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LONG-RANGE TRANSPORT OF AIRBORNE POLLUTANTS AND THEIR WET DEPOSITION TO THE BALTIC SEA AND WEST-ESTONIAN ISLANDS IN 1985—1989

Abstract. Since there are no big sulphur and nitrogen emission sources on the West-Estonian islands, the high sulphate concentrations in the precipitation are mainly caused by the long-range transport of air pollutants over the islands. Therefore, it is of interest to know the origin of air masses transferred to the West-Estonian islands. For the base of comparison data on yearly sulphur and nitrogen amounts deposited by precipitation collected at 27 stations in Scandinavia, the Soviet Union, and Central Europe were used.

Key words: air pollution, atmospheric precipitation, sulphur, nitrogen, Baltic Sea.

The UNESCO International Program "Man and Biosphere" (MAB) Secretariate Bureau in Paris approved the Estonian proposal to form the West-Estonian Archipelago Biosphere Reserve on February 8, 1990.

The author's interest in the West-Estonian islands air pollution problems was provoked in 1985 at the Baltic Sea expedition, during which high sulphate concentrations in the rain samples near these islands (Роотс, Саапе, 1988; Roots, Johannes et al., 1988) were measured.

Results and Discussion

Evidently, apart from the nitrate and sulphate concentrations in the precipitation (Figs. 1, 2), we must know the precipitation amount in order to work out the wet deposition pollution load. The high daily sulphate and nitrate wet deposition pollution load near the island of Hiiumaa is alarming (Fig. 3). Methods for the analyses of anions and cations have been worked out earlier (Роотс, Саапе, 1988; Roots, Johannes et al., 1988).

For comparison: not far from Hiiumaa, in the western part of the Gulf of Finland, the wet deposition sulphur and nitrogen daily loads rose up to 8.25 mgS per m^2 (sulphate max. concentration in the precipitation was 22.5 mg/l) and 2.8 mgN (NO_3^-) per m^2 (nitrate max. concentration in precipitation was 15.1 mg/l) during the period April-May 1983 (Pyoxo-Айрола et al., 1985). In Finland, precipitation systems from the southwest contain more nitrate, while precipitation from the east has more sulphate (Laurila, Joffre, 1987).

During the Baltic Sea expedition on RV *Arnold Veimer* in December 1989 we measured sulphate and nitrate concentrations in the precipitation (Table 1) on the Baltic proper and the western part of the Gulf of Finland (West-Estonian islands lie between these two regions). Unfortunately, it was not possible to calculate the daily wet deposition load as strong winds dominated on the Baltic Sea at that time and precipitation amounts were impossible to measure. In December 1989 the sulphate concentrations in the precipitation (collected by M. Voll of the Institute of Thermophysics and Electrophysics, Estonian Academy of Sciences) were high in all stations (Table 1). Since there are no big sulphur emission sources on the West-Estonian islands, the high sulphate concentrations in the precipitation are mainly caused by the long-range transport

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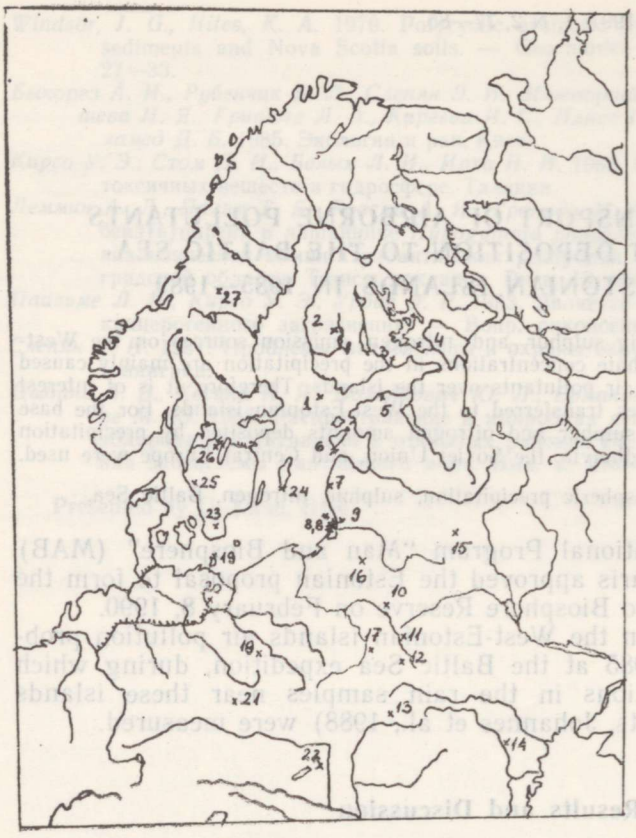
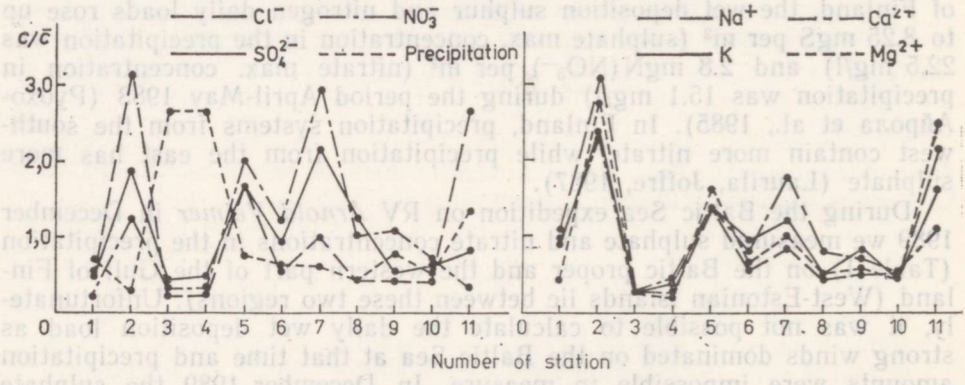


1. Utö
2. Ähtäri
3. Virolahti
4. Lesogorskii
5. Lahemaa
6. Sõrve
7. Rutsava
8. Nida
8*. Preila
9. Šilute
10. Vysokoye
11. Svityas
12. Rava-Russkaya
13. Beregovo
14. Leovo
15. Berezina Biosphere Reserve
16. Suwalki
17. Jarchev
18. Snezhka
19. Arcona
20. Neuglobsow
21. Košetice
22. K-Pusta
23. Vavihill
24. Hoburg
25. Rörvik
26. Velen
27. Bredkälen

Fig. 1. Precipitation collection stations.



$\bar{c}_{Cl^-} = 18.0$ mg/l, $\bar{c}_{SO_4^{2-}} = 11.25$ mg/l, $\bar{c}_{Na^+} = 10.09$ mg/l, $\bar{c}_{K^+} = 0.79$ mg/l

$\bar{c}_{NO_3^-} = 6.40$ mg/l, $\bar{c}_{precip.} = 1.64$ mm, $\bar{c}_{Ca^{++}} = 1.49$ mg/l, $\bar{c}_{Mg^{++}} = 1.28$ mg/l

Fig. 2. Connection between anions and cations concentrations (c) in a certain station and their average concentration ($\bar{c}$) above the Baltic Sea; August-September 1985. (The stations in Fig. 3.)

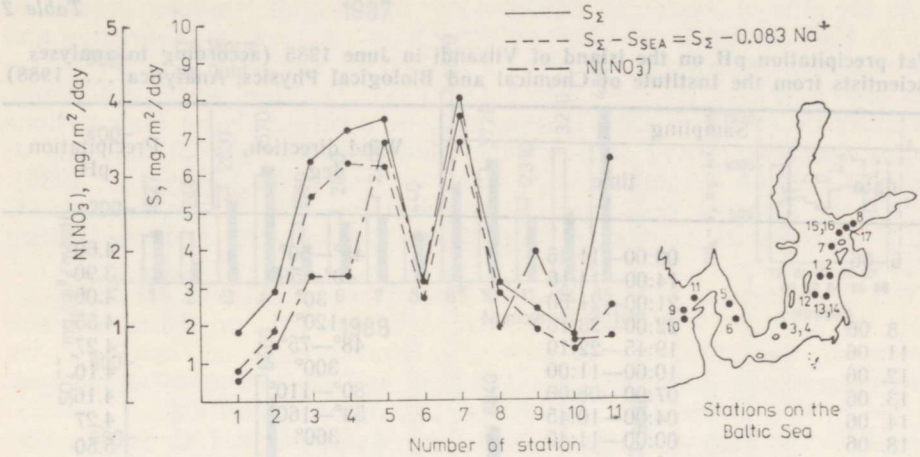


Fig. 3. Sulphur and nitrogen daily deposition in stations on the Baltic Sea; August-September 1985.

Table 1

Concentrations of anions and cations in the atmospheric precipitation above the Baltic Sea (December 1989)

№ of the staiton	Sampling		Wind		K^+, mg/l	Ca^{++}, mg/l	NO_3^-—N, mg/l	SO_4^{--}—S, mg/l	Sea origin sulphur**, %
	date	time *	speed, m/s	direction, deg.					
12	15.12	13:30—18:00	6.0—8.3	55°—96°	2.75	2.65	0.34	5.07	—
13	17.12	01:00—03:00	12.3—12.5	134°—139°	1.00	1.60	1.45	4.03	24.8
14	17.12	01:00—03:00	12.3—12.5	134°—139°	0.98	1.80	1.33	5.93	16.9
15	18.12	10:00—13:00	9.8	173°	1.00	1.75	1.92	4.70	20.9
16	18.12	10:00—13:00	9.8	173°	1.08	1.80	1.92	4.60	23.7
17	18.12	13:00—16:00	9.8—11.1	173°—200°	1.82	1.30	0.88	3.70	27.0

* Greenwich mean time.
** $S_{sea\ origin} = 0.083\ Na^+$.

of air pollutants above the islands. In the early 1980s the sulphur dioxide and sulphate concentrations in the atmosphere over the islands in June-August were respectively 1.0:3.0:2.3 and 1.0:2.0:1.6 (Брюханов et al., 1985) with air masses coming from Scandinavia, the Soviet Union, and Central Europe. The origin of air masses exerted essential influence on precipitation pH (Table 2). Therefore, it is necessary to take into consideration which air masses were transferred to the West-Estonian islands.

Table 2

Wet precipitation pH on the island of Vilsandi in June 1985 (according to analyses by scientists from the Institute of Chemical and Biological Physics, Analytical..., 1988)

Sampling		Wind direction, deg.	Precipitation pH
date	time		
6. 06	00:00—11:45	45°—60°	4.60
	14:00—14:10	40°—50°	3.90
	21:00—21:50	30°	4.06
8. 06	22:00—23:15	120°	4.55
11. 06	19:45—22:10	48°—75°	4.27
12. 06	10:00—11:00	300°	4.10
13. 06	07:00—08:00	80°—110°	4.16
14. 06	04:00—10:45	53°—160°	4.27
18. 06	00:00—11:40	360°	5.50

Wet deposition of sulphur to the West-Estonian islands area. Since we did not obtain information from all stations, we collected the data of 1986—1988. For the base of comparison yearly sulphate amounts deposited by precipitation were used. We chose the stations which collected the precipitation daily. A great number of these stations work on the basis of the EMEP (European Monitoring and Evaluation Program). Up to now the wet precipitation collectors of the Soviet stations monitoring air pollutants long-range transport (EMEP stations) operate day and night with the consequence of dry deposition being added to wet deposition. As the results of measurements in the same region might differ, we bring in addition to the data of the EMEP station in Nida (№ 8) the results of the Preila station (№ 8*) lying near the Nida station (Fig. 1).

Evidently the deposition of sulphate is conditioned by the origin of the air masses and meteorological conditions. According to Miller et al. (1987) the sulphur dioxide speed of oxidation to sulphate is accelerated by 30% if there are the so-called "sea-originated salts" in the air. In case of fog above the sea the presence of such salts motivates rapid sulphate formation from sulphur dioxide.

The first systematic (daily) measurements indicate that in 1981 during 6 months (July-December) 1604 mgSO_4^{2-} per m^2 was deposited in the Sõrve station (Information..., 1985), or in other words 4660 t sulphate (or 1553 t sulphur); in 1982 during the whole year 1461 mgSO_4^{2-} per m^2, or 4244 t sulphate (1414 t S) was deposited, and in 1983 during 11 months (data for December are missing) 1604 mgSO_4^{2-} per m^2 (Information..., 1985) or 4660 t sulphate (1553 t sulphur) was deposited on Saaremaa. For comparison with our results the sulphur load deposited with precipitation at the Hoburg station in Gotland is presented (Fig. 4).

In Fig. 5 the author shows the sulphur load (mgSO_4^{2-} per m^2) in 1986 using published data. In Fig. 4 the average monthly sulphate deposition by atmospheric precipitation is presented separately for the warm (April to September) and the cold (October to March) season of the year. As we see air masses from Central Europe are dangerous for our West-Estonian islands. But above the Baltic Sea winds from this direction prevailed: in 1981 to 1986 41.5% of the air masses came to Preila station from Central or West Europe (Определение..., 1987). According to the present author (Roots, Aasaru et al., 1988) sulphur dioxide concentrations decrease when moving from south to north. From year to year we analysed the highest sulphur dioxide concentrations (among Soviet EMEP stations) in the air samples of Rava-Russkaya station (Roots, 1990).

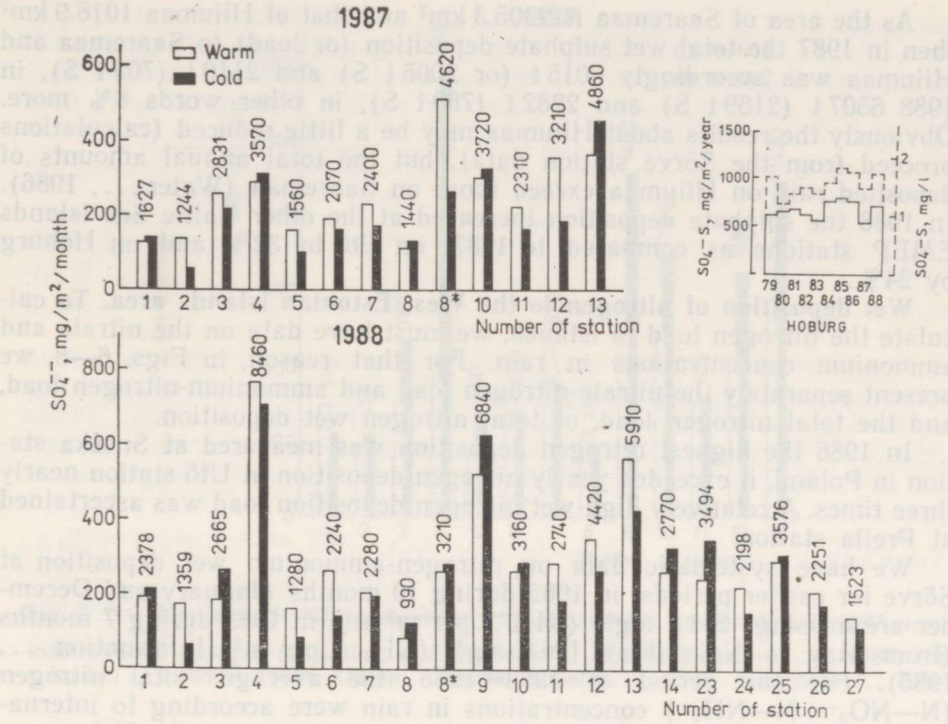


Fig. 4. Mean monthly sulphate deposition with atmospheric precipitation; numbers indicate total sulphate depositions with atmospheric precipitation in 1987 and 1988. (Ilmanlaadun..., 1987b; Бюллетень..., 1987; Ilmanlaadun..., 1988a; 1988b; 1989a; 1989b; Обзор..., 1988; Bulletin..., 1988; Обзор..., 1989; Lövblad, Sjöberg, 1988; Analytical..., 1988).

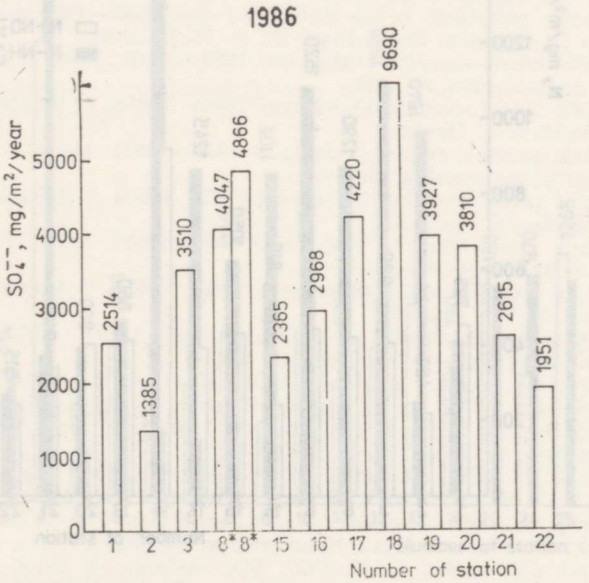


Fig. 5. Sulphate deposition with atmospheric precipitation in 1986. (Определение..., 1987; Ilmanlaadun..., 1986; 1987a; 1987b; Бюллетень..., 1987).

As the area of Saaremaa is 2905.3 km² and that of Hiiumaa 1018.9 km² then in 1987 the total wet sulphate deposition (or load) to Saaremaa and Hiiumaa was accordingly 6015 t (or 2005 t S) and 2110 t (703 t S), in 1988 6507 t (2169 t S) and 2282 t (760 t S), in other words 8% more. Obviously the results about Hiiumaa may be a little reduced (calculations proceed from the Sõrve station data), but the total annual amounts of deposited rain on Hiiumaa exceed those on Saaremaa (Water..., 1986). In 1988 the sulphate deposition increased at the other Baltic Sea islands EMEP stations as compared to 1987, on Utö by 32% and on Hoburg by 24%.

Wet deposition of nitrogen to the West-Estonian islands area. To calculate the nitrogen load to islands, we must have data on the nitrate and ammonium concentrations in rain. For that reason, in Figs. 6—8, we present separately the nitrate-nitrogen load and ammonium-nitrogen load, and the total nitrogen load, or total nitrogen wet deposition.

In 1986 the highest nitrogen deposition was measured at Sneška station in Poland, it exceeded yearly nitrogen deposition at Utö station nearly three times. A relatively high wet nitrogen deposition load was ascertained at Preila station.

We have systematic data on nitrogen-ammonium wet deposition at Sõrve for earlier periods: in 1982 during 10 months (January and December are missing) 241.8 mgN (NH_4^+) per m² and in 1983 during 7 months (from May to November) 126.2 mgN (NH_4^+) per m² (Information..., 1985). For the period of 1983—1985 the average total nitrogen ($N—NO_3^- + N—NH_4^+$) concentrations in rain were according to international data: Sõrve — 1.62 mg/l N, Lahemaa — 0.69 mg/l N, Hoburg — 2.40 mg/l N, Preila — 1.67 mg/l N, Utö — 1.35 mg/l N, and Arcona — 1.71 mg/l N (Deposition..., 1989). On the basis of calculations the total wet deposited nitrogen load in 1987 amounted for Saaremaa and Hiiumaa

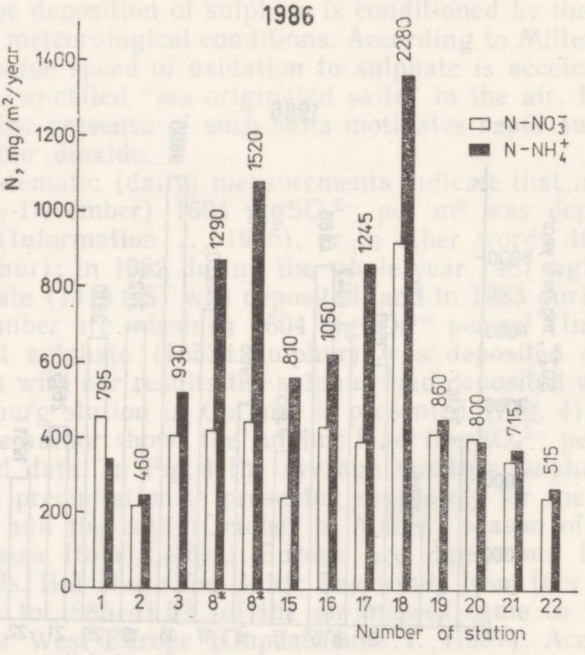


Fig. 6. $N—NO_3^-$ and $N—NH_4^+$ depositions with atmospheric precipitation in 1986; numbers indicate total nitrogen depositions. (Определение..., 1987; Ilmanlaadun..., 1987a; 1987b; Бюллетень..., 1987; Analytical..., 1988).

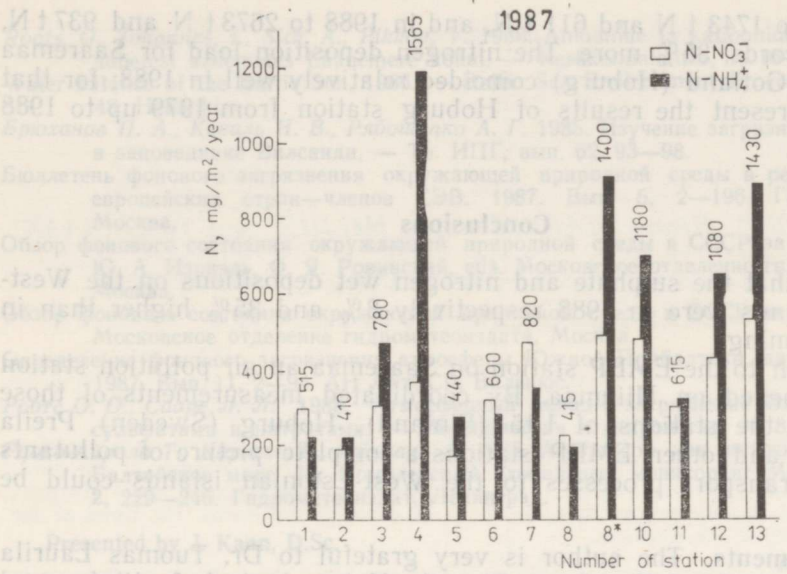


Fig. 7. $N—NO_3^-$ and $N—NH_4^+$ deposition with atmospheric precipitation in 1987; numbers indicate total nitrogen deposition. (Ilmanlaadun..., 1987b; Бюллетень..., 1987; Ilmanlaadun..., 1988a; 1988b; Обзор..., 1988; Bulletin..., 1988; Analytical..., 1988).

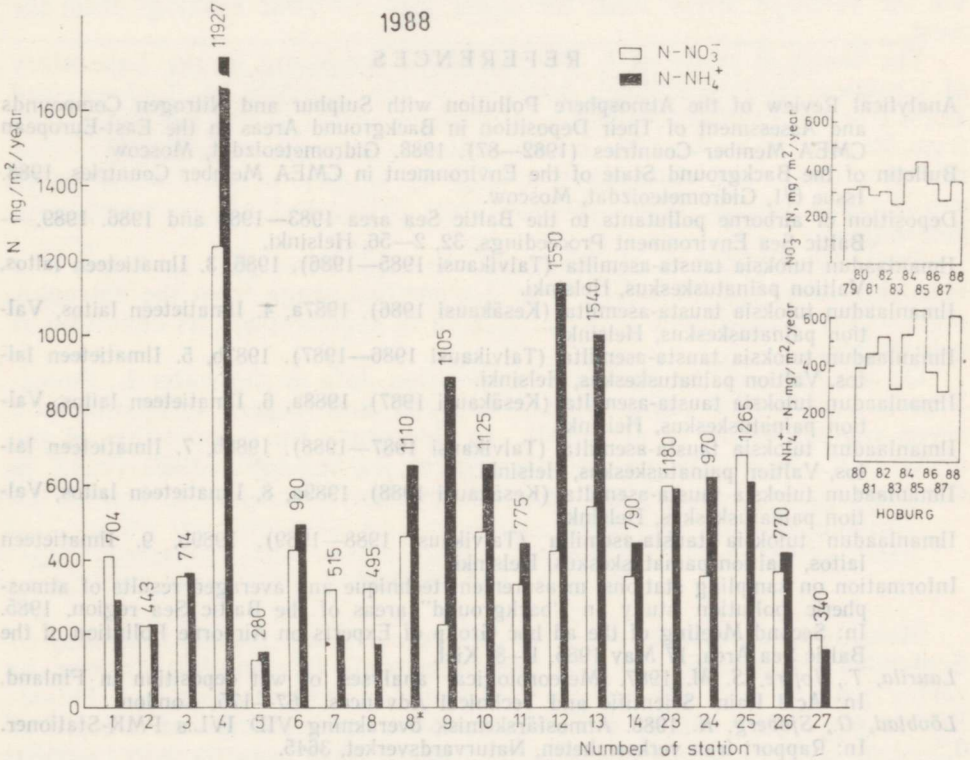


Fig. 8. $N—NO_3^-$ and $N—NH_4^+$ deposition with atmospheric precipitation in 1988; numbers indicate total nitrogen deposition. (Ilmanlaadun..., 1988b; 1989a; 1989b; Обзор..., 1989; Lövblad, Sjöberg, 1988).

accordingly to 1743 t N and 611 t N, and in 1988 to 2673 t N and 937 t N, or in other words, 35% more. The nitrogen deposition load for Saaremaa (Sõrve) and Gotland (Hoburg) coincided relatively well in 1988; for that reason we present the results of Hoburg station from 1979 up to 1988 (Fig. 8).

Conclusions

The fact that the sulphate and nitrogen wet depositions on the West-Estonian islands were in 1988 respectively 8% and 35% higher than in 1987, is alarming.

In addition to the EMEP station on Saaremaa an air pollution station should be opened on Hiiumaa. By coordinated measurements of those stations and the stations of Utö (Finland), Hoburg (Sweden), Preila (Lithuania), and other EMEP stations a complete picture of pollutants long-range transport processes to the West-Estonian islands could be obtained.

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