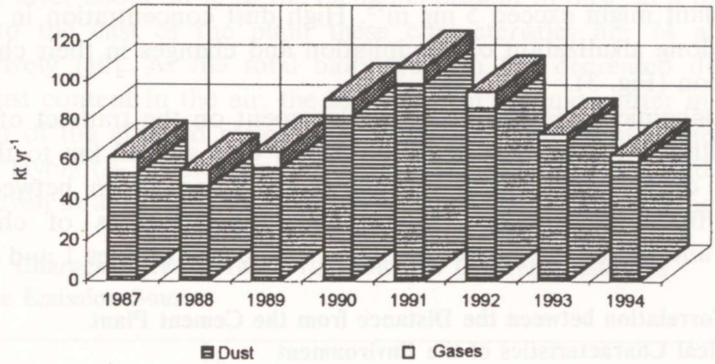

Fig. 2. Emission of dust and gaseous pollutants into the atmosphere from the cement plant in Kunda

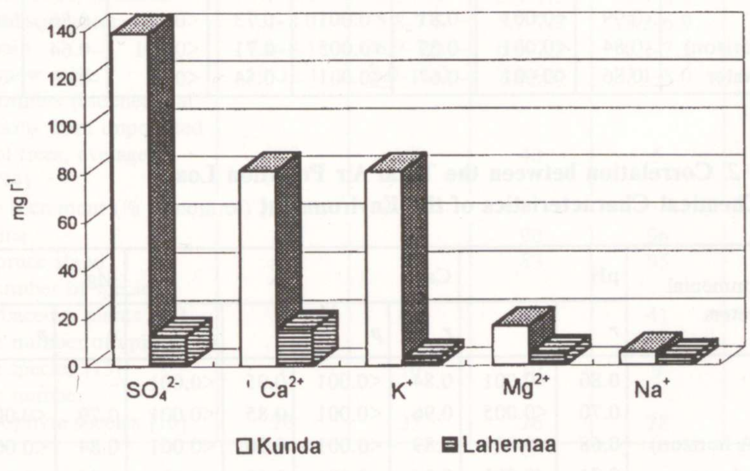

Fig. 3. Chemical characteristics of rainwater from areas influenced by cement dust in Kunda and relatively unpolluted Lahemaa National Park. Averages in 1984-94

Physical and chemical impacts of dust from the cement industry cause considerable changes in the environment and in the functioning of the ecosystems.

Cement dust from electric filters contains a complex of substances: 40-50 % CaO; 12-17 % SiO_2; 6-9 % K_2O; 4-8 % SO_3; 3-5 % Al_2O_3; 2-

4 % MgO; 1-3 % Fe_2O_3, and also small amounts of Mn, Zn, Cu, Cr, V, As, Ba, Pb, etc. Its pH is 12.3-12.6 [8].

Dust fallout at a distance of about 1-1.5 km from the emission source reached 1800-2400 g m^{-2} yr^{-1} until 1993, depending on the direction and velocity of winds, on the size of dust particles, and on the intensity of industrial production. The amount of dust in the air in the vicinity of the cement plant might exceed 5 mg m^{-3}. High dust concentration in the air brought along alkalization of precipitation and changes in their chemical composition (Fig. 3).

Biogeochemical changes in the environment on the transect of about 50 km within a distance of 30-38 km to the west and 12 km to the east from the cement plant were studied. A good correlation between the distance from the emission source and concentrations of chemical elements and pH of the environment was elucidated (Tables 1 and 2).

Table 1. **Correlation between the Distance from the Cement Plant and Chemical Characteristics of the Environment**

Environmental parameters	pH		Ca		K		Mg	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Snow	-0.80	<0.001	-0.82	<0.001	-0.63	<0.001	-0.51	<0.01
Rain	-0.99	<0.001	-0.81	<0.001	-0.73	<0.005	-0.86	<0.001
Soil (A horizon)	-0.84	<0.001	-0.59	<0.005	-0.71	<0.001	-0.64	<0.001
Ground water	-0.86	<0.001	-0.67	<0.001	-0.54	<0.05	-0.66	<0.001

Table 2. **Correlation between the Total Air Pollution Load and Chemical Characteristics of the Environment**

Environmental parameters	pH		Ca		K		Mg	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Snow	0.80	<0.001	0.84	<0.001	0.95	<0.001	-	-
Rain	0.70	<0.005	0.96	<0.001	0.85	<0.001	0.79	<0.001
Soil (A horizon)	0.68	<0.001	0.89	<0.001	0.90	<0.001	0.84	<0.001
Ground water	0.71	<0.001	0.84	<0.001	0.68	<0.001	0.76	<0.001

Soil

Soil is the recipient of dry and wet deposits of pollutants. The wastes from a cement plant cause a significant rise in the content of the predominant elements of dust in the Gleic Podzols on sands of the region surrounding the cement plant. Significant correlations between pH, Ca, K, and Mg in the humus horizon of soil, and the distance from the emission source and the total air pollution load were revealed statistically (Tables 1 and 2).

An especially high accumulation of dust components characterizes the litter horizon of forests. While in a natural, unpolluted geocomplex the upper, 0-2 cm layer of the litter horizon contains 11 %, and the deeper, 3-7 cm layer about 30 % of the elements present in dust, at a distance of 2 km to the east of the plant these characteristics are 74 and 61 %, respectively [10]. As the total bioproduction has decreased due to the high dust content in the air, the formation of organic matter in the litter horizon of the affected region is also inhibited. The dust content in the deeper layers (3-7 cm) increases to abnormally high levels, and this may occur even at a distance of 10 km in the direction of dominating winds.

Table 3. **Characteristics of Territorial Zones at Different Distances from the Emission Source**

Characteristics	Impact zones				
	I 0-1.5 km W 0-3 km E	II 2-3 km W 3-5 km E	III 3-5 km W 5-10 km E	IV 5-15 km W >10 km E	V 30-38 km W
pH of soil A_0A_1 horizons	7.7-8.1	5.5-7.4	5.4-7.3	3.9-6.8	2.9-3.1
pH of subsoil water	7.1-8.0	5.8-7.5	5.7-7.3	5.2-6.9	4.9-5.1
pH of rain	7.6-8.1	6.9-7.9	6.6-7.5	6.2-7.3	5.6-6.5
pH of snow melt	10-12.1	8.0-11.0	7.9-9.0	7.1-8.0	6.3-6.5
BI of conifers (biochemical deviations from unpolluted control trees, average 1991-94)	207	150	40	5	0
Volume increment (% of control) [13]:					
of pine	52	89	90	96	100
of spruce stand	62	78	83	95	100
Total number of species of herbaceous plants [14]	55	65	46	41	33
Average number of epiphytic lichen species [15]	7	10	10	9	9
Average number of bryophyte species [16]	26	37	26	28	32

On a territory under a high technogenic load, the influence of cement dust on the layers of soil that contain nutritionally active roots of trees and herbs may bring about significant changes in the structure and functioning of ecosystems. Soils in the region affected by the Kunda cement plant (1.25 km east, 3.5 km north-east, 5 km east, etc.) are characterized by a high saturation degree that in some excavations reaches 100 % [11]. The most remarkable phenomenon is the enrichment of soil with Ca, K and Mg, which causes changes in the balance of the absorbed cations in the absorbing complex of the soil. Compared to the unpolluted control territory, the amount of absorbed alkali has increased, and hydrolytic acidity of the soil has decreased. The content of mobile Al in the soil has become nearly zero as reported by Teras [11] and Kokk [12].

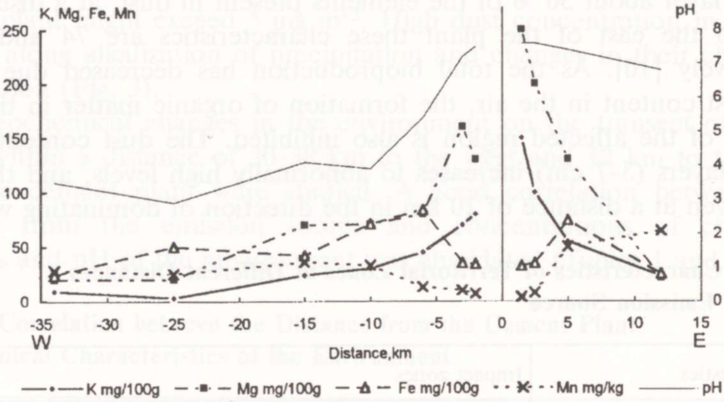

Fig. 4. Total content of some chemical elements in the humic horizons of forest sample plots on the investigated transect

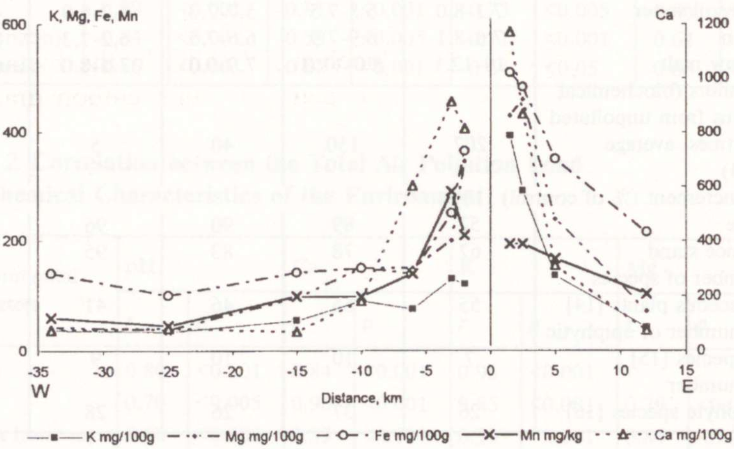

Fig. 5. Values of soil pH and content of some mobile form of chemical elements in humic horizons of forest sample plots on the investigated transect

These changes cause a significant increase in the soil pH value, reaching 7.6 in the humus horizon of forest soils (Table 3) and 8.1-8.4 in the upper horizons of the soils in urban areas around the plant [17]. The influence of alkalization decreases step by step in vertical direction towards lower horizons and with moving away from the emission source.

In mineral horizons, local changes of the same kind have been noticed at a depth of 50-60 cm [12] and at a distance up to 10 km from the plant. Owing to the high Ca, K and Mg concentrations in cement dust, the pH of the soil increases and the mobility of several elements (Mn, Fe) decreases (Figs. 4 and 5). It is well known that metals have a solubility minimum at moderately alkaline pH. In the subsoil water collected under the humus horizon of the soil from an affected territory, the content of Mn, Cu, and Zn is much lower than in the control territory at a distance of 30-38 km.

Forest

Alkalization and alterations in the biogeochemistry of the environment transform the structure and functioning of ecosystems. The most serious deviations were found in forests and bogs affected by alkaline dust. Pollution injuries of forest ecosystems are mostly expressed as changes in metabolism and nutrition conditions of trees and other plants, which are reflected in their growth and development.

Cement dust covering the above-ground parts of plants results in their incrustation. The crust on the leaves provokes changes in the light, temperature and water regimes of the plant tissues [18, 19]. High deposition rates of alkaline technogenic dust observed in the vicinity of the cement plant have caused definite biochemical shifts in the metabolism including the seasonal dynamics of pigments and carbohydrates in Norway spruce needles [13, 20].

In trees affected by cement dust more intensive lignification processes take place in the region with heavy dust loads. The lignin content of the needles of grown-up Norway spruce in the vicinity of the cement plant increases considerably, exceeding the indicators of the control trees by 30-40 %. More intensive lignification processes may hinder the growth of trees [21].

Our results showed an inhibition of the growth of conifers and a decrease in the photosynthetic area in the vicinity of the cement plant. The volume increment of forest stands has decreased in the zone with essential changes in the vicinity of the cement plant to about 52-62 % of the control (Fig. 6) [22, 23].

In the altered associations species preferring an acid substrate, which are generally typical of the *Oxalis-Myrtillus* type of forests, are suppressed while indifferent and calciphilous species become dominant (Table 3).

Besides deviations in the functions and structure of trees, great alterations were found in forest, herbaceous [24], lichen [15] and bryophyte [16] communities.

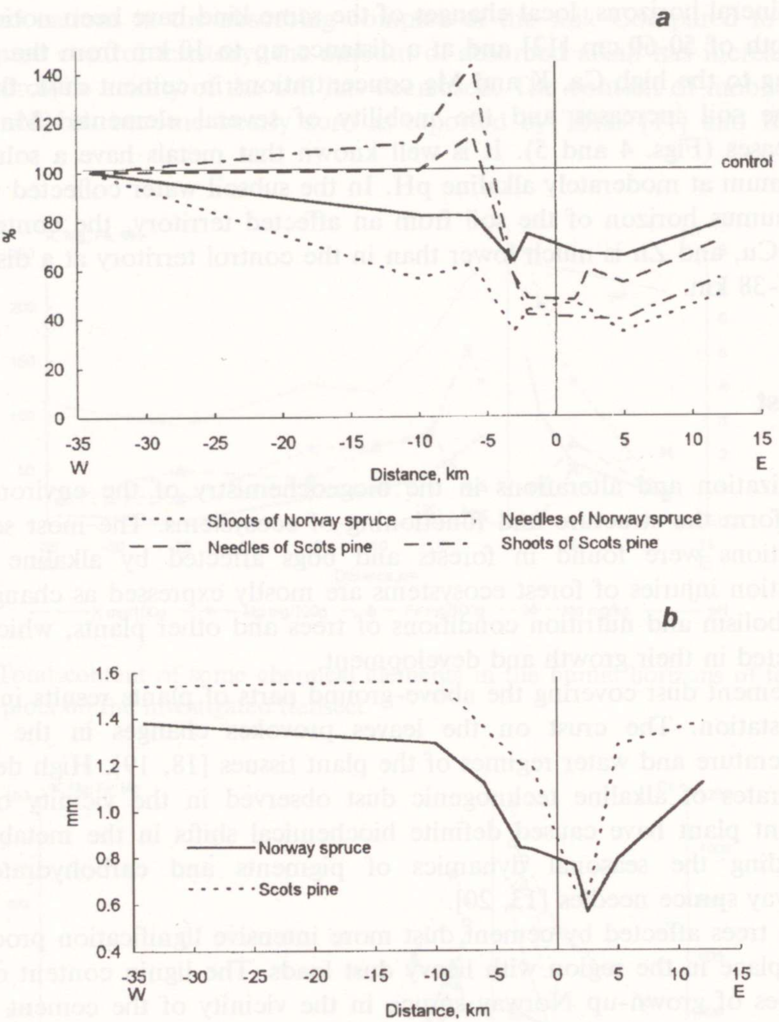

Fig. 6. Length of needles and shoots (*a*) (in 1992, % of control) [22] and radial increment (*b*) (average of 1983-92) [23] of Scots pine and Norway spruce at different distances from the cement plant

Conclusion

Considering chemical changes in the soil, precipitation and subsoil water, and the total technogenic load and volume increment of middle-aged and older forests [13], the territory surrounding the cement plant in Kunda was divided into five zones with different essentiality of changes in the forest landscape (Fig. 1, Table 3).

The investigations showed that the phenomena of alkalization of soil, precipitation and ground water due to emissions of the cement industry represented a risk to the forest quality and biomass. Forest landscape has lost its initial characteristic features within a distance of up to 10 km leeward from the emission source.

Note: In 1995, the level of dust emission from the cement plant was three times lower than in 1991-92, but there are no essential improvements in the state of the forest ecosystem in zones I and II yet.

Acknowledgements

The study was funded by the Kunda Nordic Cement Corp. (Estonia) and Estonian Science Foundation, Grant No. 2047.

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Presented by T. Purre
Received December 14, 1996