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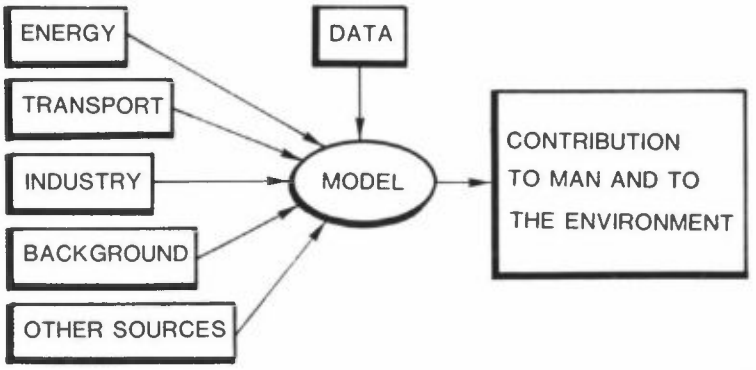

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The relative importance of pollution from different sources to man and to the environment.

NORWEGIAN INSTITUTE FOR AIR RESEARCH
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REGIONAL EXTENT AND RELATIVE PROPORTIONS OF DIFFERENT METAL EMISSIONS IN HELSINKI AIR STUDIED BY THE MOSS-BAG TECHNIQUE

Ahti Mäkinen *)

*) UNIVERSITY OF HELSINKI
Department of Botany
Unioninkatu 44, SF-00170 Helsinki 17
Finland

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Abstract

Heavy metal pollution of Helsinki air was studied in the wintertime 1982-83 with a moss-bag technique. Special attention was paid to the most important emission sources: refuse burning, traffic of motor vehicles and energy supply. About 600 moss-bags were suspended on twigs of small birches around the study area near the central and eastern part of the city. Accumulation of ash, Cd, Cr, Cu, Fe, Pb, Ni, V and Zn in moss-bags over a five-months period (146 days, from mid-October to mid-March) was studied and analysed with a standard AAS flame method.

Greatest accumulation values were found near a refuse burning plant in leeside and near the main streets with daily traffic intensity of 30.000 to 50.000 vehicles. Also the influence of coal-fired power plant in the city center was remarkable concerning especially ash, Ni and V.

The relative proportions of different emission sources were also estimated by means of a factor analytic receptor model for the whole material as well as for the representative subareas separately. Three major factors emerge and correspondingly the chemical parameters studied can be divided into three separate groups. The first one named traffic factor includes Fe, ash, Pb and Cr. The second one named energy factor includes V and Ni and on the third, incinerator factor, Cd an Zn show significant loadings.

C O N T E N T S

1. Introduction

The air quality in urban areas of Nordic Countries has been observed for several decades by scientists and health authorities co-operatively in order to improve the environmental conditions for people. Most studies are based on deposition measurements with mechanical collectors only (Laamanen 1969, Stockholms kommun 1978) or have utilized mathematical models calculated with meteorological parameters (e.g. MIL-4 projects). Actual emission measurements over a long period are few.

The use of various bio-indicators for monitoring emissions has increased in recent years (Lötchert et al. 1975, Andersen et al. 1978, Rühling & Skärby 1979, Rambaek & Steinnes 1980). Also this study is based on the bio-indicator method. The moss-bag technique originally developed in Great Britain (Goodman et al. 1974, Little & Martin 1974, Temple et al. 1981) was tryed in air pollution monitoring. Most moss species absorb efficiently air pollutants, especially wet deposition, and are much cheaper to use than mechanical collectors. So the monitoring is possible simultaneously in tens or hundreds of observation (receptor) points and the spreading of pollutants during the study period (mostly 1-6 months) may be mapped accurately.

This method further developed by the author has been used in Finland since 1976 for air pollution monitoring in cities and near industrial and traffic emission sources (Mäkinen 1977, Mäkinen et al. 1980, Nurmi 1981, Mäkinen & Lodenius 1982, 1984, Hynninen 1983, Lodenius & Tulisalo 1984).

2. Study area

The study area comprises the whole inner city of Helsinki, Finland, but the network of measuring points is denser on industrial areas and near the vicinity in the eastern part of the city (Figs. 1 and 7).

The topography of the study area is varying because the city of Helsinki is built up mainly on rocky hills lifted up from the Baltic Sea. The hills are low, most of them 15 to 30 metres above the sea level, but with the high buildings and the street clefts they have an influence on surface winds and emissions.

Densely populated city is consisting about one half of the whole 100 km^2 study area (Fig. 1) with approximately 260 000 residents (Statistical Center of the Helsinki City). On weekdays we have to take into consideration besides this all the people working in the city.

The other part of the study area consists of bays and sparsely populated land areas (Fig. 1, white parts in the map). The proportion of parks is about 1/4 of the land area. They are quite essential in the monitoring of air pollution as control areas.

On vacant hills north and east of the inner city there are dense pine forests. On lowlands the Norway spruce is more common, but the proportion of decidous forests, however, is higher especially on sea shores.

In the estuary of the Vantaa river there is a protected marshy wetland with an area of approximately 1 km^2. Northeast of that area there is a large lowland with cultivated fields

and pastures belonging to the University. Because of open exposition towards the city and emission sources on wind sides suitable conditions for considerable deposition have been found there (Mäkinen & Lodenius 1984).

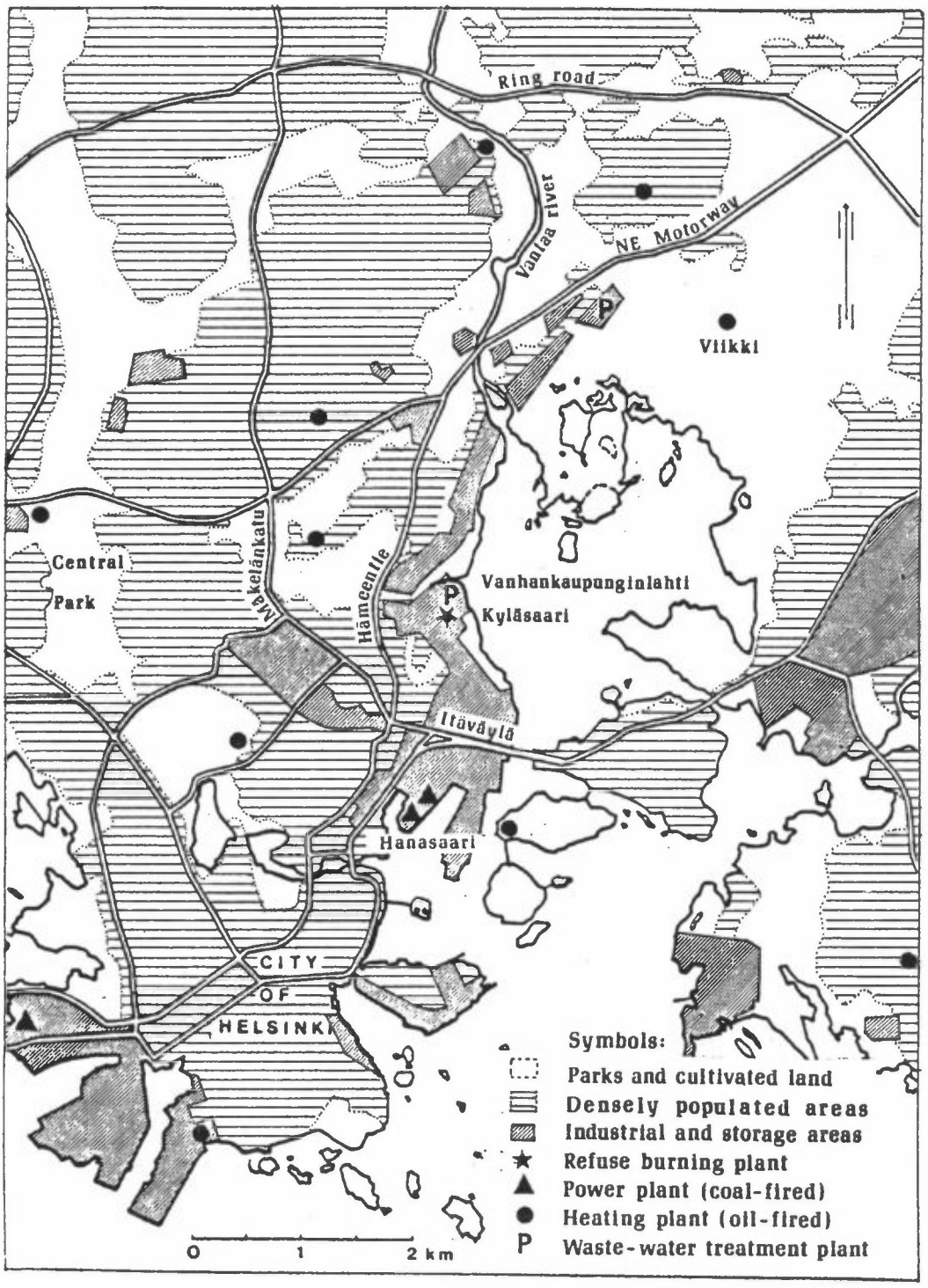


Fig. 1. Study area with the most important emission sources. The main streets and highways are also indicated.

3. Emission sources

3.1. Traffic

The busy traffic in the City of Helsinki is channelled by local geography. The main streets east and west run over bays via islands. The major road to eastern suburbs runs through the study area as well as the highway to the northeast. Between these streets there is a small marshy bay of the Baltic (Fig. 1). Other districts of the study area with lower traffic density are the Central park and some smaller forested tracts between transverse avenues. The built-up areas with dense network of streets cover more than two thirds of the land area (Fig. 1).

The traffic into and out of the city runs through some main streets. In the study area there are three such main streets with very busy traffic (Fig. 2). The greatest density (49 400 vehicles per day, including automobiles and trams) was estimated on Eastern Highway (Haataja 1984). On both north and northeast highways the average traffic density is about 30 000 vehicles per day. In the inner city the traffic is divided more evenly and on most main streets there are less than 25 000 cars daily, excluding the shore street with twice so busy traffic (map by the City of Helsinki,Traffic planning Division 1982). On smaller streets like those are running into harbour and industrial areas the density of traffic is decreasing to 7 500 vehicles per day.

The traffic volumes mentioned above are daily averages in 1981. However, there is a great periodic variation. The maximum density has been recorded on the last Friday in May at 16.30 hrs. The low season is in July during summer holidays.

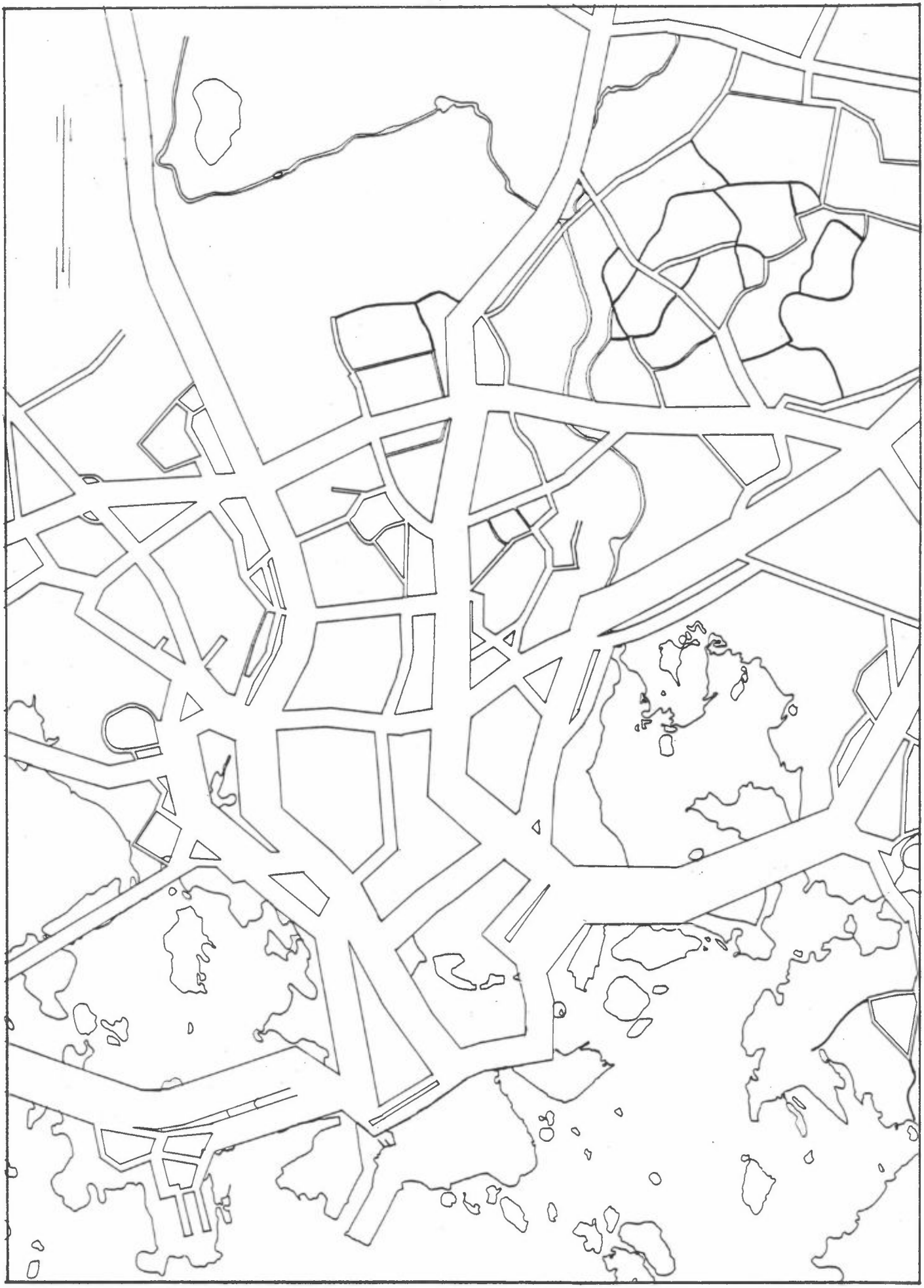


Fig. 2. Average daily traffic volumes (automobiles and streetcars) in 1981 on the main streets of the study area. Scale: 1 mm corresponds to about 4300 vehicles. (Source: Traffic planning Division of Helsinki City).

The yearly variation may be 35 %. The study period from October to March represents well the mean traffic density values.

While about 70 % of all vehicles in Helsinki traffic are private cars, a significant proportion of them using high-octane (99) gasoline with 0.40 g lead in 1 liter gas, they are considerable emission sources.

On the presumption that the traffic density on main streets is about 25 000 vehicles, we get 17 500 cars which use about 10 liters of gasoline/100 km with 0.4 g Pb/l. This makes 0.7 kg of lead/km daily and c. 102 kg during the whole study period (146 days). Detailed daily consumption of gasoline in city traffic shows, however, that the fuel consumption values are somewhat higher (Table 1 and the City of Helsinki, Traffic planning division 1983).

Table 1. The daily use of gasoline (l/day) in cars on main streets around the study area and corresponding estimated lead emission (kg Pb). The lead content of gasoline was estimated at 0.4 g/l.

Main street	Length of the streets on the study area km	Mean daily traffic density	Daily use of gasoline l/day	Estimated daily Pb emission kg
Itäväylä	5.4	46 400	13 500	5.4 kg
Mäkelänkatu	3.6	30 000	8 064	3.2 "
NE Highway	4.5	29 900	6 525	2.6 "
Hämeentie	3.0	16 700	4 920	2.0 "
Sum	16.5	123 000	33 009	13.2 kg
Whole City	1 027.7	4 940 000	308 310	124.8 "

On main streets of the study area the range of daily lead emissions was 0.58-1.00 kg/km. If we take into consideration the minor streets, too, the lead emissions caused by traffic is about 500 kg monthly around the bay of Vanhankaupunginlahti in the middle of the study area, representing one seventh of the total lead emissions caused by the cars in the City of Helsinki.

Fig. 3. Traffic and power plants are great emission sources in Helsinki. In the foreground the Eastern Highway (Itäväylä) with a mean daily traffic density of 49 400 vehicles. Left in the background the greatest coal-fired power plants of the City, Hanasaari A and Hanasaari B (with high smokestack) are prominent.

3.2. Energy supply

The energy supply on the study area is based mainly on two coal-fired power plants, Hanasaari A and B, which produce a major part of the electricity and heating energy used in Helsinki.

The power plant A started at 1960. Its condense turbines have a maximum capacity of 180 MW. The smokes are cleaned by electric filters with a separation efficiency of 92-96 % (Lämpövoimalaitosten ilmansuojeluselvitys 1980). The height of the smoke stack is 87.5 metres.

The power plant B was ready at 1974. Its maximum output is 420 MW. The cleaning efficiency of electrofilters is 99.2 % and the height of the smoke stack is 150 metres.

Both power plants are coal-fired but they also use heavy fuel oil in auxiliary boilers. The coal comes mainly from Poland, with some English coal mixed. The operation values of the power plants during the study period are presented in Table 2 (Helsingin kaupungin energialaitos 1982-83).

With a maximum emission of the fly ash measured in the power plant Hanasaari B (127 kg/h) the values mentioned in Table 2 may increase 34 % in the unit B and even more in the unit A.

In addition to the coal-fired power plants in Hanasaari, there are some smaller oil-fired heating plants in the study area (Fig. 1). They are in function of cold winter days only when the need of energy becomes higher. They produce some nickel and vanadium emissions to their nearest vicinity (Pohjola et al. 1983). The mean concentrations of nickel and vanadium used in calculation were Ni 30 ppm and V 150 ppm.

Table 2. The use of fuel in Hanasaari power plants during study period (19.10.1982-14.3.1983) and the corresponding metal emissions*.

	Unit A	Unit B	Total
The use of fuel (tonnes)			
Coal	136 179	288 518	424 697
Heavy oil	975	4 148	5 123
Emissions (kg)			
Ash	850 000	400 000	1250 000
Lead (Pb)	720	340	1 060
Cadmium (Cd)	13	6	19
Chromium (Cr)	200	100	300
Copper (Cu)	442	208	650
Iron (Fe)	21 200	10 000	31 200
Nickel (Ni)	430	200	630
Zinc (Zn)	1 870	880	2 750
Vanadium (V)	680	320	1 000

*) The estimation of emissions is based on chemical analyses of fly ash from the power plant unit Hanasaari B (Pohjola et al. 1983) and on the mean separation efficiency of the electrofilters mentioned above.

Other coal-fired power plants are situated 5.4 km SSW and 6.5 km ENE from the center of the study area (Salmisaari and Myllypuro, respectively) and may have some influence upon the heavy metal pollution. Because of effective electrofilters and smaller capacity at these power-plants, their influence seems to be quite small.

3.3. Refuse burning

The influence of refuse burning on air pollution has been in many cases quite considerable (Heimler 1975, Jacko & Neuendorf 1977, Freeman 1978, Granath 1978, Greenberg et al. 1978a and b, Stockholms kommun 1978, Lorber 1980, Vornanen 1982). A special problem of such burning facilities is that neither has any electric filters nor smoke washing.

The refuse burning incinerator in Kyläsaari, Helsinki in the middle of the study area was among that group. By late 1970s nearly all of the local refuse furnaces in apartment buildings were replaced by one great burning plant in Kyläsaari (Fig. 4).

Fig. 4. The refuse burning plant in Kyläsaari (left) and the power plants in Hanasaari (in the background) in full function in March 1983. In the foreground there is a waste-water treatment facility.

At the end of 1960s the number of smaller furnaces in Helsinki area was 1000 (Mattsson & Jaakkola 1979). In March 1983 the refuse burning plant in Kyläsaari, however, was closed because of environmental pollution. About 26 % of community waste of Helsinki city was burned in Kyläsaari until March 1983 (Henttu 1982). That makes approx. 8000 tonnes monthly or 250-272 tonnes per day. During the study period about 38 000 tonnes of miscellaneous housing, shop and work-place waste was burned in Kyläsaari incinerator. The composition of this material is listed in Table 3 (cf. Mroueh & Laukkarinen 1981).

The amount of metal scrap burned yearly was approx. 5 600 tonnes. That makes 2 240 tonnes during the study period from which about 95 % could be separated with magnete. The composition of this scrap varies considerably (Table 4).

Table 3. The composition of the refuse burned in Kyläsaari incinerator in 1981 according to Anttila & Lindström (1981).

Paper and carboard	59.2 %
Food waste	18.2 "
Plastic and rubber	9.8 "
Metal	4.0 "
Glass	3.2 "
Wood	2.6 "
Textiles	2.3 "
Other	0.7 "

The smoke of the burning plant was cleaned by cyclones with a separation capacity from 37 to 73 % and conducted through smoke stack into 105 metres height, where their temperature was 230^{o}C. The burning temperature varies

during intensive burning between 800 and 1000°C (Äikäs & Hahkala 1982).

Table 4. The composition of the metal scrap burned in Kyläsaari incinerator in Helsinki according to Anttila & Lindström 1981.

	Housing waste	Waste collected mainly from working places
Tins	56.4 %	20.9 %
Small metal components	35.5 "	7.9 "
Metal dishes	5.8 "	0.4 "
Components of cars	4.6 "	70.8 "

According to the measurements in Kyläsaari incinerator during 1981-82 (op.c.) as well as in other Nordic Countries and U.S.A. (references in Mroueh & Laukkarinen 1981 and Greenberg et al. 1978) the metal emissions of Kyläsaari refuse burning plant were estimated during the study period (Table 5). Because of great variation in the composition of burned refuse the deviation of all measurements is also high, approximately 25 % or more (Äikäs & Hahkala 1982).

Table 5. The estimated emissions of ash and heavy metals in Kyläsaari refuse burning plant during the study period (from 19th October 1982 to 14th March 1983) according to the emission measurements and neutron activ. analyses of fly ash published in Äikäs & Hahkala 1982 (+) and Mattsson & Jaakkola 1979 (++).

Ash	143 200 kg(+)	Ni	151 kg(+), 22 kg(++)
Cd	164 " ("), 37 kg(++)	Pb	3 200 " ("), 1375 kg(++)
Cr	230 " (")	V	5 " (")
Cu	127 " (++)	Zn	4 668 " ("), 3222 kg(++)
Fe	1 824 " (+)		

3.4. Other sources

In addition to the emission sources mentioned above also a number of smaller sources on the grey areas of the Figure 1 and many long-distance air pollutants have some influence upon the air composition in Helsinki.

From local emission sources glass and porcelain industry, concrete industry and numerous foodstuffs industries may be mentioned. Their emissions are not known, but are apparently small on the ground of the size of facilities and measurements in their vicinity.

There are no great processing factories or large metal smelters in the study are, whereas two waste-water treatment plants (in Kyläsaari and Viikki) may have some influence on the gaseous content of the air (Fig. 1).

The long-distance emissions may originate from industrial areas, traffic or power plants situated further from the study area. For instance in exceptional climatic conditions the influence of a lead smelter situated 15 km north of Helsinki was measured in the city (Mattsson & Jaakkola 1979).

Because of the prevailing winds are from south and southwest (Fig. 5), the pollutants carried over the Baltic (or the Gulf of Finland) may have a greater influence on the air of Helsinki than some small factories situated inland.

4. Climatic and weather conditions

A representative meteorological station for the City of Helsinki is situated in the SW corner of the study area, in the Botanical Garden of the University. The wind observations used in the calculation of heavy metal emissions were, however, made on the roof of the Meteorological Institute at the height of 29 metres a.s.l. in the vicinity of the station mentioned above. The distance between the station and the centre of the study area is 3.2 km.

4.1. Dominating winds

The reverse wind directions and velocity of Helsinki during study period 19th October 1982 to 14th March 1983 are shown in Fig 5 excluding calm and heavy winds, because their proportion was very small: calm 0.9 % and high wind 0.5 % (over 11 m/sec) of all observations (8 daily). The proportion of light wind during study period was 73 % and the proportion of wind with medium velocity 25.6 % of all observations, the mean value being 4.0 m/sec.

Near the ground where the moss-bags were situated, the wind directions and velocity may be different because of some turbulence caused by topographic conditions. This should be taken into consideration when estimating the spreading of emissions. During the study period there are no accurate wind observations on the street surface in the study area.

During the summer time the daily seawinds and the inland

winds at night have some influence upon air pollution pattern. However, the intensity of industrial function and traffic are major factors at daytime.

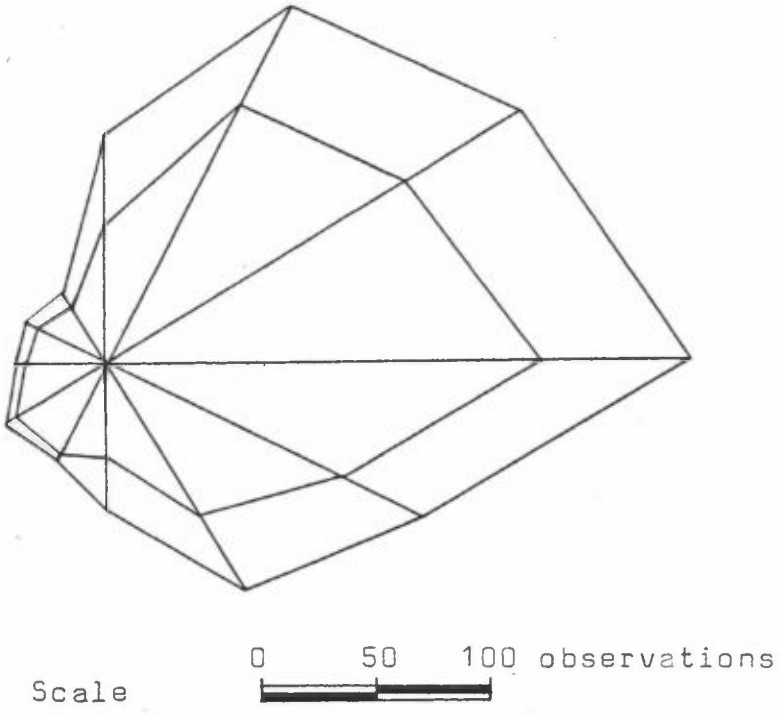


Fig. 5. Reverse wind directions in the city of Helsinki during the period 19.10.82-14.3.83. The winds of light speed ($\prec$ 5 m/sec, inner diagram) and medium to strong speed ($\succ$ 5 m/sec, outer diagram) are indicated.

4.2. The humidity and precipitation

The relative humidity of the air during the study period was on average 82.9 %. The smallest mean value (74.5 %) was observed in March, the greatest one (87.2 %) in October. The rainiest period occurred in the end of November. Therefore the precipitation for the month exceeded 100 mm which is clearly more than long-term monthly values (59.4 mm, Heino 1976). February was relatively dry (Fig. 6 and the statistics of the Finnish Meteorological Institute).

Great humidity and precipitation are important for mosses, because they absorb efficiently wet deposition. Also chemical weathering of particles and the exchange of cations is accelerated on moss surfaces (Puustjärvi 1955, 1968; Clymo 1963).

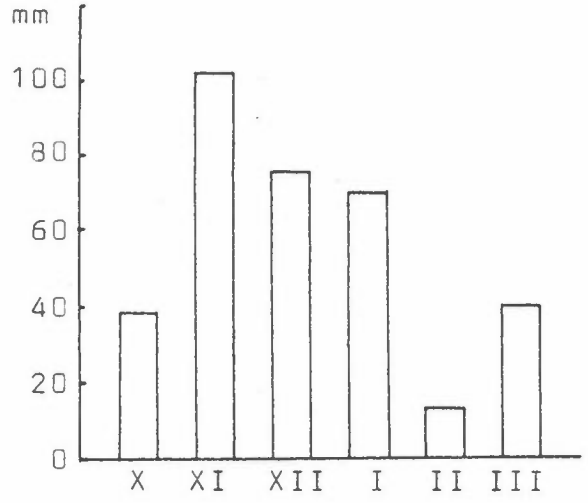


Fig. 6. Monthly precipitation (mm) in the city of Helsinki during the period 19th October 1982 - 14th March 1983.

5. Material and methods

The primary material of this study is based on analyses of bioindicators. Acid-washed moss-bags were used in heavy metal monitoring (Goodman et al. 1974 and 1975, Little & Martin 1974). More than 600 moss-bags (each about 1 g of dry weight) were suspended in nylon nets in 164 receptor points all over the study area and reference areas in the vicinity of Helsinki and elsewhere in southern Finland (Fig. 7). In these points moss bags were placed at about 3 meters height on the top twigs of young birchs (Fig. 8). Special attention was given to the equality of all receptor points. All moss bags were situated on open rocky hills or near by the sea shore. So the particles coming anywhere were caught by the bags. Suspending of the moss bags near the streets was avoided, where the emissions caused by traffic were not studied.

A great part of the 135 receptor points in the study area were placed along two lines running away from the main emission sources (Fig. 7). From the background receptor points 5 were situated in Pälkäne, 150 km north of Helsinki on remote area where the moss-bag material, Sphagnum girgensohnii and S. angustifolium mosses, were taken. Five additional background points were situated in Inkoo 60 km west from Helsinki, 4 in Sipoo 20 km east from the main study area and the remaining 15 points in Vantaa and northern Helsinki about 12 km NW from the study area.

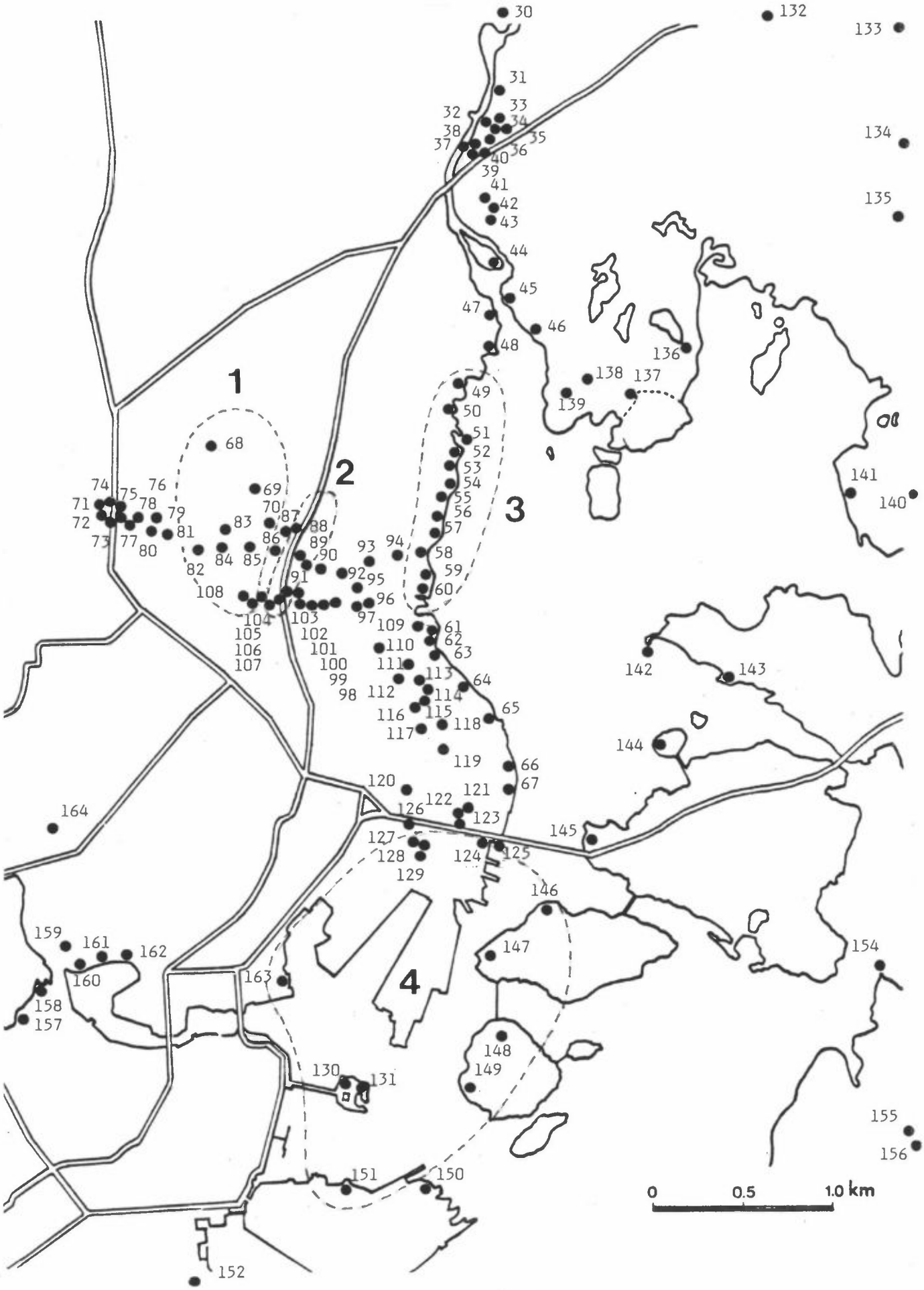


Fig. 7. Location of the receptor points in the study area (four moss-bags in each point). The special subareas 1-4 are marked with broken line (see text).

After about 5 months accumulation time the pretreatment of the moss-bags included drying for two days at +40°C temperature and dry-ashing at 450°C. The ash was extracted with 5 ml of conc. HCl on hot plate. From the filtrate the heavy metals were determined by a standard AAS-flame method (Allen 1974, Mäkinen 1977). The mean monthly accumulation, µg/g weight, based on 2-4 replicate analyses, was calculated at all receptor points for lead, cadmium, chromium, copper, iron, nickel, vanadium and zinc as an increase of the metal content of the moss-bag material from the beginning of the test. The monthly accumulation of ash is indicated in per cent units.

The statistical calculations of the data were carried out with BMDP and MINITAB programs at the Computer Center of the University of Helsinki.

To estimate the relative influence of different emission sources on air pollution, four representative subareas were selected on the basis of factor analysis of metal accumulation (Fig. 7).

The first one is a quite unpolluted park area, where the concentrations of all metals studied are low in moss-bags. The second one is a typical traffic area with a daily traffic density of 17 000 vehicles. The third subarea is situated on the lee side of the prevailing wind near the Kyläsaari refuse burning plant, and the fourth one in the vicinity of a major power plant (Hanasaari).

When calculating the relative values of metal pollutants, the following parameters were taken into consideration.

1. The mean monthly accumulation rate of metals in moss-bags in subareas and vs. in South Finnish background areas.

2. The emission measurements as well as the amount and composition of fuels used in the power plant and in the refuse burning plant situated in the study area (Tables 2 and 5). Also the efficiency of the cleaning of smokes and the height of smoke stacks as well as the most important meteorological parameters were taken into consideration.

3. The proportion of the long-distance transport was estimated from the background values of the moss-bags (Tab. 7).

4. The amount of the traffic emissions during the study period was calculated from the daily use of gasoline per one meter of street (Tab. 1). Also wind directions, re-emission and the logarithmic decrease of deposition values on road sides were taken into consideration.

Fig. 8. Moss-bags in nylon nets on the top twigs of a small leafless birch.

6. Accumulation of ash and heavy metals in moss-bags: absolute and relative values

6.1. Background levels

The background values of heavy metals and ash accumulated in moss-bags in relatively remote sites were determined at the same time and with the same method as in the city area. Background levels can be estimated from four South Finnish areas:

1. Inland sites 150 km north of Helsinki (Pälkäne)
2. Coastal sites 60 km west of Helsinki (Inkoo)
3. Forested areas about 15 km north of Helsinki
4. Central park of the city 3.5 km north of the downtown area. There are no traffic or other emissions sources in the nearest neighbourhood.

In the coastal area somewhat higher accumulation ranges may be due to local sources (Fe, Zn, V) or due to long distance transport (cf. Mäkinen 1982 and 1983). In the Central park of the city (4) the values are about 3-8 times higher than in other areas (Tab. 6).

Table 6. Background values of heavy metals (ppm/dry wt./month) and ash (%-units/month) for the regions 1-4 mentioned above:

No.	Ash	Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	n
1	0.1	0.02	0.1	0.5	28	0.2	1.8	0.7	3.4	6
2	0.3	0.05	0.1	0.5	101	0.5	4.2	2.6	7.4	5
3	0.3	0.03	0.2	0.6	55	0.4	4.3	1.0	4.4	12
4	0.8	0.13	0.8	3.1	322	1.5	15.9	4.3	10.0	8

The regions 1-3 are considered as representative control areas in S Finland. Their values (Tab. 7) have been used as background levels of heavy metal accumulation into the moss-bags during the study period. In figures 11, 15, 19, 23, 27, 31, 35, 39 and 43 the background level is marked with a dotted line.

Table 7. Mean monthly background values (ppm/dry wt, ash in %-units) of heavy metal and ash accumulation into the moss-bags in Southern Finland during winter time 1982-1983.

Ash	Cd	Cr	Cu	Fe	Ni	Pb	V	Zn	n
0.3	0.03	0.1	0.6	74	0.4	4.3	1.5	5.5	23

6.2. Ash

The ash content of living Sphagnum moss varies between 1.3-4.4 % in the bogs in Finland depending on the collection point (Pakarinen 1981). The original ash content of Sphagnum mosses used in this study was before acid washing about 2.1 % and after that 1.7 %. The soluble part of ash in part consists of long-transported mineral components (cf. also Kivinen 1933).

When the ash content of moss-bags was redetermined after about five-month collection time it had increased in all receptor points by 0.5-40 %-units. In monthly accumulation values this corresponds to an increase of 0.1-8.3 %-units. The mean increase for the whole material was 1.9 ± 1.5 %-units ($n = 164$).

In some parts of the study area the ash content of moss-bags may be ten times higher than in the other part (Fig. 11).

When compared with the background areas the differences are even greater. This is due to the local influence of the emission sources that rapidly decrease away from the source.

The greatest mean ash accumulation values were measured in busy traffic areas loaded with energy supply and long-transport emissions (Fig. 10). In the middle of a four-laned road the ash accumulation of moss-bags was about 30 % higher than above the nearest pavement (Fig. 9). In comparative studies carried out in 1980, a corresponding decrease of ash accumulation in vertical direction was established (Mäkinen & Lodenius 1982 and 1984).

The smallest ash accumulation values ($<$ 1 %) were measured in park areas more than 0.5 km from the nearest emission source. In the inland background areas, corresponding ash accumulation values were in Pälkäne 0.1 %-units only and in Inkoo and in northern periphery of Helsinki 0.3 %-units (Tab. 6). They are equal to about 10 g/m^2/yr total deposition in southern Finland (Kulmala et al. 1982). When related to the monthly values measured in the study area (up to 12 g/m^2/month, Helsingin kaupungin ympäristönsuojeluneuvottelukunta 1979) the proportion of the long-transported dustfall may be estimated.

In Fig. 12 the relative values of different emission sources are presented as well as the estimation bases discussed in section 5. The area of the circles is proportional to the ash accumulation in the subareas. The great proportion of the traffic in the subarea 2 is particularly noticeable. In other subareas too, its proportion was estimated at 1/4 of the ash accumulation at least.

Part of that ash, however, comes apparently by re-emission, i.e. the deposition lift up by the cars. Another part comes from exhaust fumes and from the corrosion of vehicles. Also the energy supply has a great influence on the particle pollution of urban air.

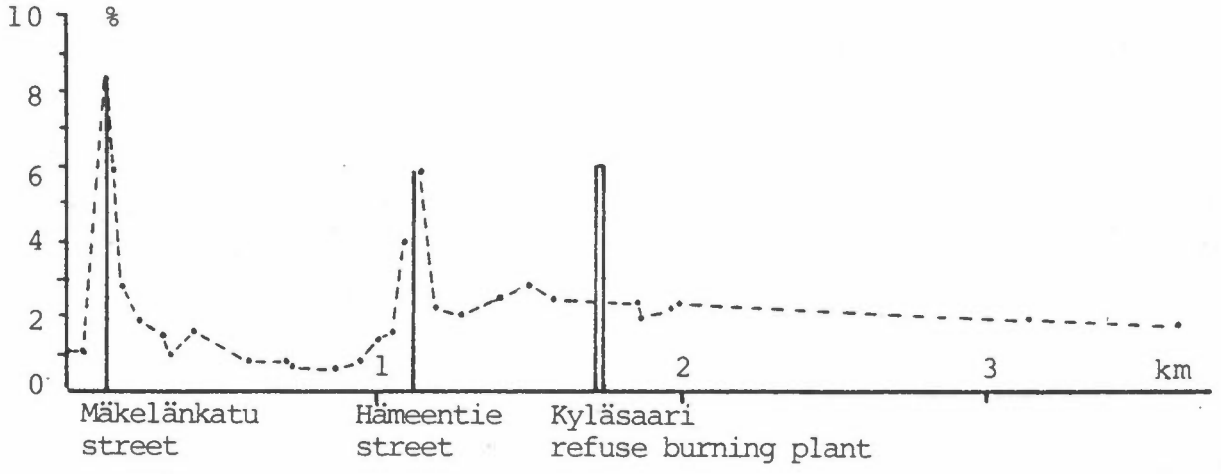


Fig. 9. Accumulation of ash in moss-bags along transect from west (left) to east through the study area.

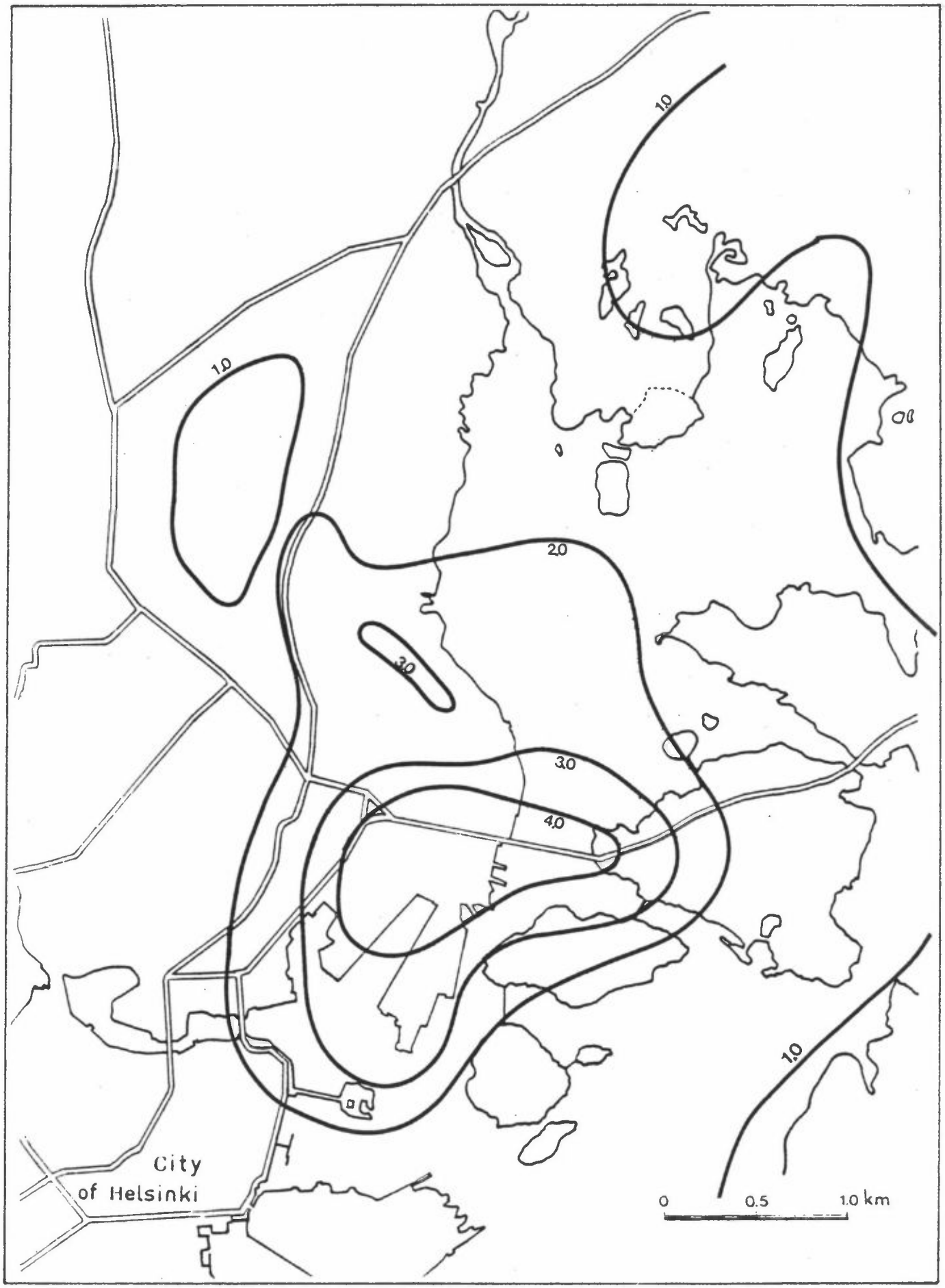


Fig. 10. Mean monthly accumulation of ash (% units) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

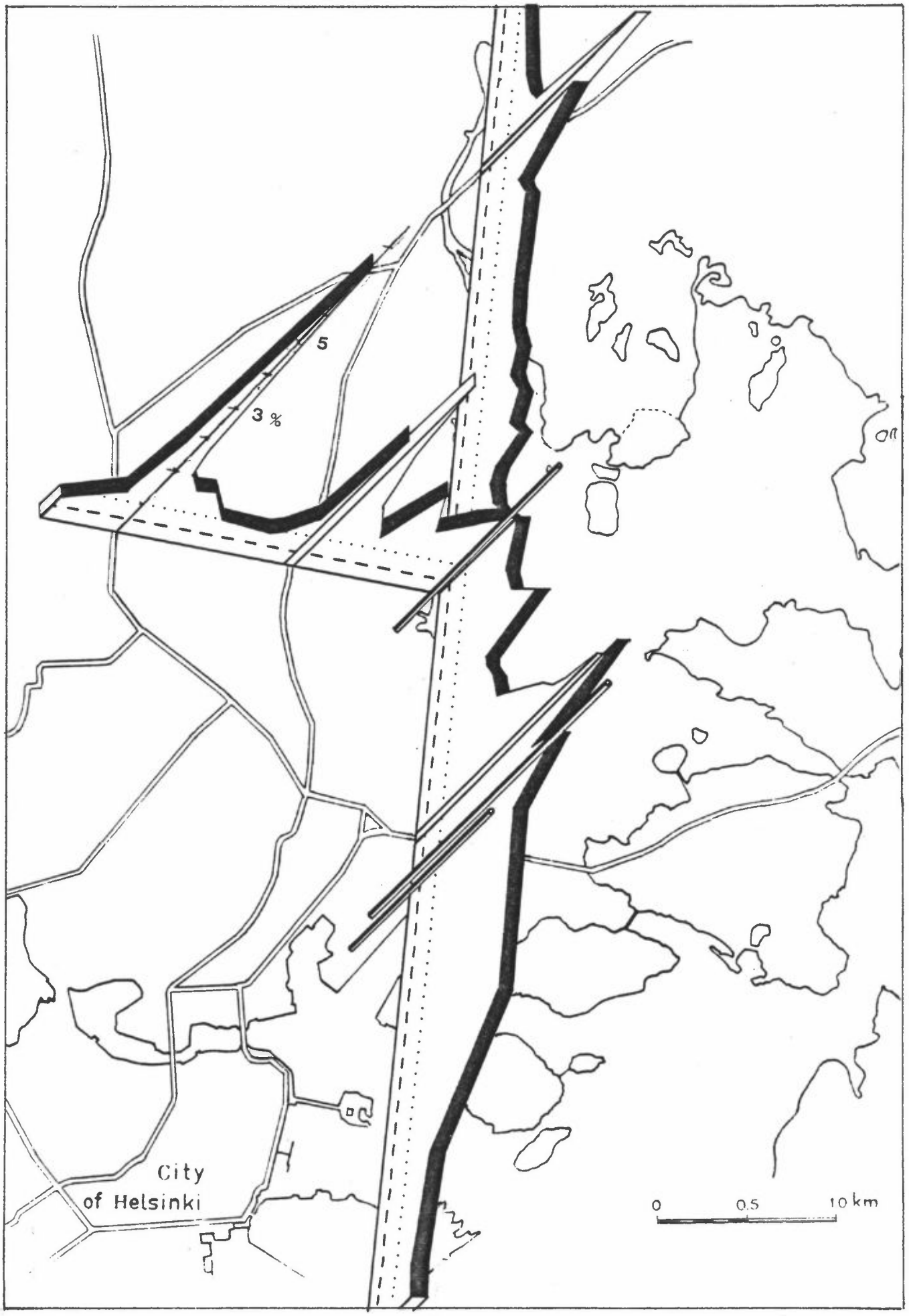


Fig. 11. Ash accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Receptor points within 200 m of the line are included. Mean background values are indicated for Central Park (dotted line) and for remote areas (n=23) in southern Finland (dashed line).

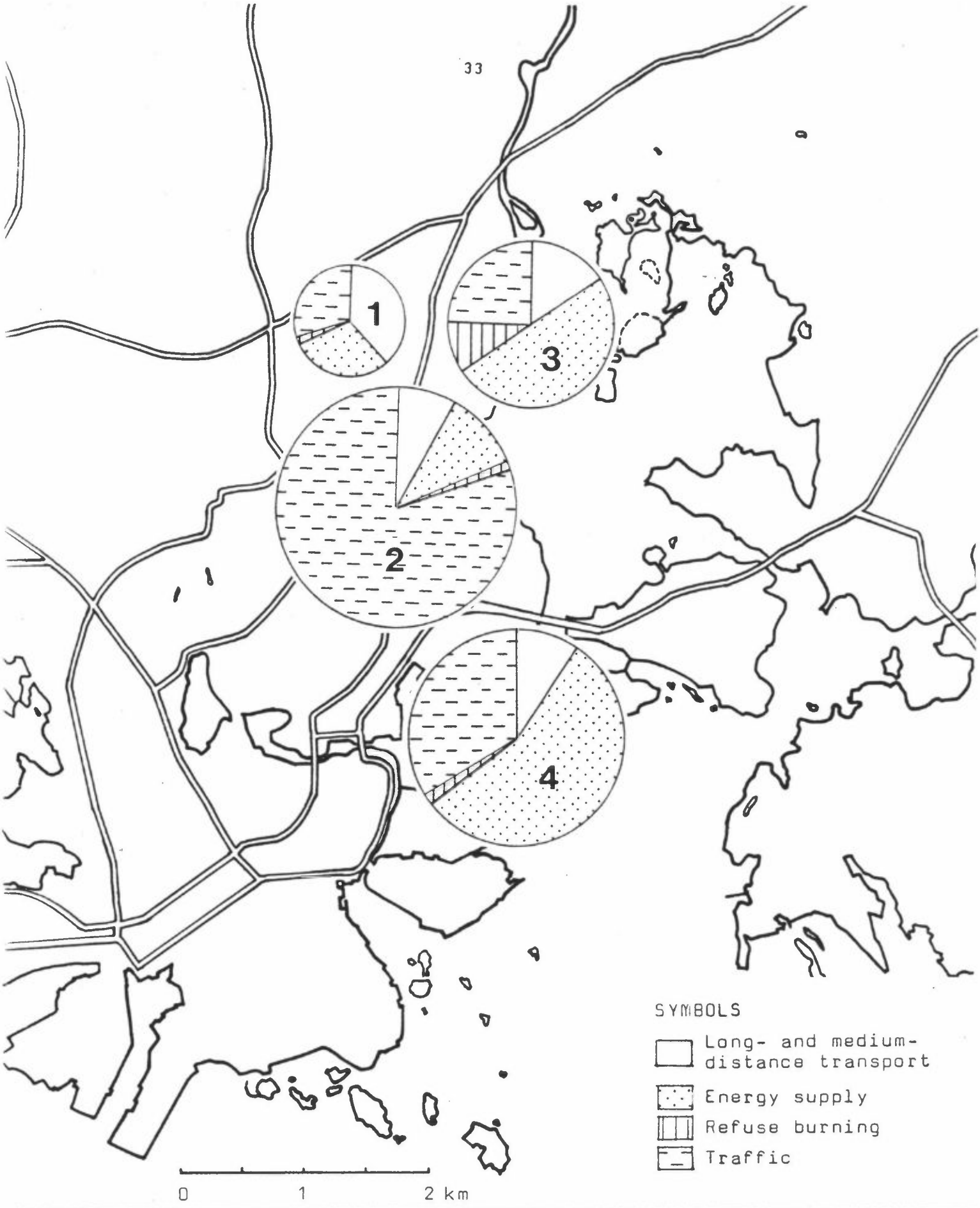


Fig. 12. Relative accumulation values of ash in moss-bags, indicating the origin of emissions in four subareas:
1. Central Park area (Kumpula) far away from emission sources.
2. Traffic area (Hämeentie) with daily traffic intensity of 26 200 vehicles.
3. Refuse burning area (Kyläsaari) near incinerator.
4. Energy supply area (Hanasaari) near coal-fired power plants

6.3. Cadmium (Cd)

The monthly accumulation of cadmium in moss-bags ranges from 0.01 to 0.65 ppm/dry wt. The greatest values are in the study area leewards from the Kyläsaari refuse burning plant, while the smallest values were measured in remote inland areas. The mean monthly accumulation of cadmium in the whole material is 0.20±0.15 ppm (n = 164) which is exactly the same average value as measured in autumn 1981 in similar study in the same area (Mäkinen & Lodenius 1982 and 1984).

The areal distribution of cadmium accumulation shows a distinct pattern (Fig. 14). The values near the refuse burning plant area approx. 20 times higher than in remote background areas, while in the Central park only six times higher values were measured. Other notable Cd values in fig. 14 were found by the main streets and in the vicinity of power plants (approx. 10 times higher than in background areas, Fig. 15).

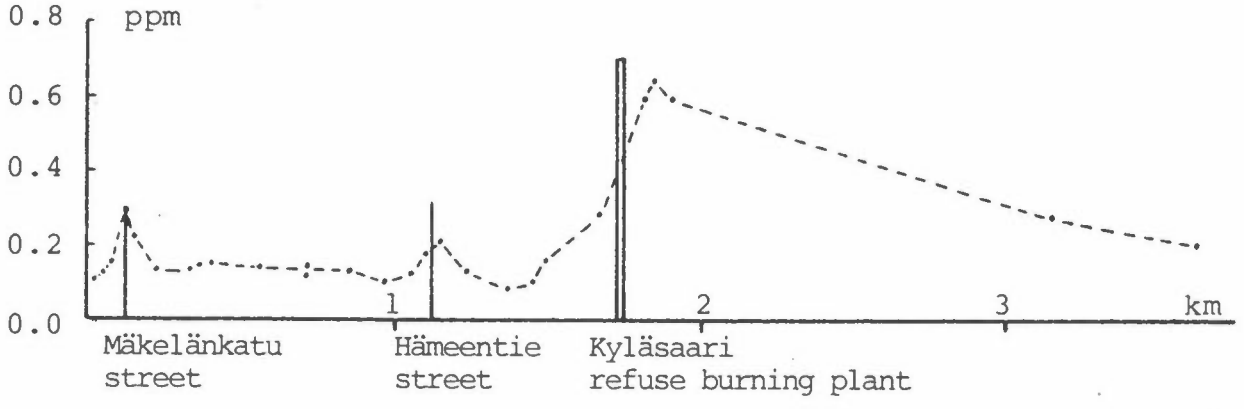


Fig. 13. Accumulation of cadmium in moss-bags along transect from west (left) to east through the study area.

Because of the elevated Cd values found also in moss-bags situated along roadsides outside the city, part of cadmium emissions may originate from vehicles. An additional, significant part comes also from deposition taking off with the currents of air caused by busy traffic (re-emission). Accumulation values elevated remarkably are found beyond 100 meters distance from the road.

Also in vertical direction the Cd values in moss-bags decrease steeply. In 1980 the accumulation value of cadmium was 0.40 ppm/dry wt recorded by the author at 3.5 m height above the pavement of the street Helsinginkatu, while at the height of 6 m cadmium content was 27.5 % lower.

The relative proportions of different emission sources are indicated in Fig. 16. According to the results of this study, the refuse burning plant had the greatest influence on Cd content of air in Helsinki. The percentage proportion in all subareas was more than 50. The second significant emission source seems to be the long-distance transport, which in some subareas makes 25 % of the monthly cadmium accumulation. According to the emission measurements, the importance of energy supply as a Cd source was only 8.6 % of that measured in refuse burning incinerator (Tables 2 and 5).

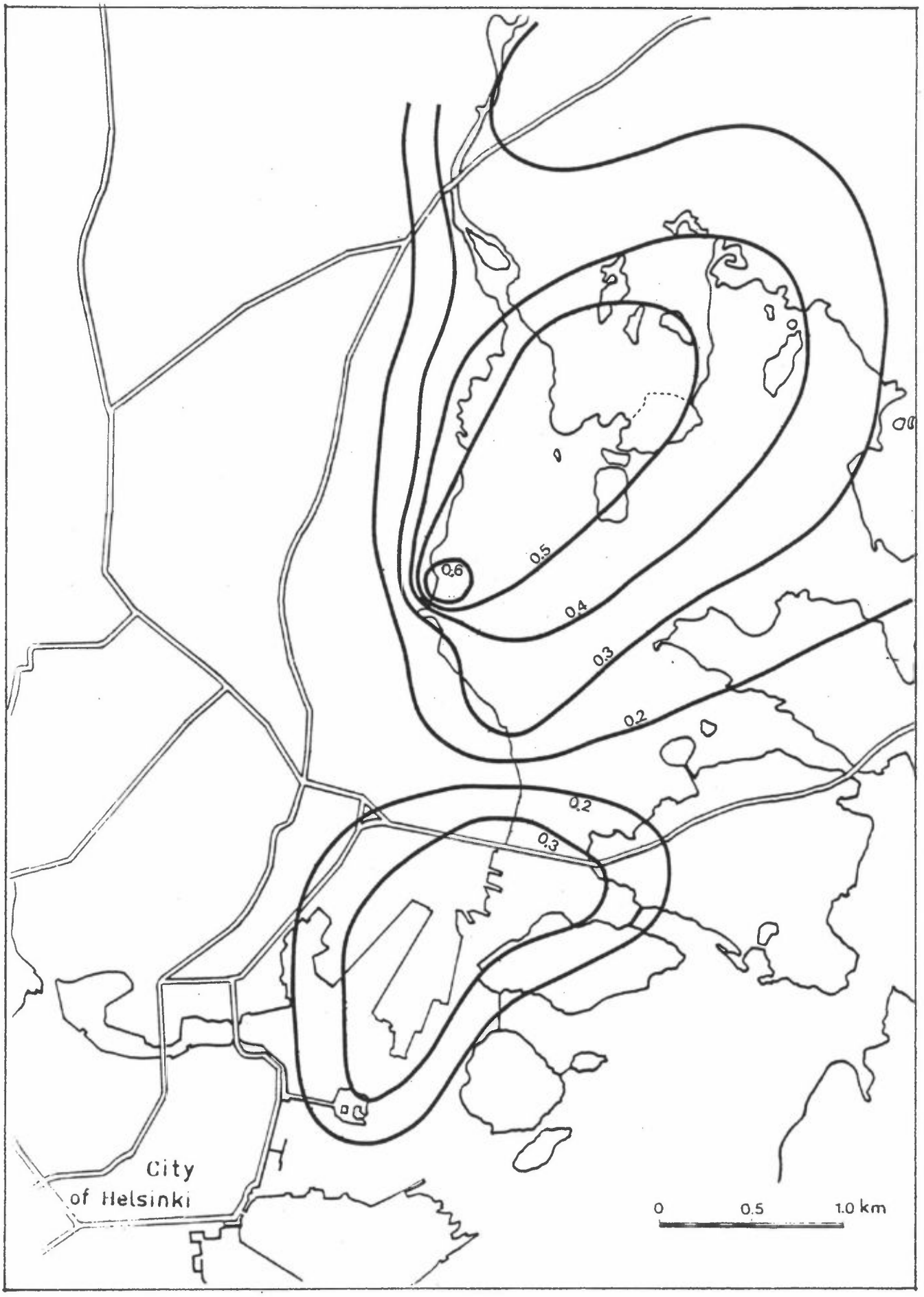


Fig.14. Mean monthly accumulation of cadmium (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

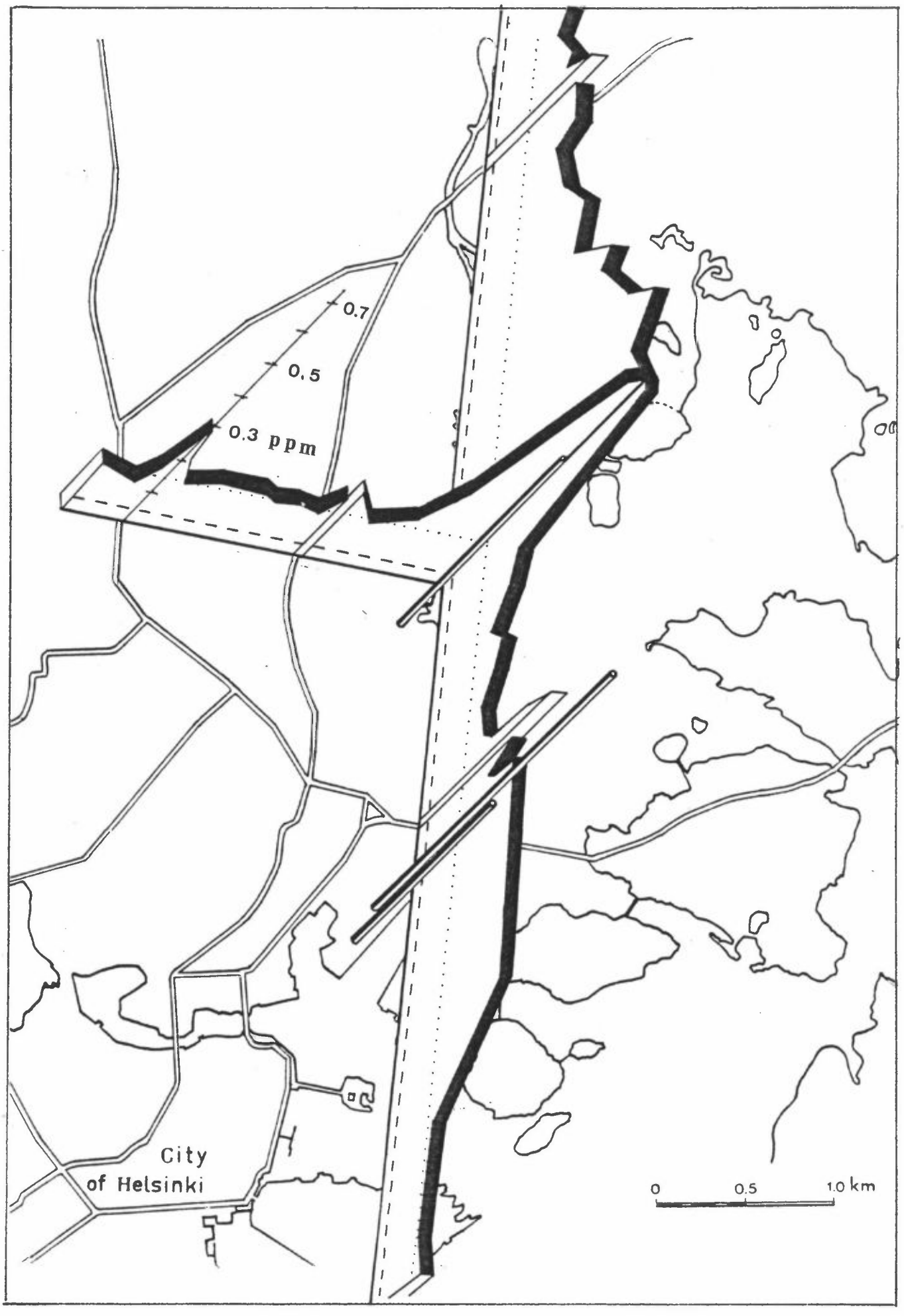


Fig.15. Cadmium accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

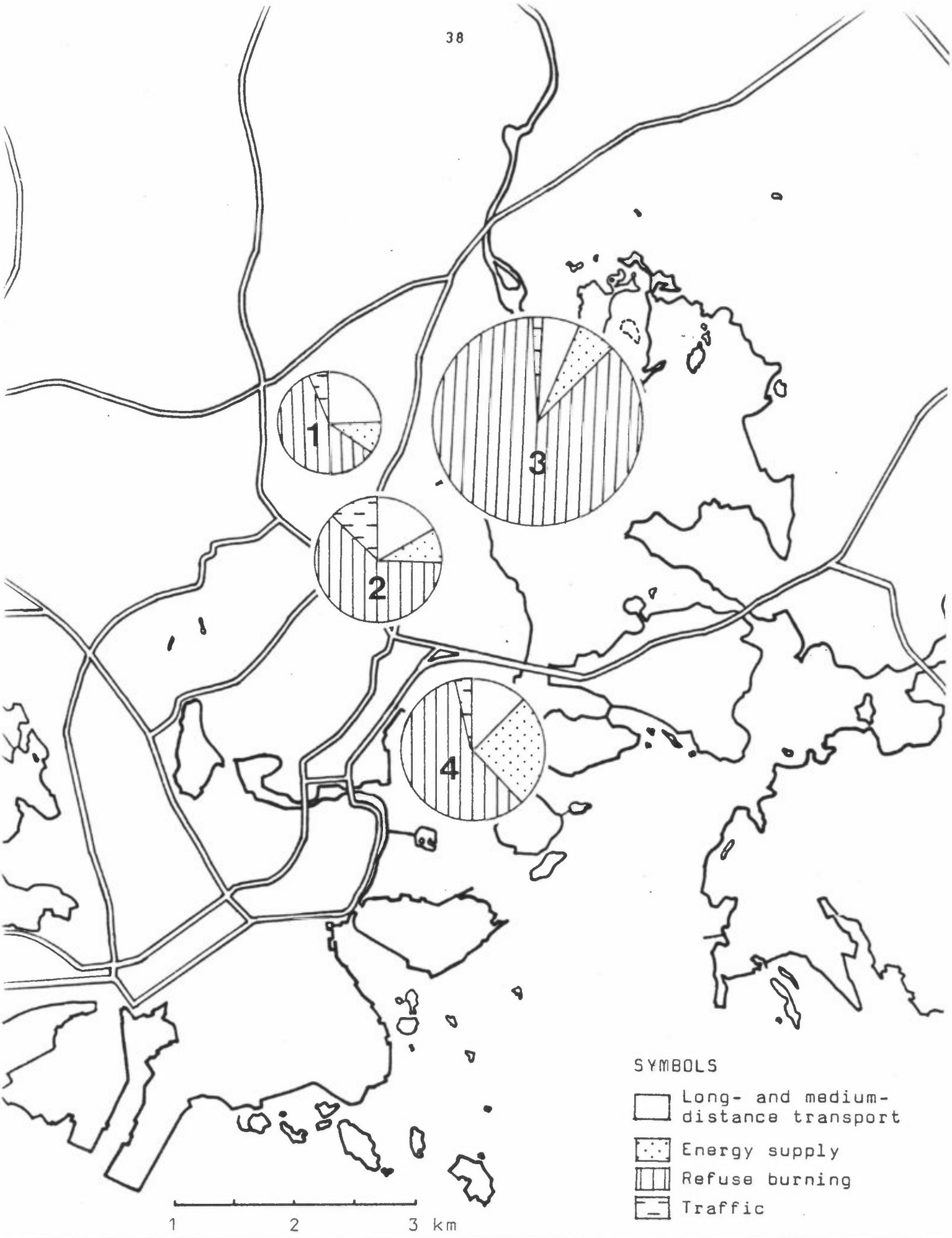


Fig.16. Relative accumulation values of Cd in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

6.4. Chromium (Cr)

A great part of chromium accumulated in moss-bags comes apparently from the city. This conclusion may be drawn if the accumulation values of the background area and the study area are correlated. In the southern Finnish background areas (Pälkäne and Inkoo), the mean monthly accumulation value was 0.1 ppm/dry wt only or 0.2 ppm at most (in remote areas of Vantaa and northern part of the Helsinki City (cf. Table 6), while the chromium values of moss-bags in great part of the study area were 10 times or more higher (Fig. 18). The highest values (over 3 ppm) were found near the main streets and leewards from the coal-fired power plants (Figs 17-19).

Because the chromium content of moss-bags was somewhat higher along all streets, the traffic may be considered as a noticeable chromium source. This is stressed in accumulation profiles across the streets (Figs 17 and 19). Far away from the main street the chromium content decreases rapidly. In the central park area of Kumpula the monthly accumulation value is less than 1 ppm/dry wt and near the City center

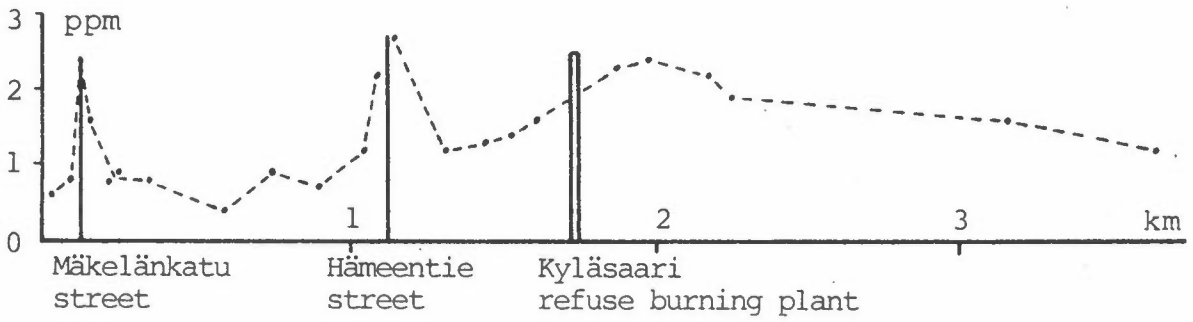


Fig. 17. Accumulation of chromium in moss-bags along transect from west (left) to east through the study area.

1.1 ppm. In the periphery of the city area the chromium content of moss-bags approaches the background level (Fig. 18).

In addition to the roadsides, distinctly increased chromium values were found near the refuse-burning plant (Fig. 18). The largest area with more than 2.2 ppm monthly chromium accumulation was found, however, in the nearest vicinity of the coal-fired power plant Hanasaari. Also in earlier studies made in the surroundings of a great coal-fired power plant in Inkoo, southern Finland, elevated chromium values were found in a feather moss (Hylocomium splendens) (Mäkinen 1982 and 1983).

The relative importance of the energy supply is to be seen in Fig. 20 when the chromium values of different sources in four subareas are compared. Near a street with busy traffic only part of the energy supply is covered by traffic emissions. In other three city areas the relative proportion of energy supply is more than 37 %, in the subarea 4 about 50 %.

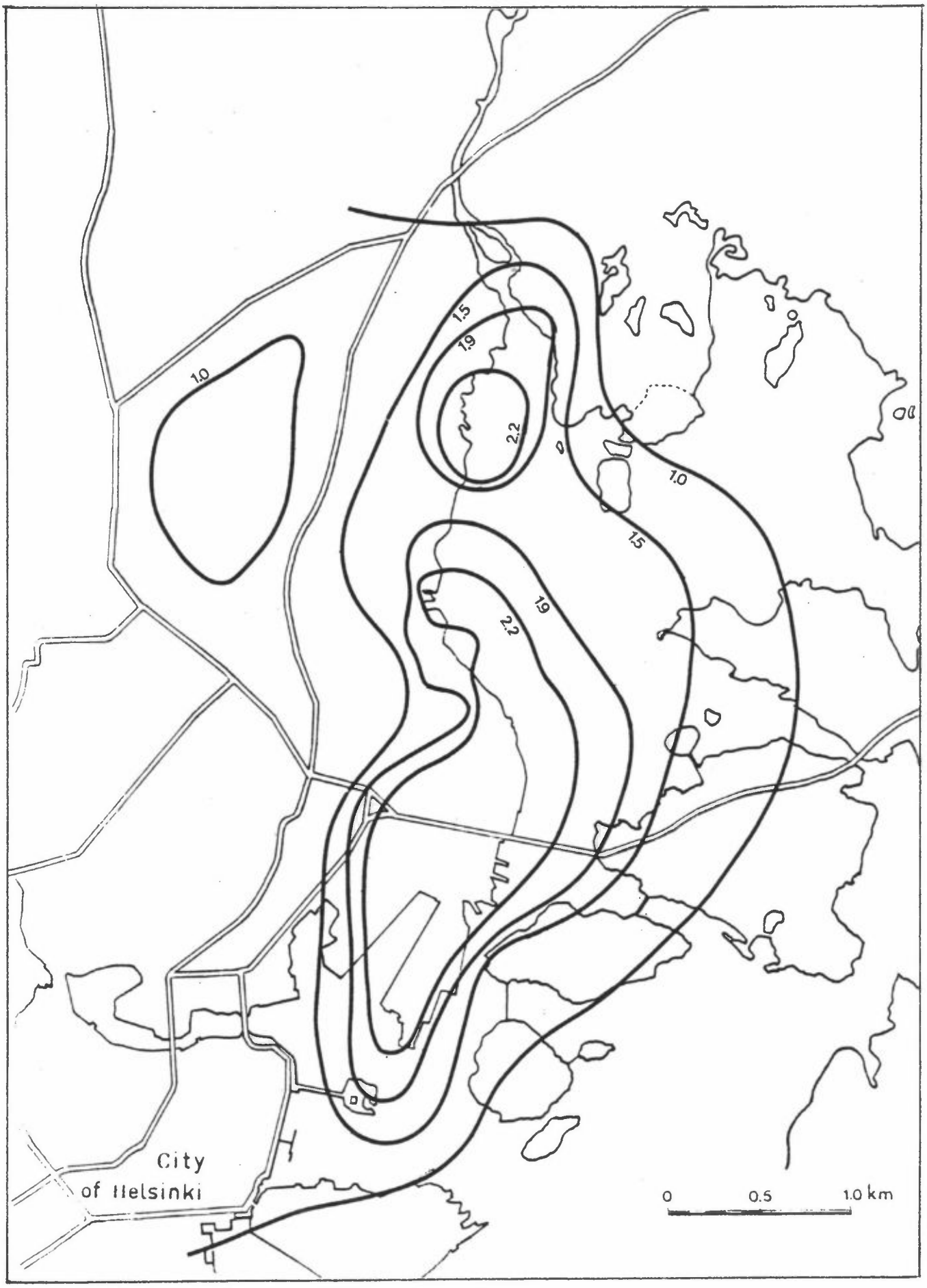


Fig.18. Mean monthly accumulation of chromium (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

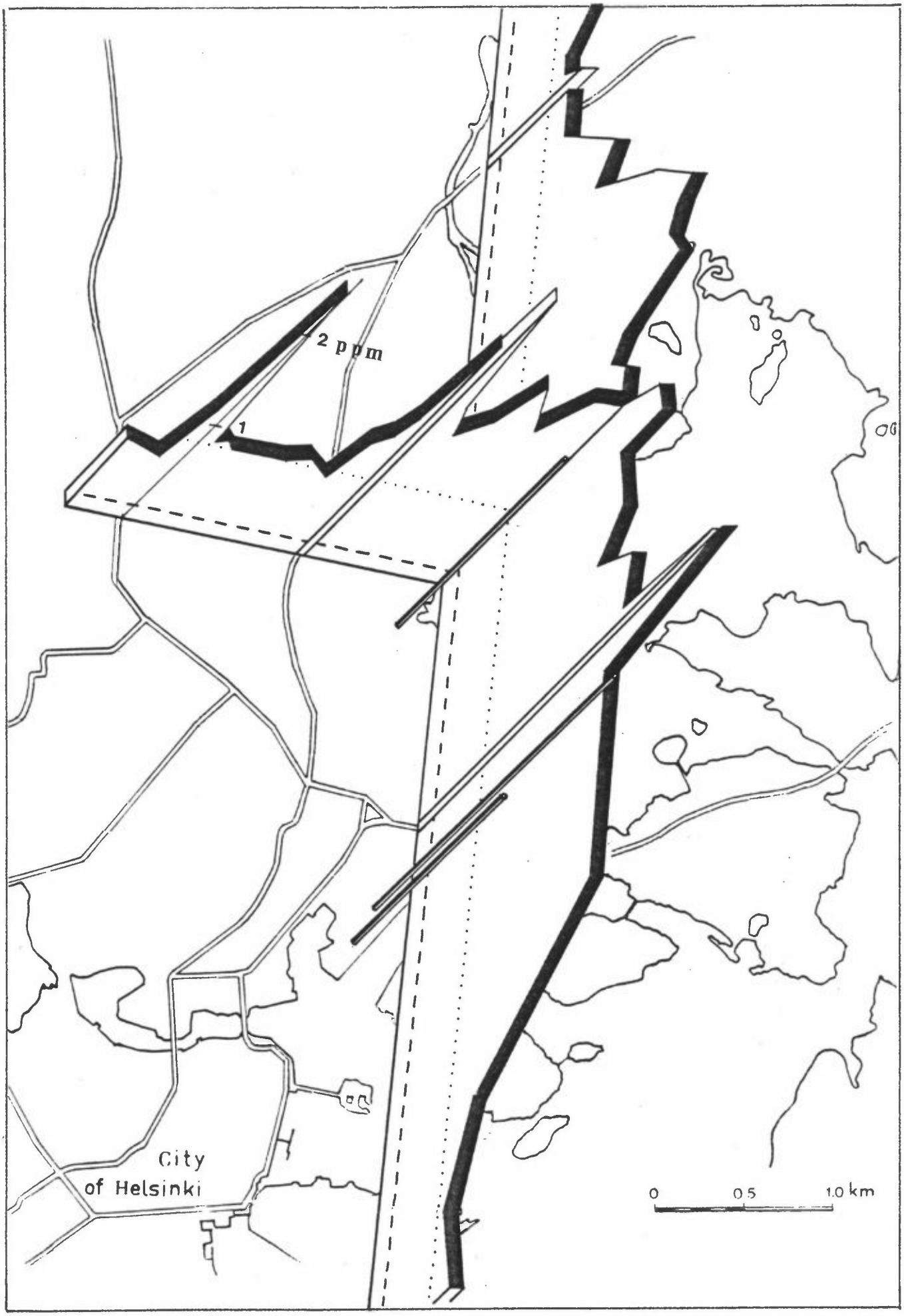


Fig.19. Chromium accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

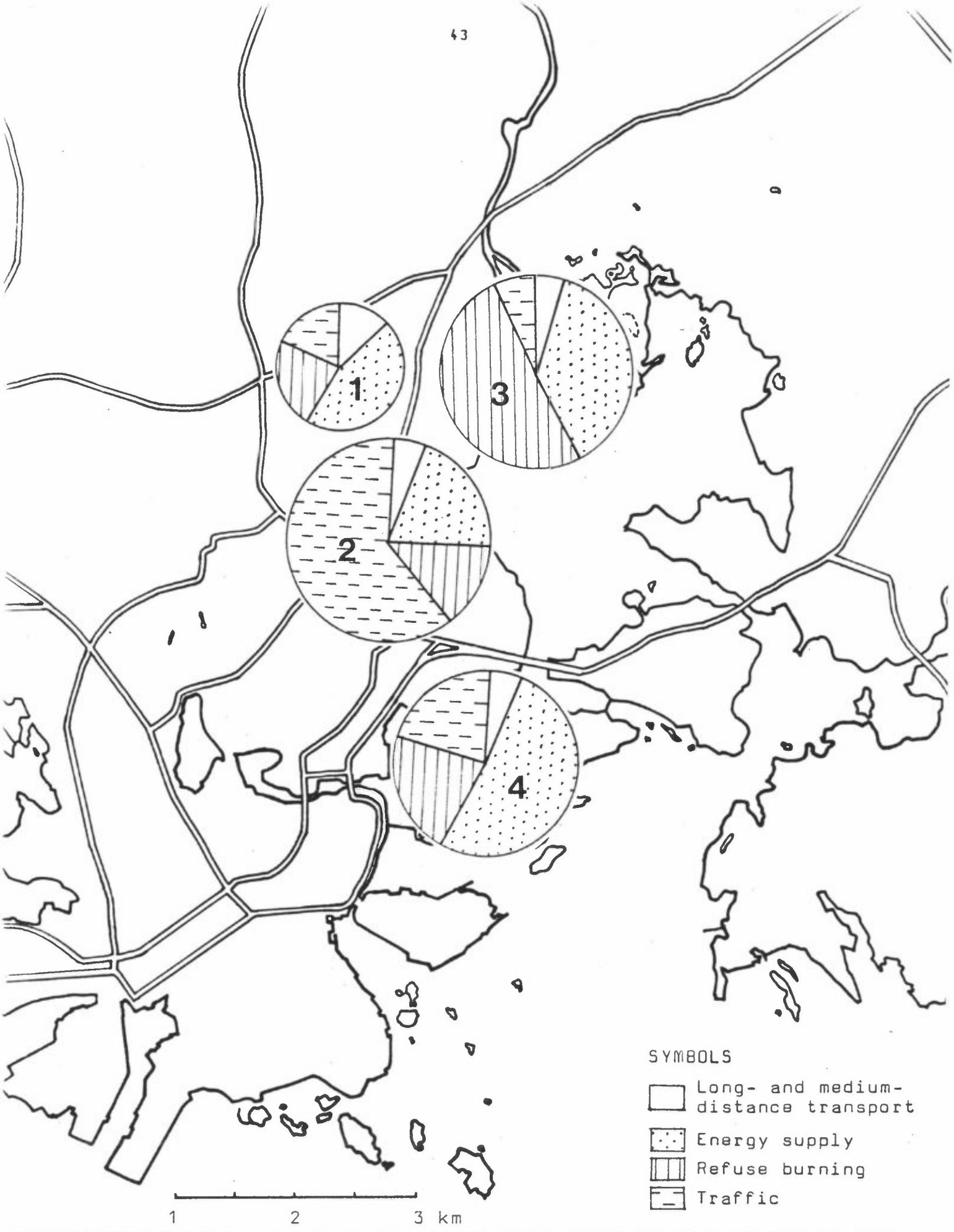


Fig.20. Relative accumulation values of Cr in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

6.5. Copper (Cu)

The distribution pattern of copper accumulation in moss-bags was quite similar with that of chromium which fact may suggest a common emission source (Figs 21 and 22). The amounts of copper in moss-bags, however, are 4 to 5 times higher than corresponding chromium values. The mean monthly accumulation of copper was 5.1±2.9 ppm/dry wt (n = 164) ranging from 0.5 to 12.3 ppm.

The smallest values (0.5 ppm) were measured in background stations of the inland (Pälkäne) and coastal (Inkoo) regions (Table 6). In remote areas of Vantaa and Helsinki, the monthly accumulation of copper was somewhat greater (0.6 ppm/dry wt) while in the Central Park area the mean accumulation value was 3.1 ppm/dry wt (Fig. 23).

The greatest mean values were found along main streets and in Tervasaari island near the coal-fired power plant (Fig. 22). As the copper values of all measuring points near the power plant were somewhat elevated, the power plant may be considered as one emission source. The copper content of Polish coal

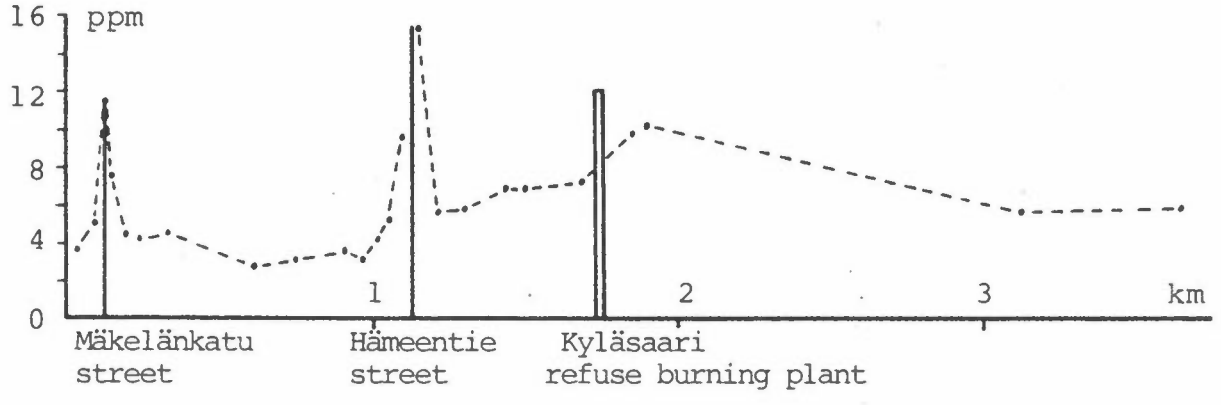


Fig. 21. Accumulation of copper in moss-bags along transect from west (left) to east through the study area.

used in Hanasaari is 12-15 g/tonne (Lautkaski et al. 1980). The corresponding copper content of fly ash is about 174 ppm (Mäkinen 1983).

The importance of traffic for copper emissions, however, was at least of the same order as the energy supply, but a great majority of surface emissions is deposited near the streets, while on the other hand the stack heights of power plants in the study area are 87.5 m and 150 m.

Also near the Kyläsaari refuse-burning plant, the monthly accumulation values of copper in moss-bags are distinctly elevated and approach the level in roadsides. The copper emissions of the refuse-burning plant originate mainly from the electric components and wires. Their proportion in community waste was estimated approximat. 0.4 g/tonne (Hovsenius 1977 and 1979, Mroueh & Laukkarinen 1981).

In different parts of the study area the origin of copper, however, varies remarkably (Fig. 22). According to the calculations by the author, the proportion of the energy supply is dominating (more than 50 %) in all subareas except near the main streets. This calculation is based on emission measurements and copper accumulation in moss-bags. The proportion of traffic in subareas (except the one mentioned above) was estimated at 10 to 20 % (Fig. 24).

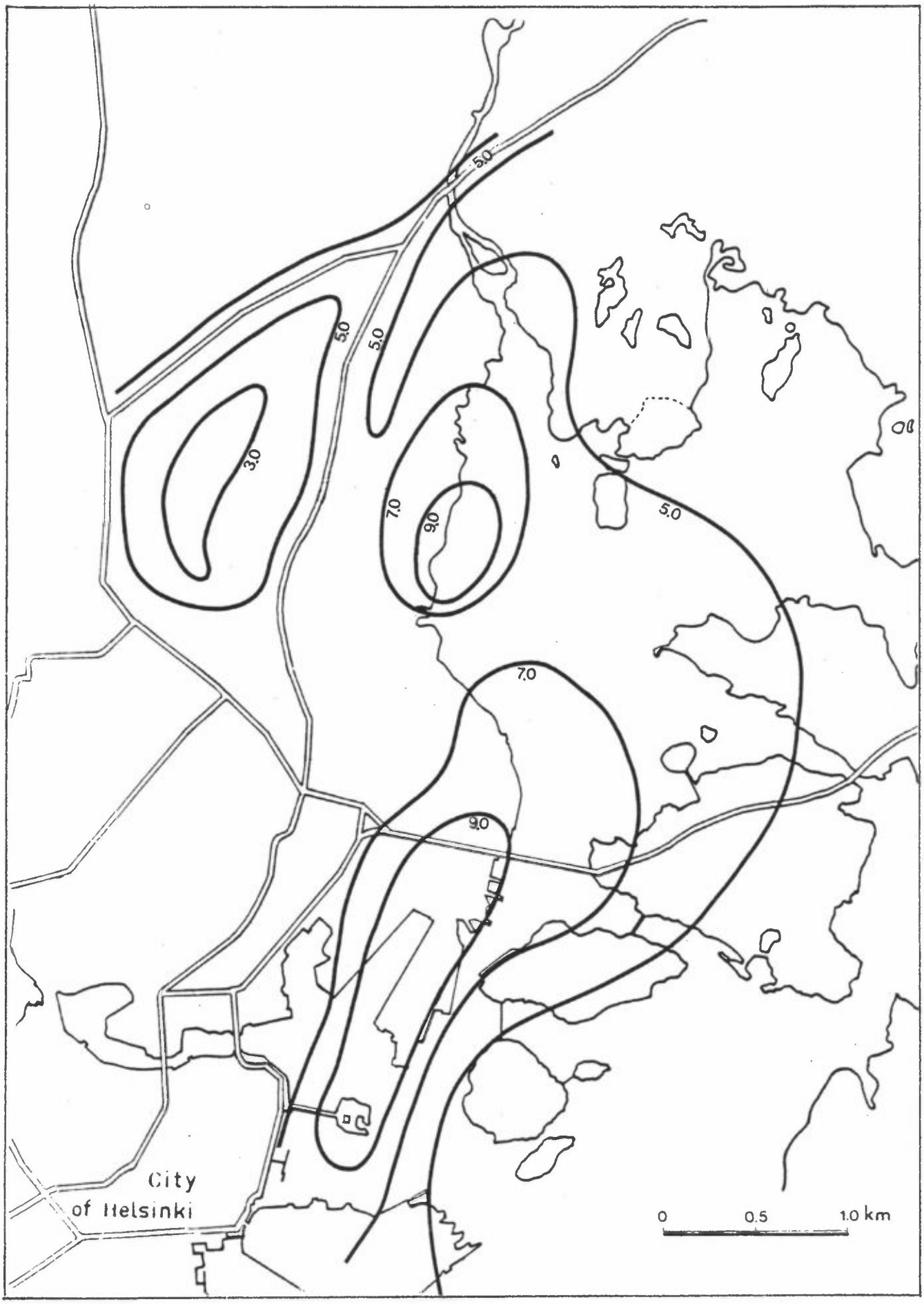


Fig.22. Mean monthly accumulation of copper (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

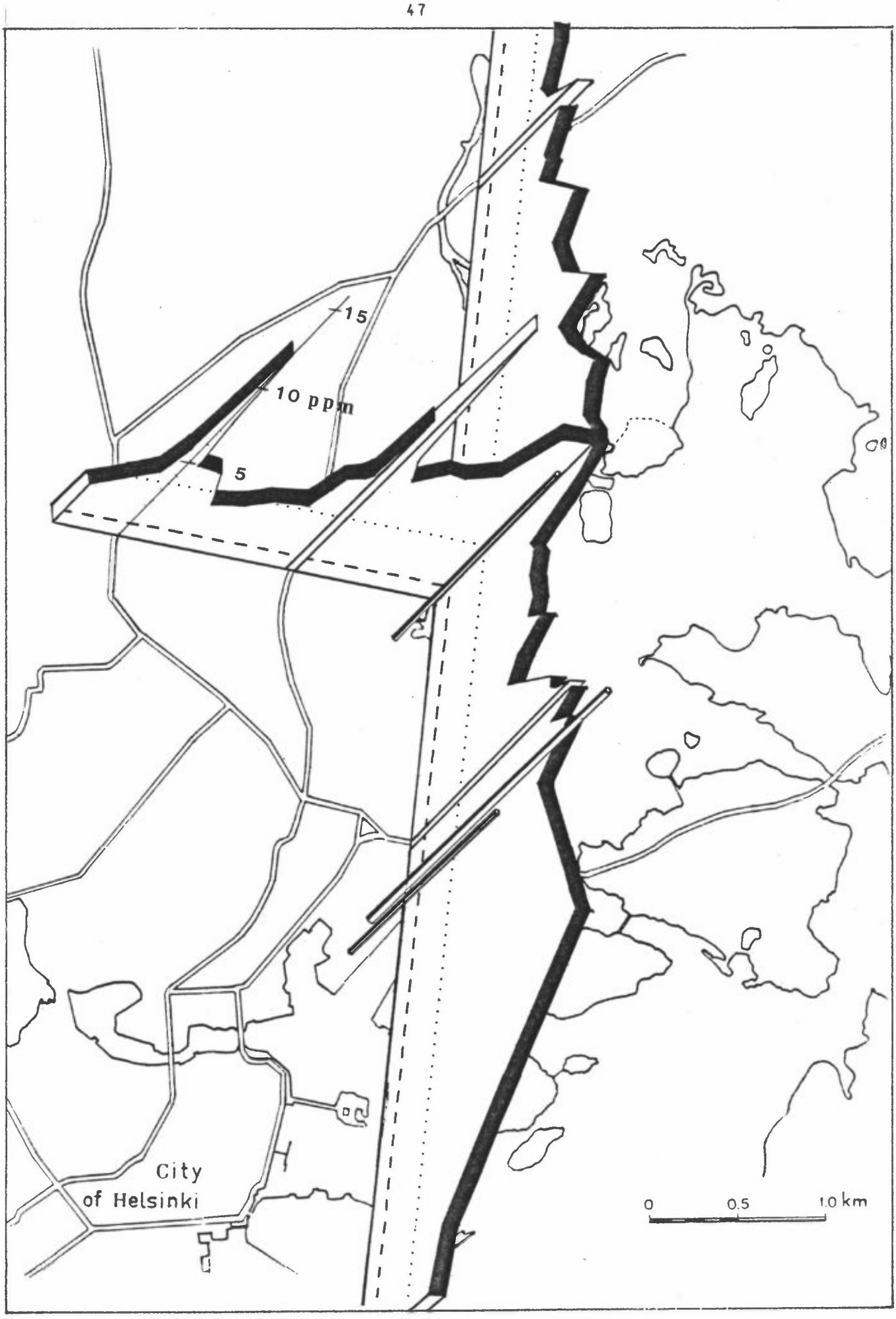


Fig.23. Copper accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

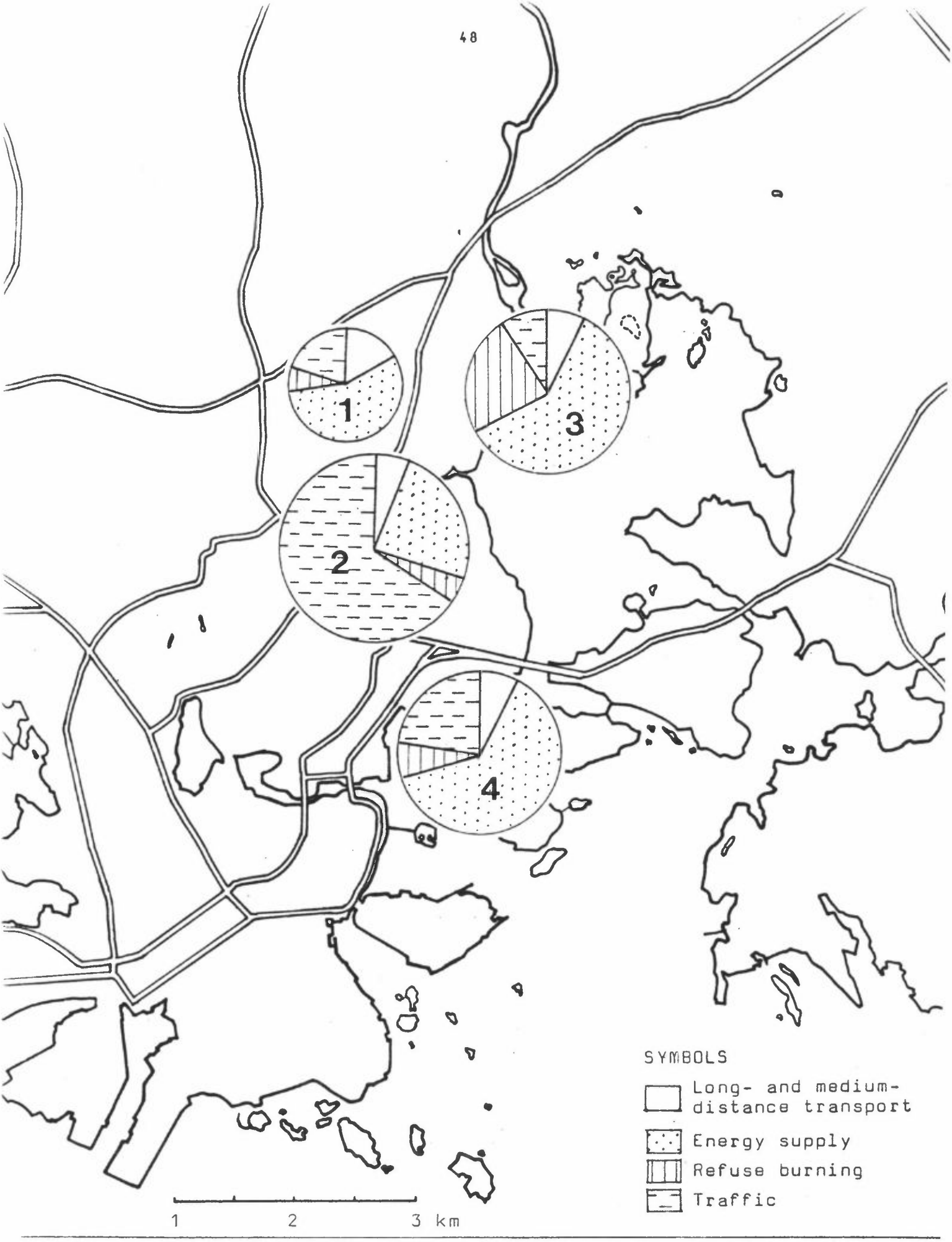


Fig.24. Relative accumulation values of Cu in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

6.6. Iron (Fe)

Iron is a very common mineral in nature, both plants and soil containing plenty of this element. From the weathering soil surface, dust is easily raised up, particularly in open places and especially in polluted areas.

Another emission source of iron is coal. The fly ash of power plants consists of 3 to 21 % of iron oxides depending on the origin of coal (Pohjola 1981). The iron oxide content of Polish coal is approx. 11 % and that of Russian coal about 8.3 % (Keppo & Ylinen 1980, Mäkinen 1983).

In communal waste there is much iron, too. From 5600 tonnes of metal waste burned in Kyläsaari incinerator in 1981, about 95 % consisted of iron and could be separated with a magnete (Table 4 and Anttila & Lindström 1981). This amount makes about 400 tonnes monthly.

Other iron sources in the study area are metal industries and vehicles and metal constructions (corrosion). The

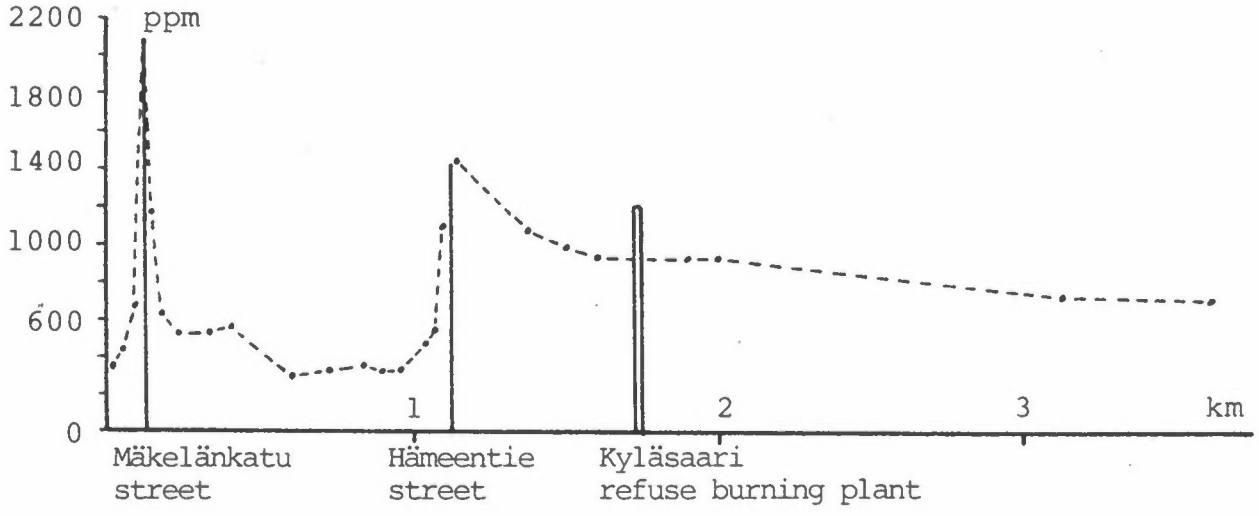


Fig. 25. Accumulation of iron in moss-bags along transect from west (left) to east through the study area.

influence of traffic on iron accumulation into the moss-bags is to be seen best in street profiles (Figs 25 and 27). The iron emissions of traffic, however, are limited to narrow belts beside the streets. Instead, the influence of energy supply and refuse burning is to be seen in moss-bags more widely because of high smokestacks. By estimating the relative influence of different emission sources, the proportion of energy supply was found to be dominating ($\geq$ 50 %) in all subareas except near traffic roads (Fig. 28).

The greatest accumulation values of iron in the study area were approximately 60-70 times higher than in the background areas (Table 6, Fig. 26). Also inside the study area the concentrations between the subareas may vary by a factor of 20.

In the Central park of Kumpula, the mean iron content of moss-bags was about 4 to 5 times higher than outside the city but only one tenth in relation to the inland values.

In Inkoo, 60 km west of Helsinki, the iron content of moss-bags was distinctly higher than in the northern periphery of the Helsinki region (Table 6).

The mean monthly iron accumulation of moss-bags in the whole material was 63$\pm$43 ppm/dry wt.

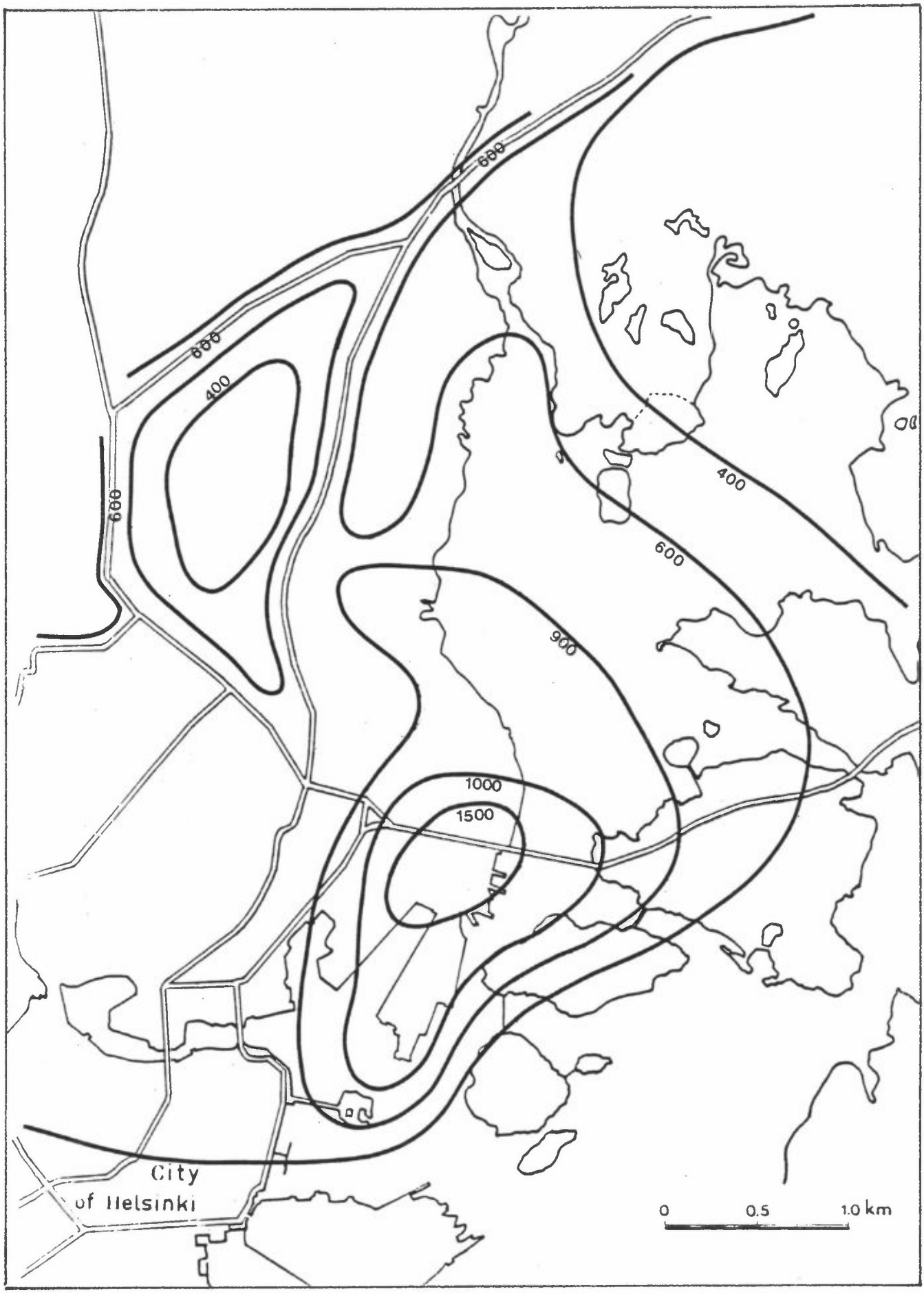


Fig. 26. Mean monthly accumulation of iron (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

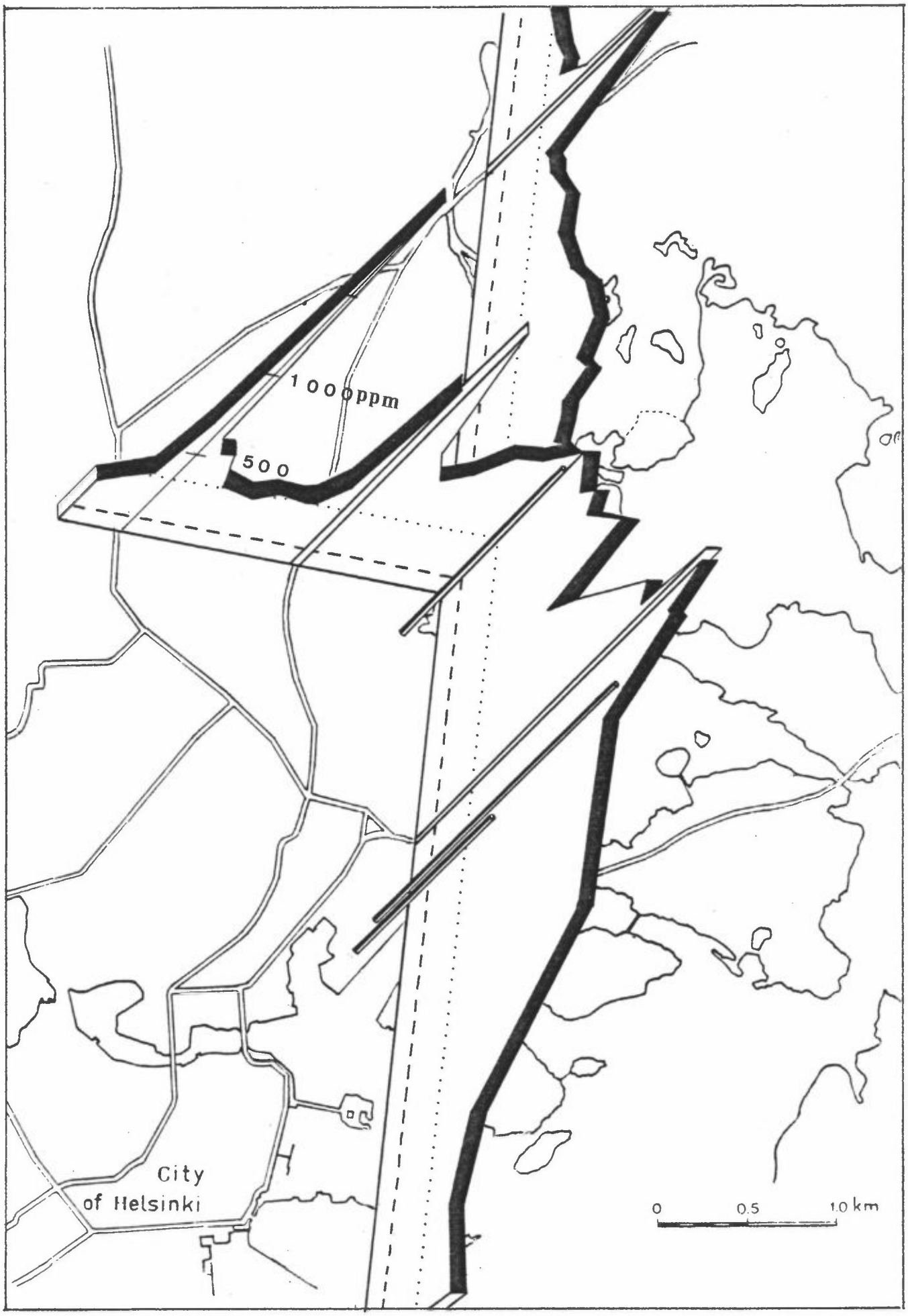


Fig. 27. Iron accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

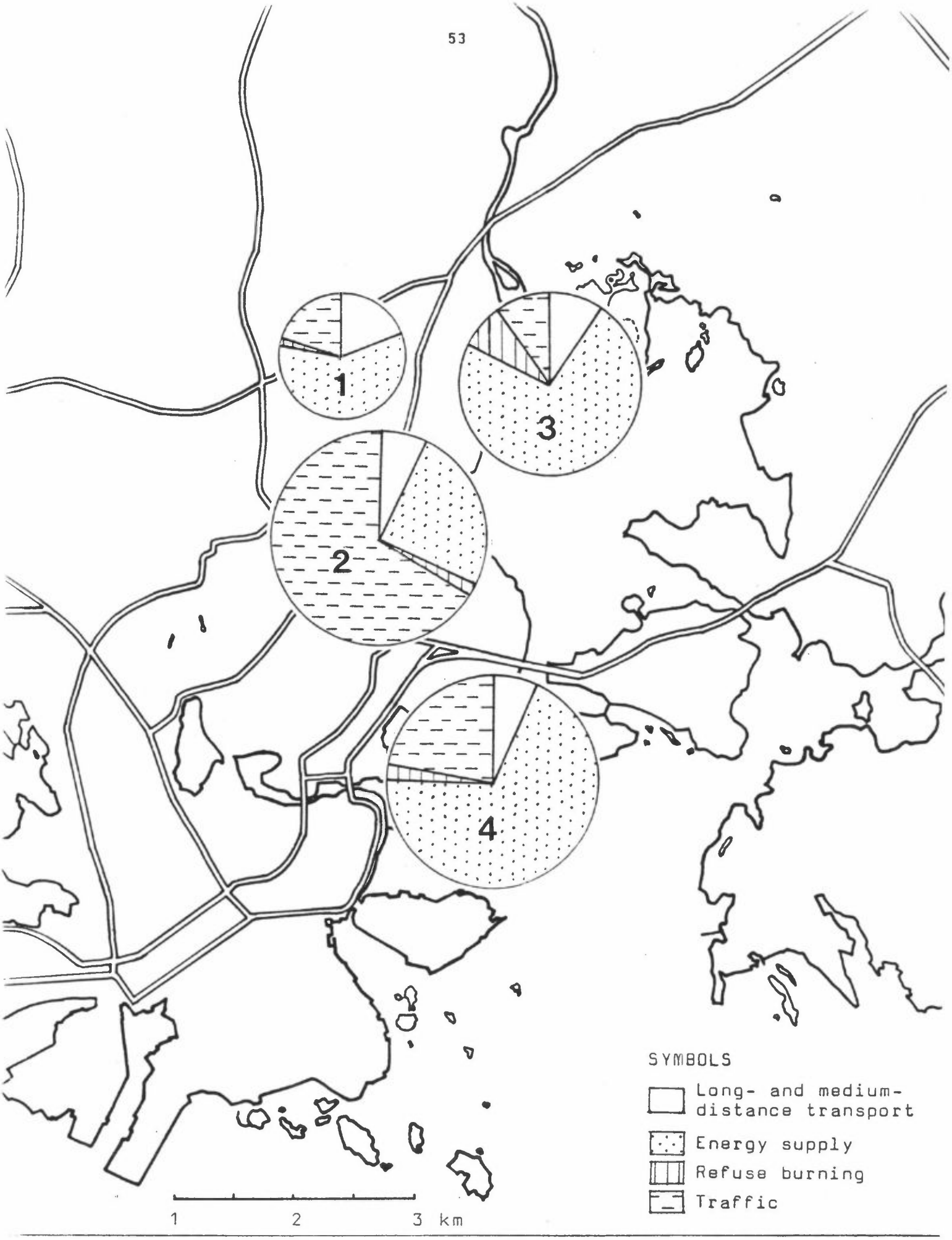


Fig. 28. Relative accumulation values of Fe in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

6.7. Lead (Pb)

The accumulation of lead in moss-bags ranges from 1.0 to 88.3 ppm/dry wt/month in whole material. The mean value ($\bar{x}\pm SD$) is 28.8±17.5 ppm (n = 164). From every point several moss-bags were analysed.

In all measurement points of the Helsinki area the accumulation of lead exceeds the background value of southern Finland, 4.3 ppm. In the most heavily polluted subarea the accumulation is about 20 times higher than the background level. All observation points with Pb level greater than 50 ppm are situated along the main streets, excluding one separate area in the estuary of Vantaa river (Fig. 30). There the mean values of 7 adjacent measurement points exceeded 50 ppm although there is no traffic nearer than at 300 metres distance behind tall buildings, while another possible source, the refuse burning plant is situated at 1 km distance windward (Figs 1 and 30).

The influence of traffic on lead accumulation can be seen in transects shown in figures 29 and 31.

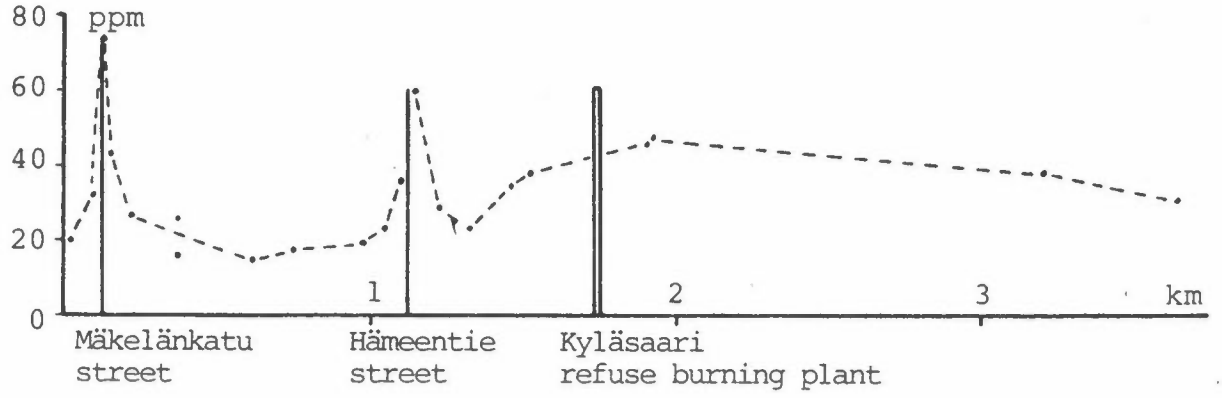


Fig. 29. Accumulation of lead in moss-bags along transect from west (left) to east through the study area.

The influence of the main streets does not, however, extend far. At the distance of 200 m the lead values in moss-bags are on average only 13 % of those measured by the street (Nurmi 1981, Mäkinen & Lodenius 1982).

Beyond the street sides the lead accumulation varies between 30 and 60 ppm (Figs 30 and 31). The lowest values (less than 30 ppm) are measured consistently on park areas where the influence of traffic is slight. One exception is found on the shores and islands of the bay Vanhankaupunkinlahti near the central parts of the study area (Fig. 30) where higher than 30 ppm accumulation values were measured even at 1 km distance from the nearest streets. This pattern is possibly caused by the power plants as well as by the refuse burning incinerator, because west of the study area in the park area of Töölö the lead values are distinctly smaller while the influence of traffic is higher (Fig. 30).

The relative proportions of different emission sources in four city areas are indicated in Fig. 32 (cf. Fig. 31 too). The method of estimation was outlined in section 5. The first subarea (the Central Park) is situated between main streets and its mean lead accumulation is considered as background value for the city (cf. Table 6). It is still four times higher than mean rural background value.

The city area 2 is situated along the main street Hämeentie (Fig. 7). The lead accumulation values are on average 11 times higher than in rural areas. The city area 3 is near refuse incinerator Kyläsaari in the estuary of Vantaa river and without any traffic roads. The city area 4 near

the large power plants in Hanasaari is surrounded on three sides by busy main streets. Their influence does not reach into the nearest island where also great accumulation values of lead were measured.

The relative proportion of the four main emission sources vary considerably in different subareas (Fig. 32).

The influence of energy supply is highest in subarea 4. In other areas it is not much higher than the background values. While the influence of refuse burning plant is considerable, at least 25 % in all subareas, the highest relative value for this factor, approximately 70 % is found in subarea 3.

The influence of traffic is greatest in subarea 2 as expected. The neighbourhood of refuse burning plant, however, appears in results. Also background values include traffic emissions. The majority of that lead, however, comes from far away.

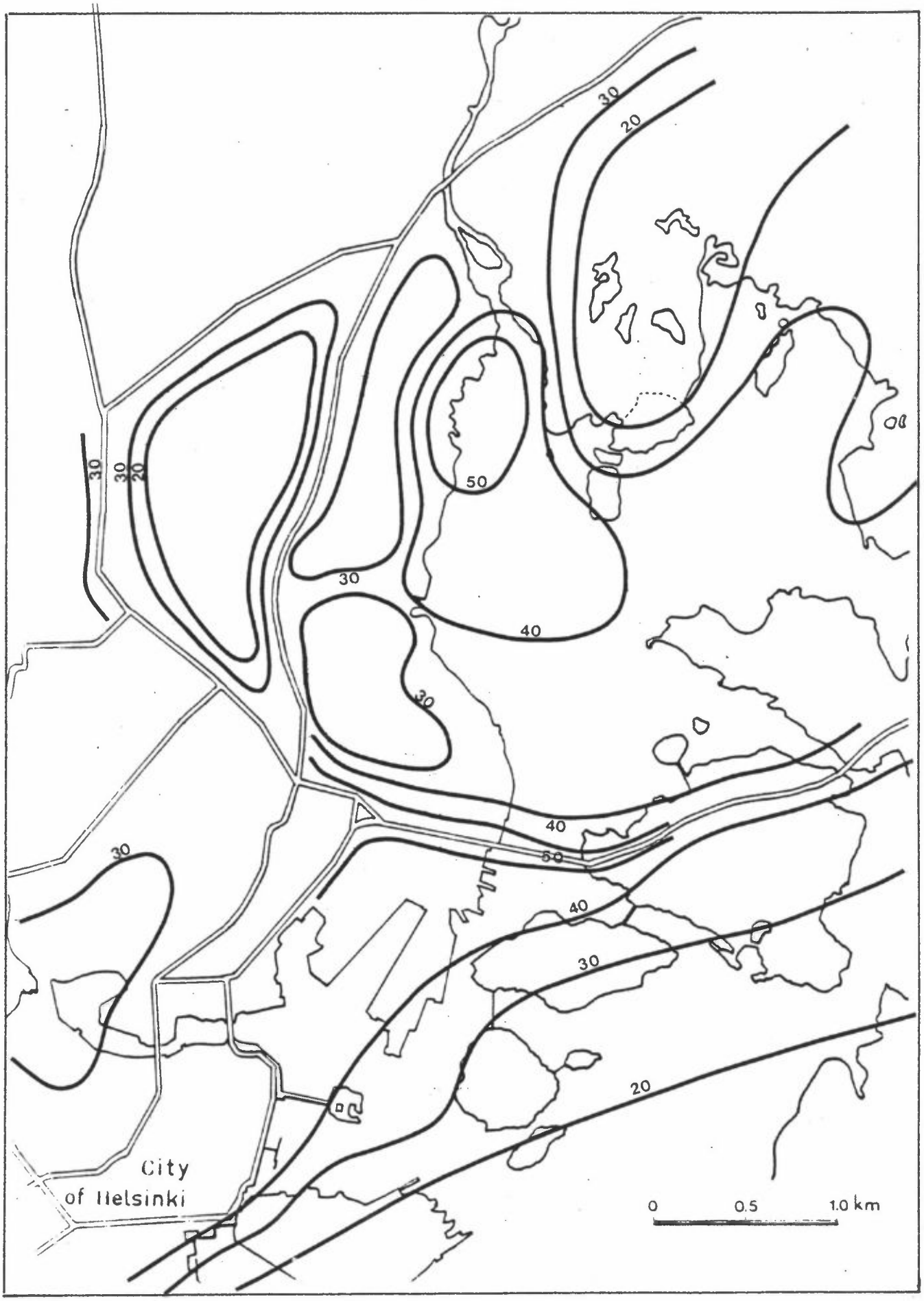


Fig.30. Mean monthly accumulation of lead (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

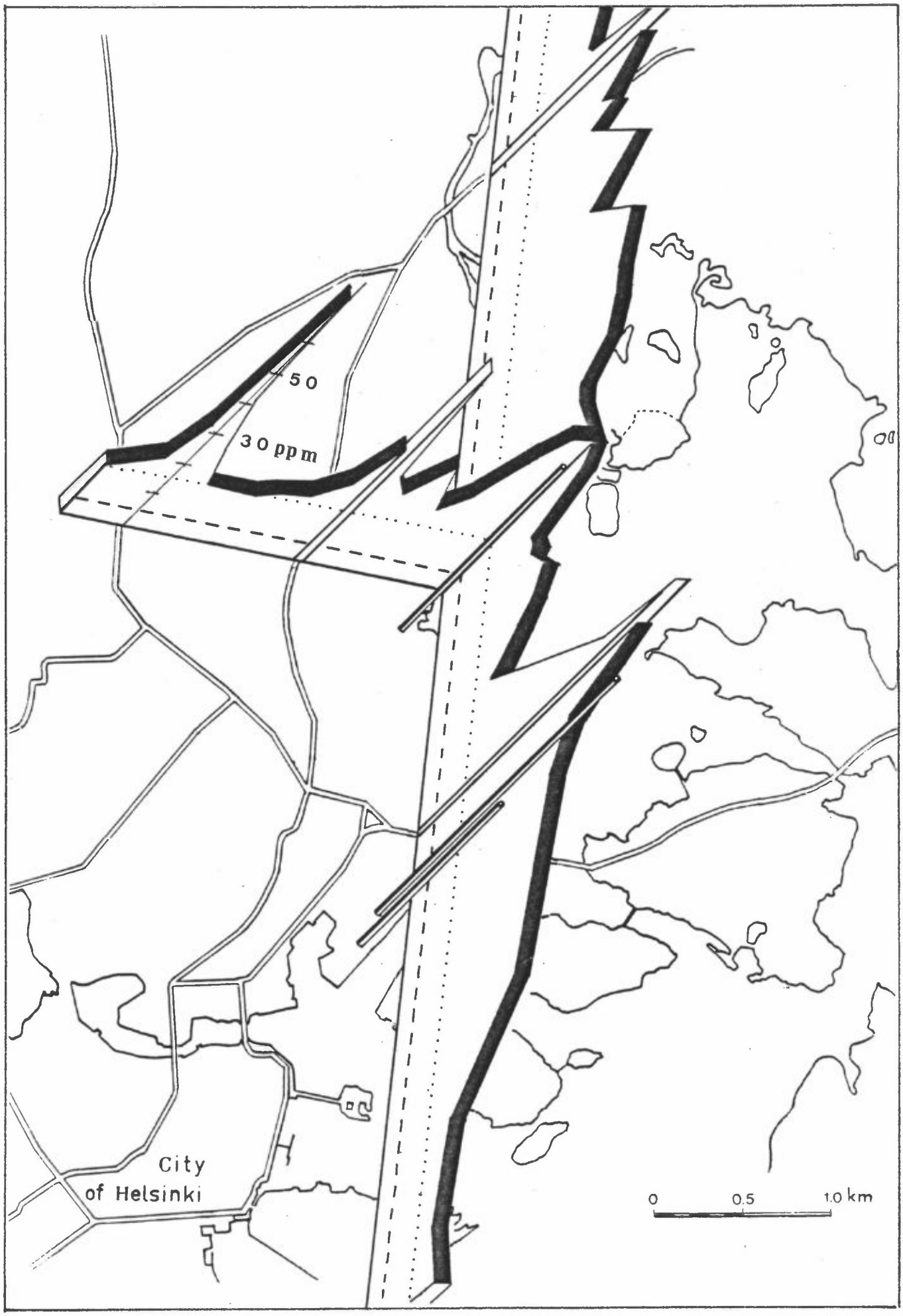


Fig. 31. Lead accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

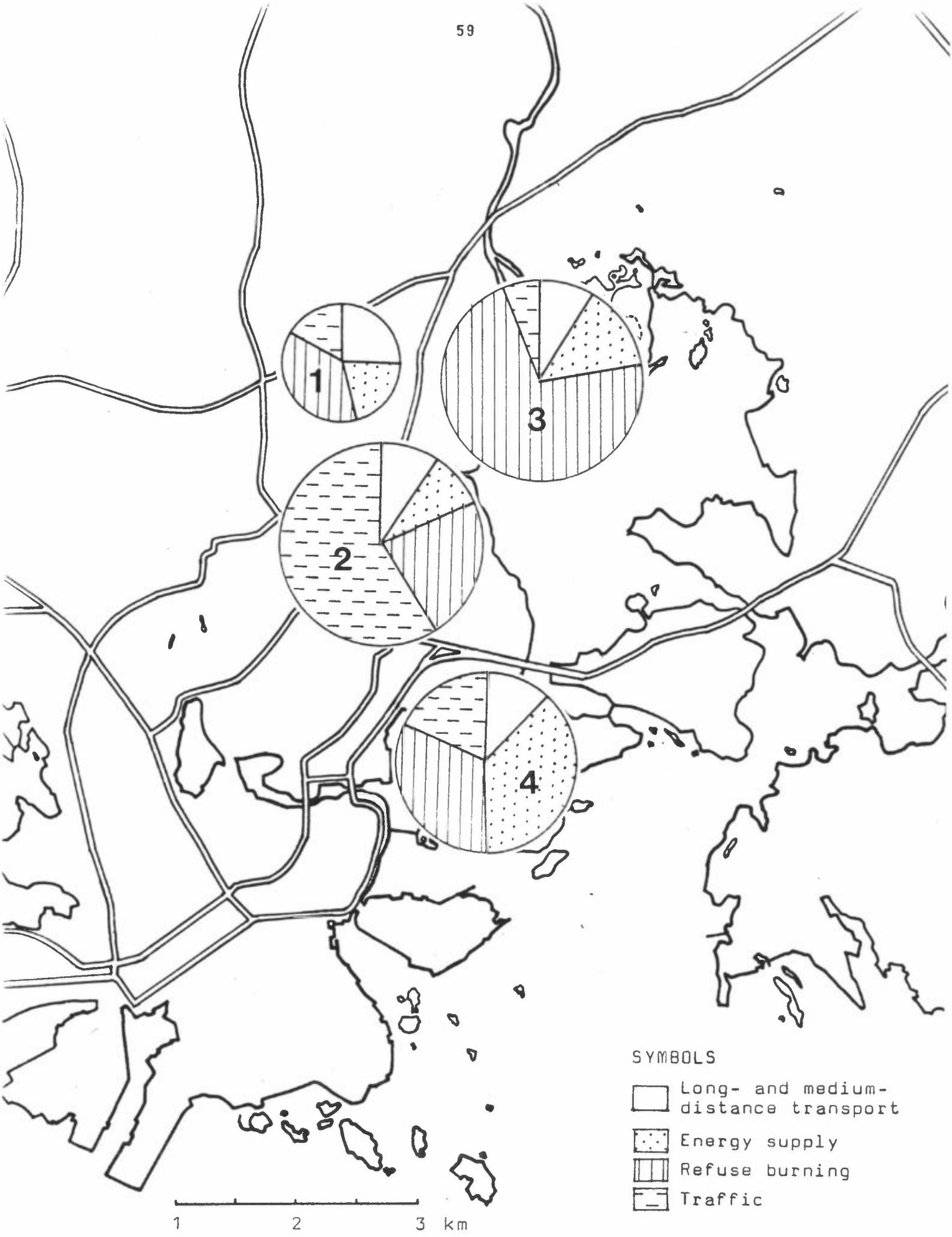


Fig. 32. Relative accumulation values of Pb in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

6.8. Nickel (Ni)

The nickel content of the Sphagnum mosses used in this study was at the beginning on average 1.6 ppm/dry wt. After about four months accumulation time the nickel content was increased in many places over 20 ppm. Converted into monthly accumulation values, that means a rate of more than 4 ppm/dry wt. Two such areas are to be seen in Fig. 34 . The first one is situated near the Kyläsaari refuse-burning plant, the other one around the Hanasaari coal-fired power plant.

While high values were found near the channel to the coal harbour, one may suppose that part of nickel emissions originate from heavy oil used in ships, the nickel content of heavy oil being approx. 30 ppm. The same conclusion may be drawn near oil-fired heating plants, where the nickel content of moss-bags is distinctly elevated (Figs 1 and 34, Mäkinen 1983). Also coal-fired power plants use some heavy oil as fuel in auxiliary boilers and in the starting stage (Mäkinen 1983, Table 2).

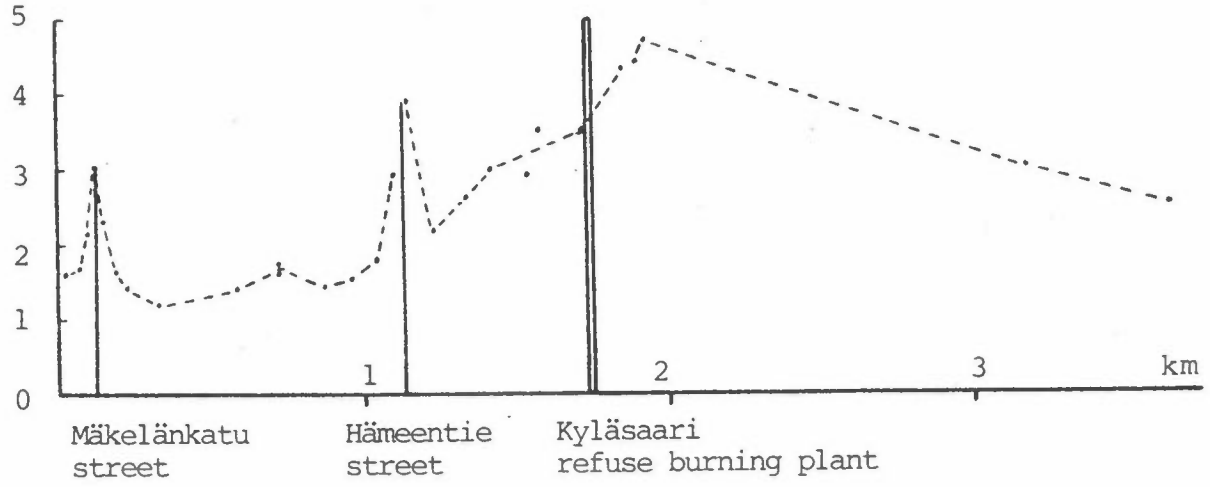


Fig. 33. Accumulation of nickel in moss-bags along transect from west (left) to east through the study area.

The monthly accumulation of nickel in moss-bags ranges in the whole material (n = 164) from 0.2 to 9.3 ppm/dry wt. The mean value was 2.2±1.4 ppm. It is somewhat higher than in 1981 apparently because of the greater number of receptor points in the polluted part of the study area (cf. Mäkinen & Lodenius 1982).

The smallest accumulation values (0.8-0.9 ppm Ni) were situated near the NE and SE corners of the study area. The mean value for the Kumpula Central park area was 1.5 ppm (Table 6). The mean background value for the inland areas of Vantaa and northern Helsinki was 0.4 ppm Ni/dry wt.

The greatest mean nickel values were thus about 20 times higher than in rural areas.

By estimating the relative proportion of different emission sources in the study area, the energy supply comes more forward than other sources (Fig. 36). The second one in order seems to be the refuse burning. The proportions of traffic and long-distance transport remain smaller. The relative importance of traffic as an emission source of nickel is smaller than for other metals. This may be due to the durability of nickel against corrosion. Also the amount of nickel in vehicles has decreased in recent years.

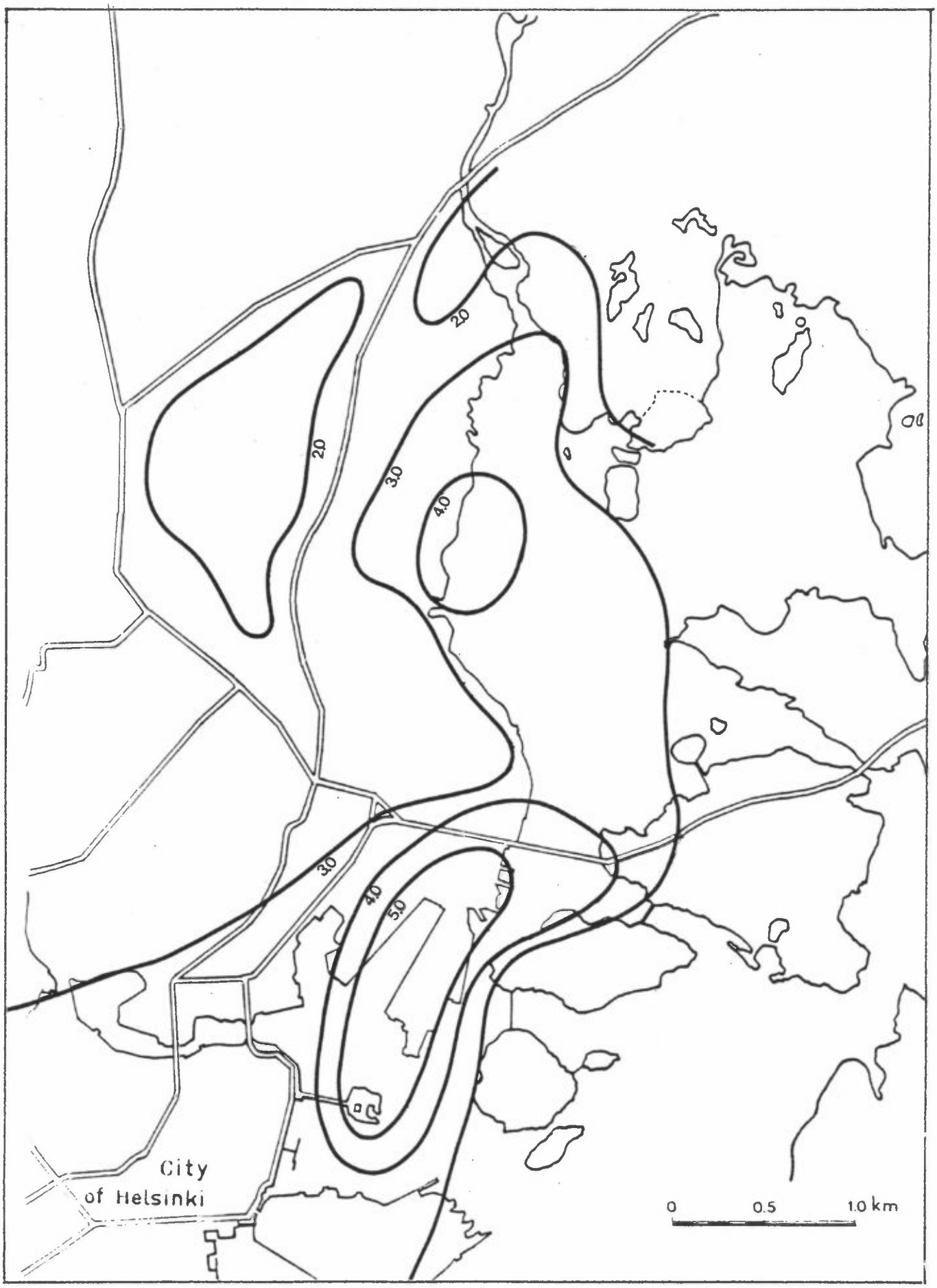


Fig. 34. Mean monthly accumulation of nickel (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

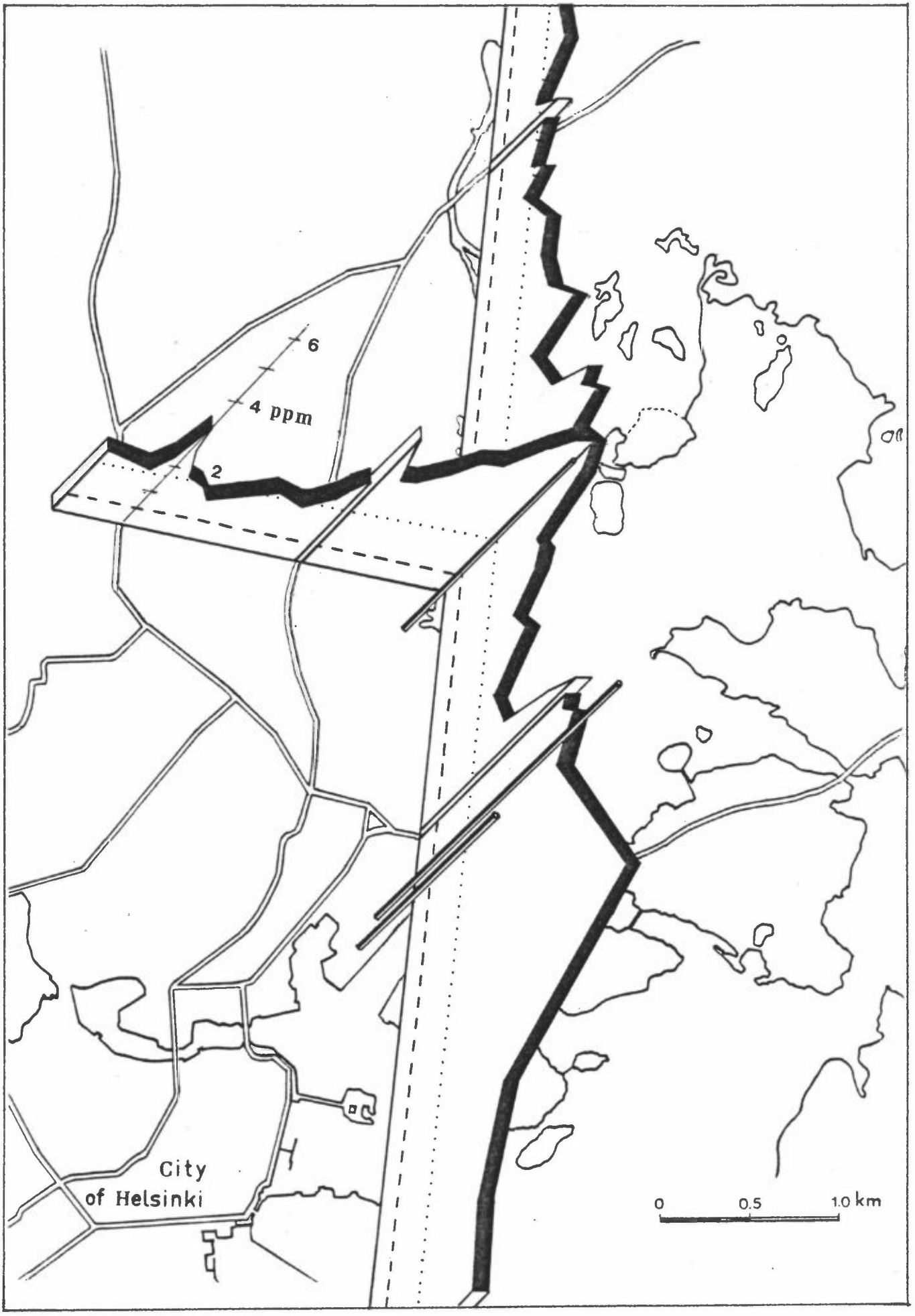


Fig. 35. Nickel accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

Fig.36. Relative accumulation values of Ni in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

6.9. Vanadium (V)

The most important vanadium source of densely populated areas is as a rule heavy fuel oil which contains approximately 150 ppm of vanadium (Pohjola et al. 1983). When heavy oil is used as fuel of auxiliary boilers in coal-fired power plants too, elevated vanadium concentrations are commonly found in plants around power plants using fossil fuels (Mäkinen 1982 and 1983). The findings of the current study give similar results (Fig. 38.). The greatest monthly accumulation values were situated in the nearest vicinity of oil-fired power plants. In relation to the background values, the greatest vanadium concentrations in the study area were about 12 times higher. The smallest monthly accumulation value of vanadium in Pälkäne is 0.7 ppm/dry wt only (n = 6). A corresponding mean value of remote areas in Vantaa and northern Helsinki is 1.0 ppm (Table 6). Northeast of the Inkoo coal-fired (1000 MW) power plant, the vanadium concentration of moss-bags decreases progressively from the power plant.

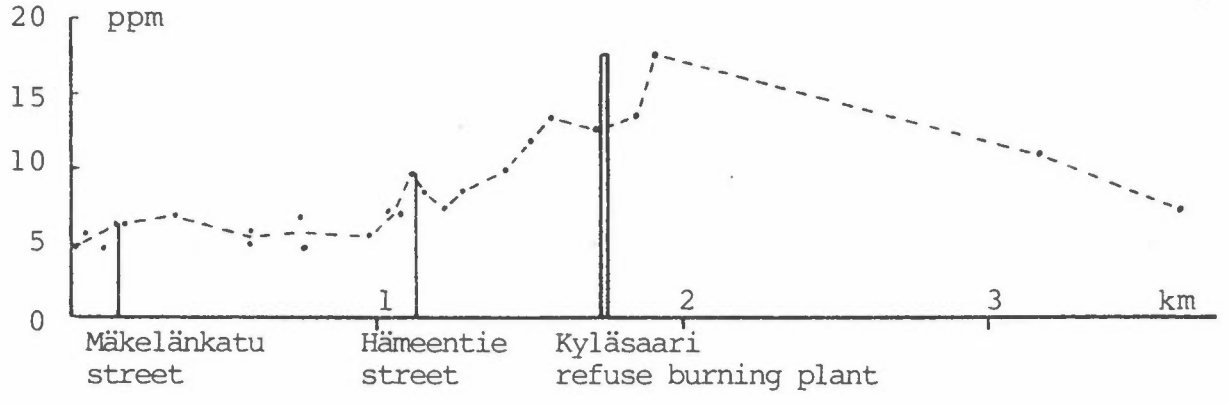


Fig. 37. Accumulation of vanadium in moss-bags along transect from west (left) to east through the study area.

Besides heavy oil another small emission source of V in the study area is refuse burning (Fig. 38). The area where increased vanadium concentration were found is nearly of the same size as around the coal-fired power plant, but the elevated values were limited to 0.5 km distance. Vanadium clearly originates from the waste, because the incinerator does not use heavy oil as fuel (cf. however Table 5).

The proportion of the third possible vanadium source, traffic, is very small. On the basis of accumulated vanadium in moss-bags the question is about re-emission, that means uprising of formerly deposited material (Figs. 37 and 39).

The relative proportions of emission sources mentioned above are presented in Fig. 40 . The dominating influence of energy supply is to be seen in all subareas. Also the material carried by long-distance transport apparently originates from energy supply.

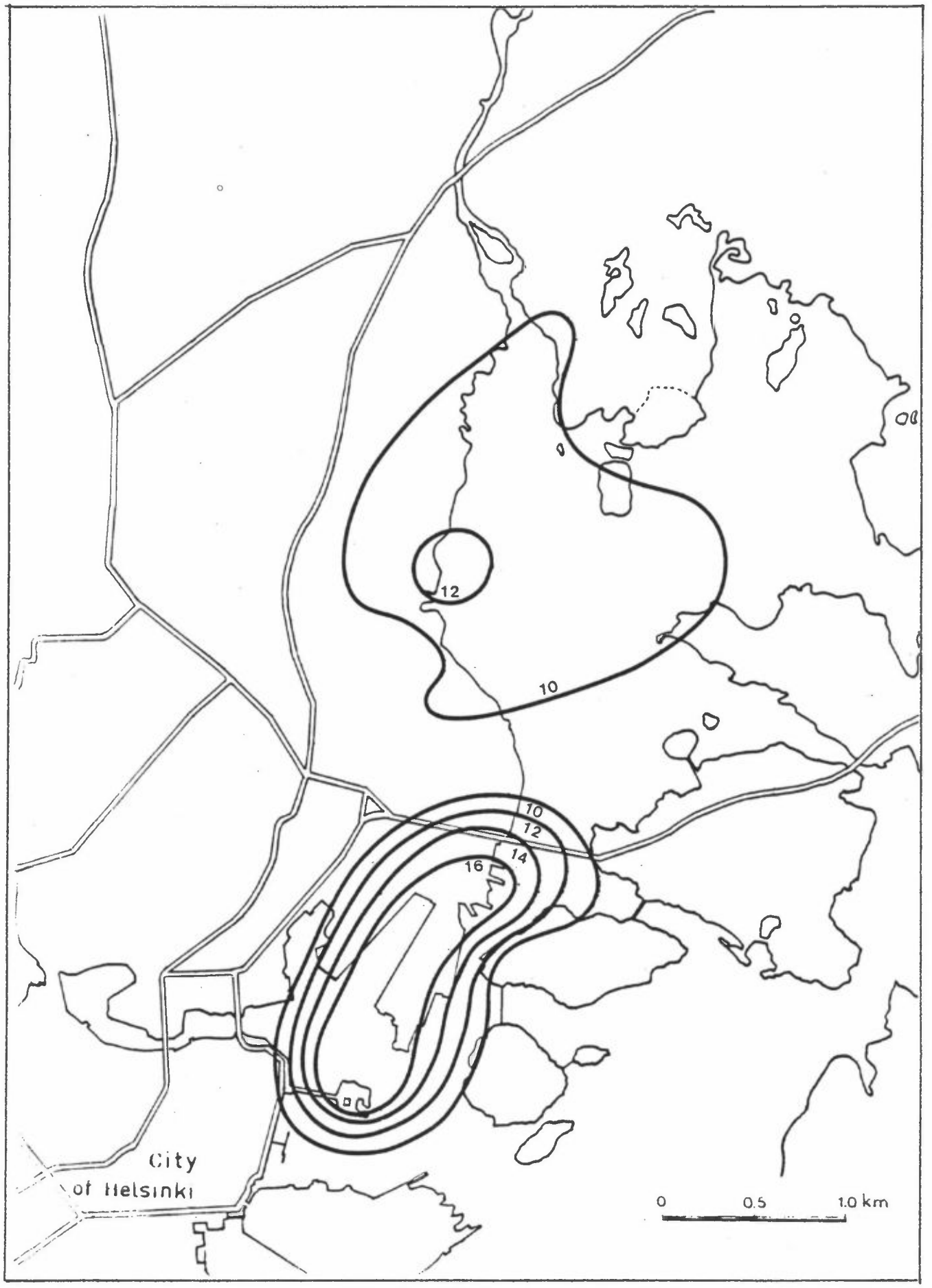


Fig. 38. Mean monthly accumulation of vanadium (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

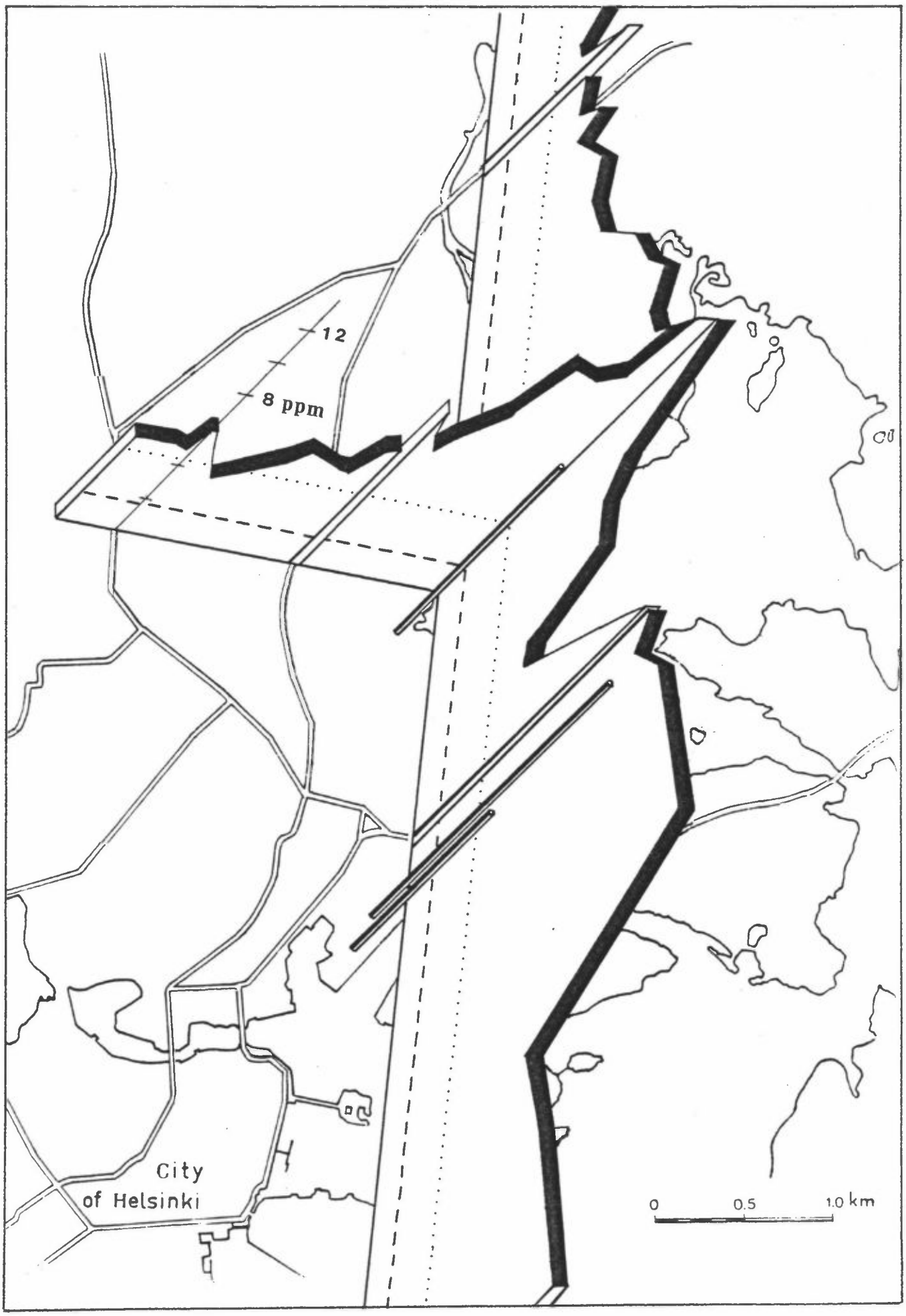


Fig. 39. Vanadium accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

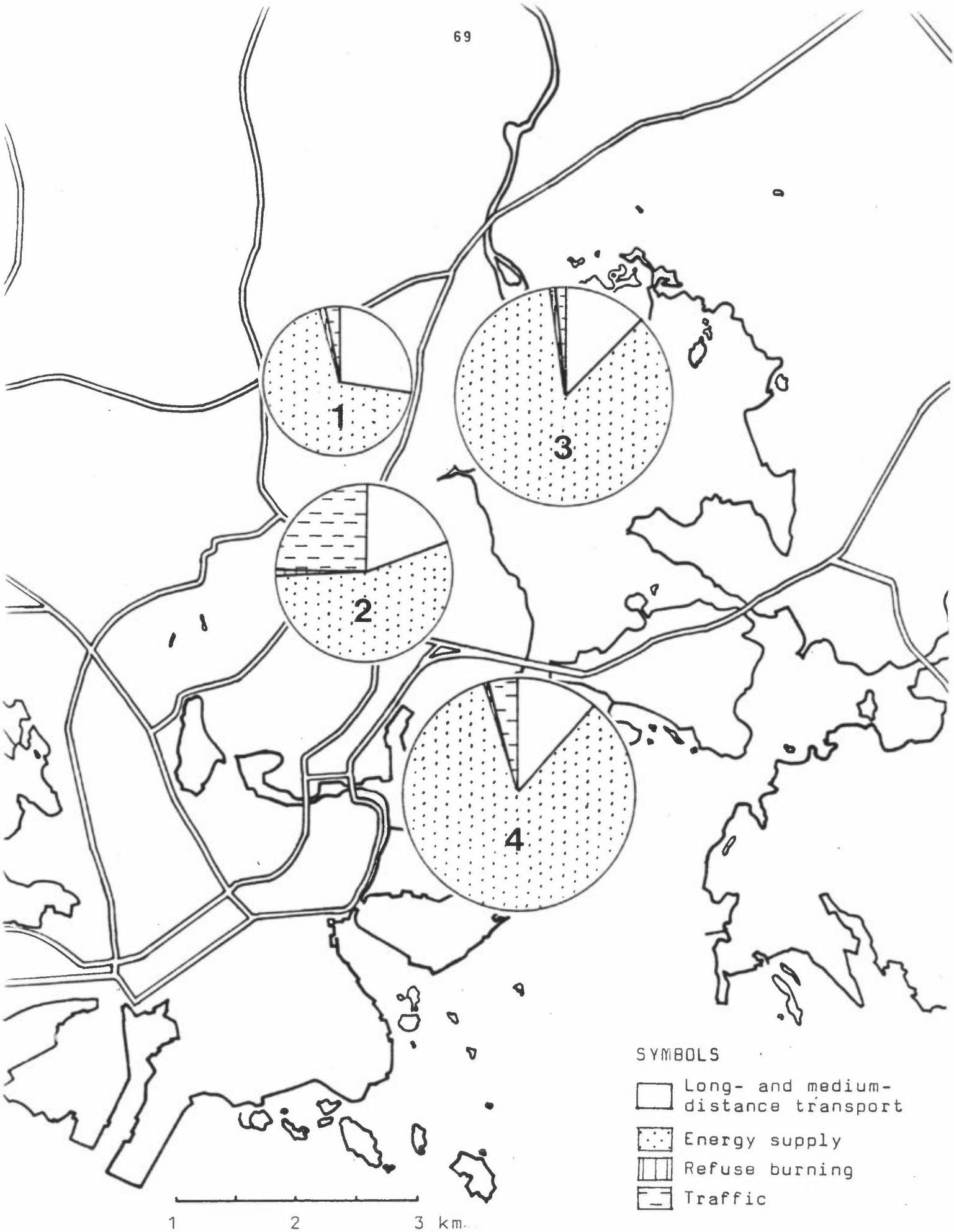


Fig. 40. Relative accumulation values of V in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

6.10 Zinc (Zn)

The mean monthly accumulation of zinc in moss-bags during the study period ranged between 0.9 and 66.4 ppm/dry wt. The mean value for the whole material was 16.9±11.5 ppm (n = 164). The mean monthly zinc accumulation value of background stations in southern Finland was 5.5 ppm/dry wt (n = 23).

The smallest values of study area (≦ 10 ppm) are situated in the SE corner far away from possible emission sources (Fig. 42). Outside the City in remote areas of Vantaa and northern Helsinki, the zinc accumulation continually decreases to about one half of those values measured in the Central Park (Table 6).

According to Fig. 42 , there are two great emission sources in the study area: the Kyläsaari refuse-burning plant and the coal-fired power plant in Hanasaari. The former seems to have somewhat greater area of influence, although the network of receptor points is not dense.

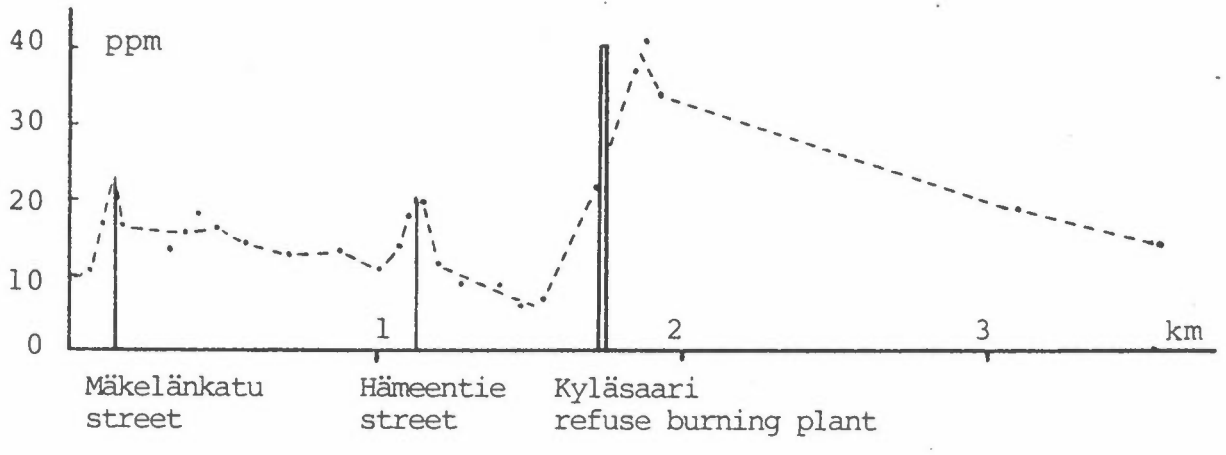


Fig. 41. Accumulation of zinc in moss-bags along transect from west (left) to east through the study area.

A reason for great zinc values near the incinerator seems to be the content of burned waste. It consists of about 1.2 kg zinc per one tonne of dry waste (Hovsenius 1977, Mroueh & Laukkarinen 1981).

The zinc content of the coal burned in Hanasaari power plant is about 50 g per tonne (Pohjola et al. 1983). The amount of coal used is, however, much greater than the amount of burned waste (cf. Table 2 and page 11). The zinc emissions of Hanasaari power plant measured in 1980 were about 35 g/h with a 77 % boiler effect (Pohjola et al. 1983) corresponding monthly emission values of about 25 kg of zinc.

The monthly zinc emission estimate of Kyläsaari refuse burning plant was over 900 kg (Mattsson & Jaakkola 1979, Äikäs & Hahkala 1982).

The proportion of traffic for zinc accumulation is much smaller than the sources mentioned above. This is to be seen in profiles 41 and 43. Also in figure 44 the relative proportion of traffic is quite small in all subareas in relation to the refuse burning and energy supply.

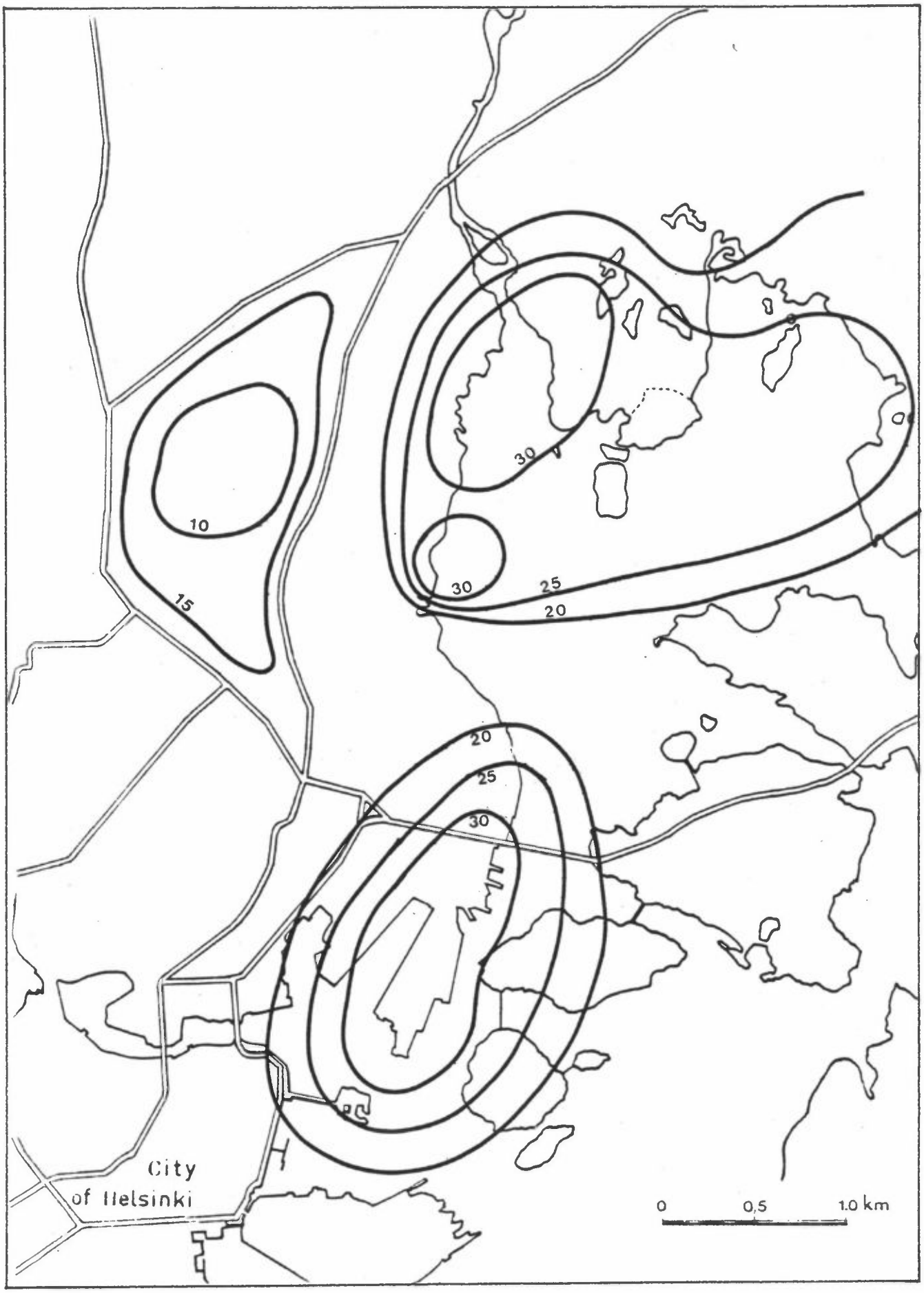


Fig. 42. Mean monthly accumulation of zinc (ppm/dry wt) in moss-bags in Helsinki during the winter 1982/83. Interpolated graphs of equal value are shown.

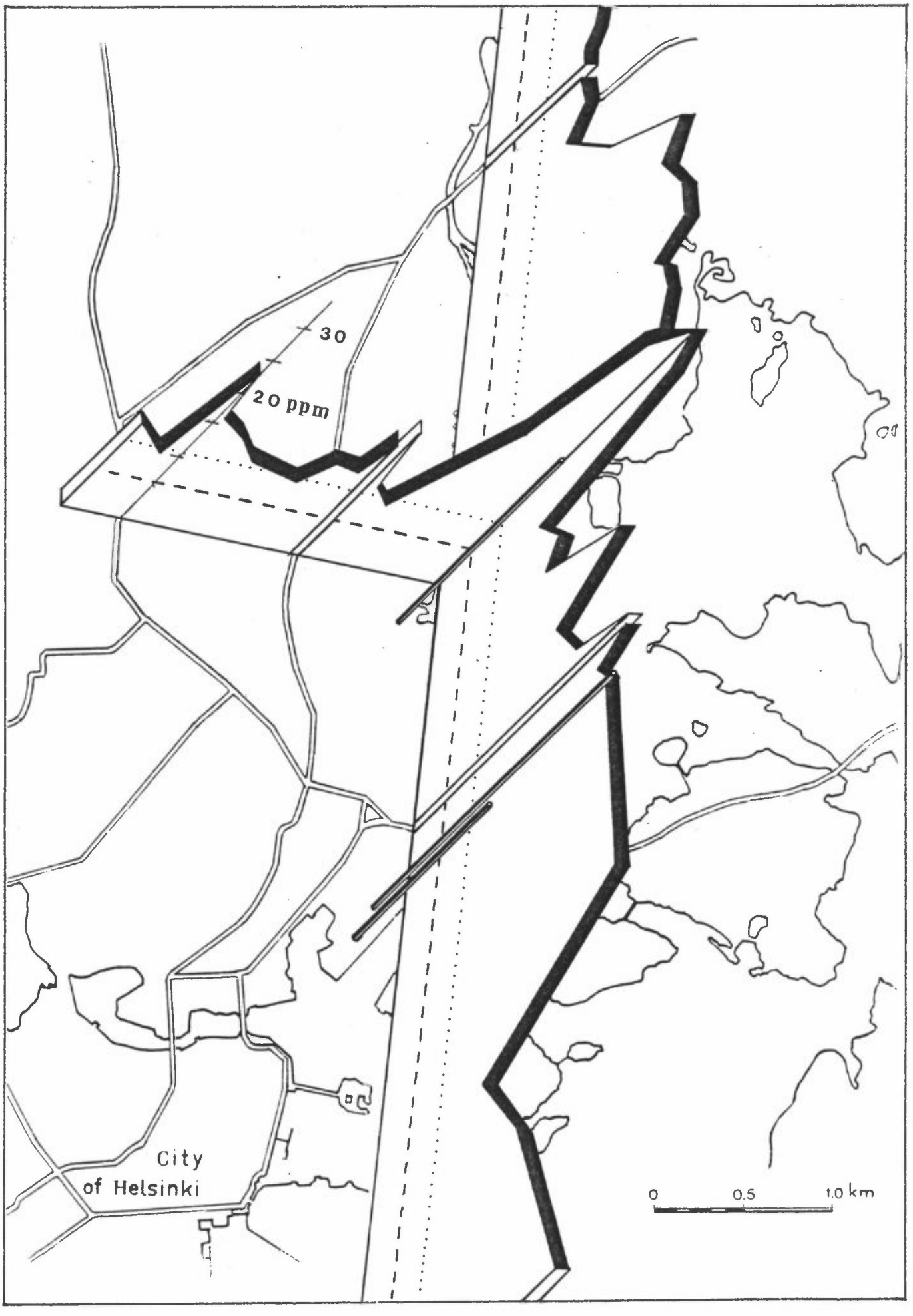


Fig.43. Zinc accumulation in moss-bags along two transects in Helsinki during the winter 1982/83. Further information in text and fig. 11.

Fig.44. Relative accumulation values of Zn in moss-bags, indicating the origin of emissions in four subareas. Further information in text and fig. 12.

7. Relative significance of different emission sources for the heavy metal accumulation in moss-bags in Helsinki

7.1. Receptor models

To determine particle sources, various receptor models have been used recently (Cooper & Watson 1980). Principal component analysis was used in this study to categorize the chemical parameters. Instead of filters, moss bags were used as receptors. Primary data consists of 164 mean monthly accumulation values (ppm/dry wt/month) of 8 heavy metals (Pb, Cd, Cr, Cu, Fe, Ni, Zn, V) and ash. Thus the number of variables in this material is 9. In computer treatment, the BMDP4M version of factor analysis (PCA) converted for use on Burroughs by M. Conveney, K. Halstead and I. Liddel was used. The number of factors was limited to three.

In the first stage the correlation matrix between all variables was calculated. This information will be taken into closer consideration in the next section (Table 8).

7.2. Elemental correlations

The correlations between heavy metals and ash cumulated in moss bags was studied. In all cases (between all elements) a highly significant correlation ($p < .001$) was established (Fig 45, Table 8). That indicates that the spreading mechanism of all elements is quite similar (and the dust accumulating on moss bags is an alloy). This apparently

CORRELATION MATRIX

			X(1) 1	X(2) 2	X(3) 3	X(4) 4	X(5) 5	X(6) 6	X(7) 7	X(8) 8	X(9) 9
X(1)	Pb	1	1.000								
X(2)	Cd	2	0.642***	1.000							
X(3)	Cr	3	0.750***	0.528***	1.000						
X(4)	Cu	4	0.775***	0.557***	0.805***	1.000					
X(5)	Fe	5	0.787***	0.393***	0.852***	0.828***	1.000				
X(6)	Ni	6	0.644***	0.493***	0.713***	0.830***	0.735***	1.000			
X(7)	Zn	7	0.548***	0.742***	0.436***	0.505***	0.378***	0.540***	1.000		
X(8)	V	8	0.613***	0.564***	0.646***	0.722***	0.601***	0.890***	0.608***	1.000	
X(9)	Ash	9	0.766***	0.306***	0.717***	0.673***	0.923***	0.588***	0.309***	0.437***	1.000
			Pb	Cd	Cr	Cu	Fe	Ni	Zn	V	Ash

SORTED ROTATED FACTOR LOADINGS (PATTERN)

			FACTOR 1	FACTOR 2	FACTOR 3
X(9)	Ash	9	0.936	0.000	0.000
X(5)	Fe	5	0.895	0.380	0.000
X(1)	Pb	1	0.757	0.232	0.493
X(3)	Cr	3	0.745	0.428	0.272
X(4)	Cu	4	0.649	0.582	0.307
X(8)	V	8	0.259	0.851	0.376
X(6)	Ni	6	0.433	0.838	0.246
X(2)	Cd	2	0.233	0.000	0.895
X(7)	Zn	7	0.000	0.320	0.849
		VP	3.552	2.315	2.160

THE ABOVE FACTOR LOADING MATRIX HAS BEEN REARRANGED SO THAT THE COLUMNS APPEAR IN DECREASING ORDER OF VARIANCE EXPLAINED BY FACTORS. THE ROWS HAVE BEEN REARRANGED SO THAT FOR EACH SUCCESSIVE FACTOR, LOADINGS GREATER THAN 0.4000 APPEAR FIRST. LOADINGS LESS THAN 0.2000 HAVE BEEN REPLACED BY ZERO.

Tab. 8. Correlation matrix and sorted rotated factor loading matrix of the chemical parametres analysed.

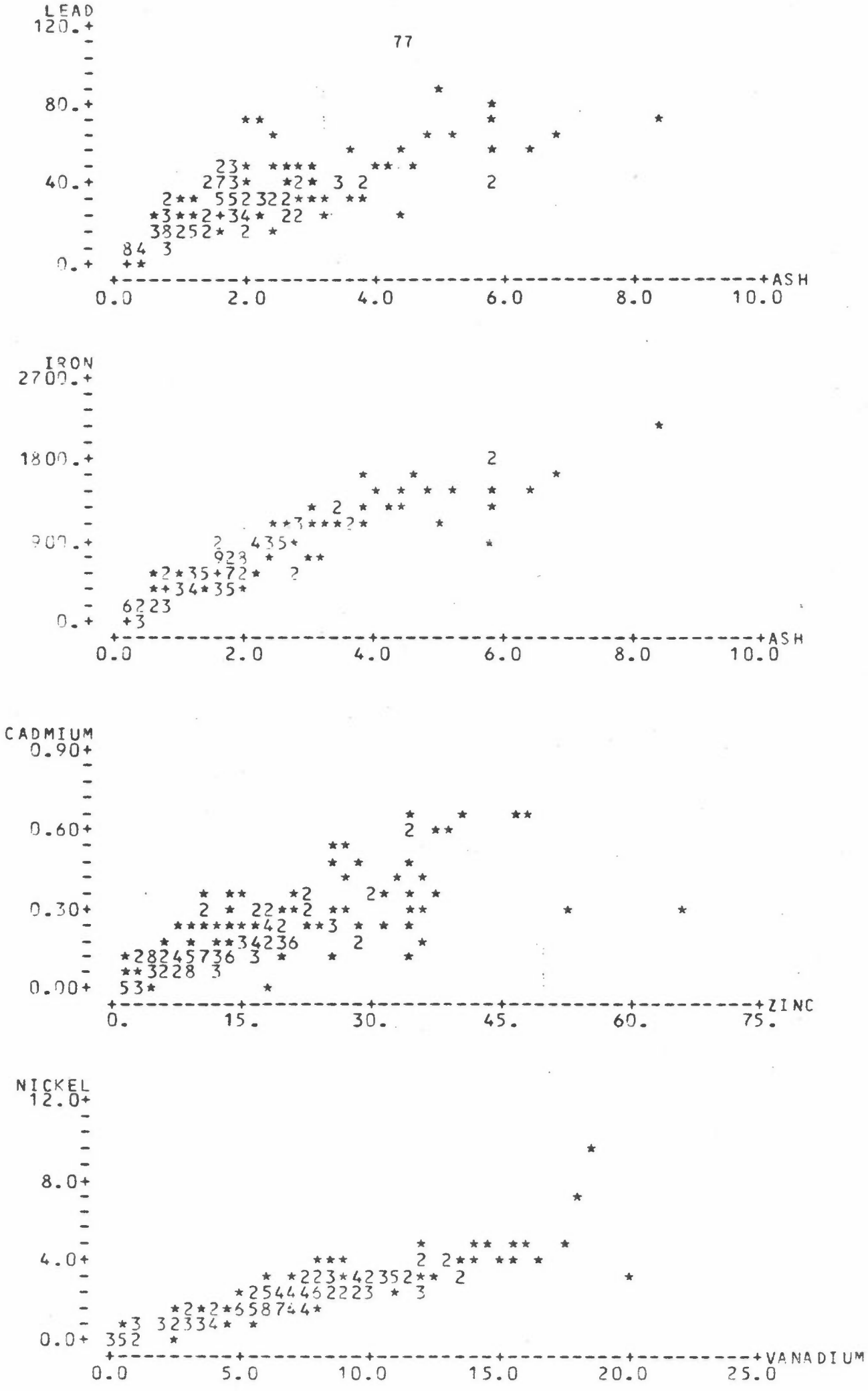


Fig. 45. The relationships between heavy metals and ash in the study material.

concerns the background areas, too. The smallest particles, however, may contain one element only as shown by fly ash analyses (e.g. Mäkinen 1982). From every emission source in the study area several kinds of particles are spreading into surroundings. Also the emissions from high levels mix with low level emissions and are influenced by traffic emissions and turbulence. Consequently, the ash values on road sides are in correlation with all heavy metals. Also the energy supply produces fly ash.

The highest correlation value, r = 0.923***, was found between iron and ash. These are including to the major components of fly ash , but also the traffic produces both elements. Some iron comes from corrosion of exhaust pipes and other parts of vehicles as well as from studded tyres on winter time. The sanding of roads produces dust that lifts up by traffic and is absorbed by the moss-bags.

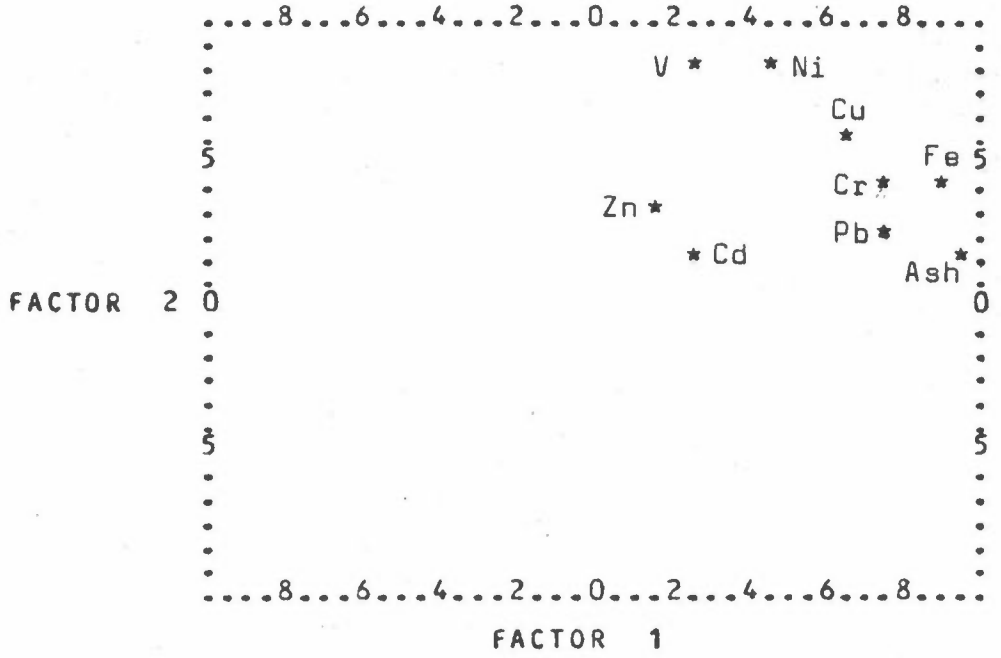
The greatest correlations between element pairs indicate which components are probably spreading together or are coming from the same emission source:

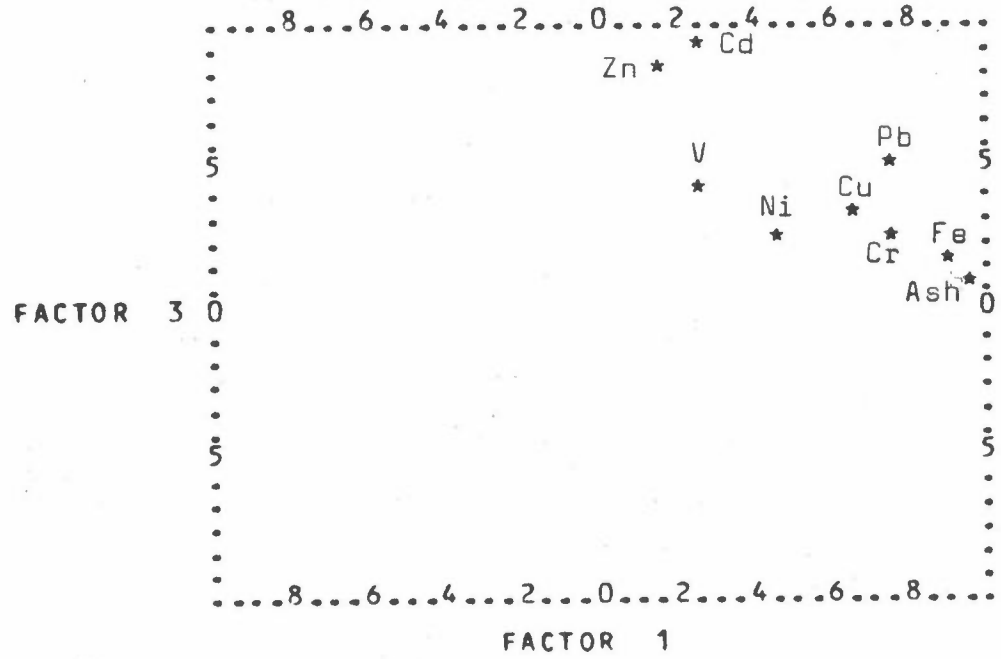
Element 1	Fe	Ni	Cr	Cu	Pb	Cd
Element 2	Ash	V	Fe	Ni	Fe	Zn
Correlation	0.923	0.890	0.852	0.830	0.787	0.742

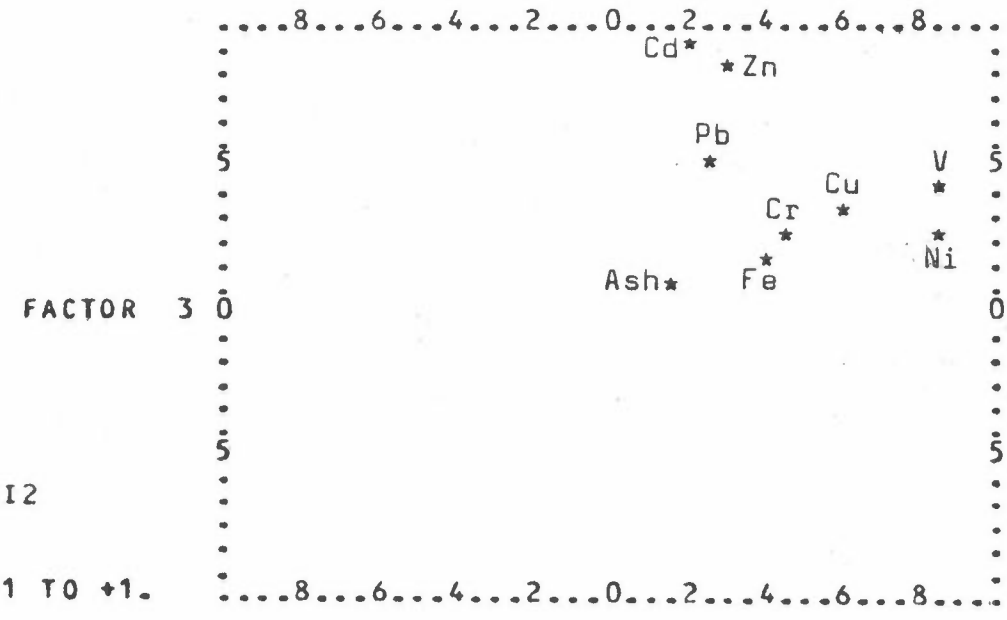
7.3. Pattern recognition by principal component analysis

The BMDP factor (principal component) analysis produces a rotated factor loading matrix (Tab. 8) where the variables are sorted in decreasing order according their loadings.

Fig. 46. ROTATED FACTOR LOADINGS







BMDP4M KYLÄSAARI2

SCALE IS FROM -1 TO +1.

Thus the elements can be grouped (Fig. 46) and the groups correlated with emissions in the study area.

The moss bag material (n = 164) computed gives three factors when the eigenvalue is greater than 0.600. Consequently, there are three separate groups to identify. The first one includes iron, ash, lead and chromium. The second group includes nickel and vanadium which occur in heavy fuel oil used in power plants. The third group includes zinc and cadmium, that very often are together in alloys. Outside the groups is copper that has a great correlation both with nickel and iron.

Because lead belongs to the first group and we know its origin in high octane gasoline, this factor was named as traffic_factor.

In factor 2 vanadium and nickel get distingtly higher loadings as other elements. In former studies (cf. Mäkinen 1983) these elements appear elevated in mosses near coal-fired power plants. Therefore factor 2 was named as energy_factor. A real emission source is not coal alone but heavy oil used as fuel in auxiliary boilers. A representative receptor point is number 164 near the oil-fired plant (Fig. 7).

In factor three, cadmium and zinc show high values. Because cadmium, according to areal distribution in the study area and formerly emission data, occurs in higher amounts in fly ash of incinerators this factor was named as incinerator_factor (cf. Fig. 14 and Äikäs & Hahkala 1982). Also lead (Pb) gets a relatively high loading on this factor.

Tab. 9. The factor scores for all (h=164) receptor points.

CASE LABEL	NO.	FACTOR 1	FACTOR 2	FACTOR 3
	1	-0.963	-1.224	-0.972
	2	-1.049	-1.151	-0.550
	3	-1.000	-1.164	-0.883
	4	-0.962	-1.178	-0.890
	5	-1.057	-0.958	-0.512
	6	-1.217	-1.132	-0.207
	7	-0.830	-0.951	-0.677
	8	-1.087	-0.811	-0.742
	9	-1.126	-0.937	-0.447
	10	-1.204	-0.619	-0.637
	11	-2.442	3.065	-1.327
	12	-0.956	-1.141	-0.929
	13	-1.014	-1.014	-0.737
	14	-0.860	-0.916	-0.659
	15	-0.976	-0.709	-0.861
	16	-0.928	-1.345	-0.791
	17	-0.897	0.001	-0.713
	18	-0.890	-1.181	-0.924
	19	-0.885	-1.197	-0.988
	20	-0.885	-1.017	-1.082
	21	-0.878	-1.020	-1.059
	22	-0.920	-1.161	-1.012
	23	-0.897	-1.077	-0.829
	24	-0.402	-0.276	-0.529
	25	1.829	-1.895	-0.347
	26	-1.047	-0.505	-0.583
	27	-0.861	-0.952	-0.608
	28	-0.713	-0.880	-0.567
	29	-0.084	-1.170	-0.614
	30	-0.640	-0.699	1.701
	31	-0.192	0.004	0.343
	32	-0.253	-0.640	0.472
	33	-0.314	0.179	0.466
	34	-0.051	-1.162	0.526
	35	0.099	-0.351	-0.396
	36	0.215	-0.956	0.093
	37	0.223	-1.086	0.970
	38	0.023	-0.953	0.219
	39	0.661	-1.209	0.217
	40	2.371	-1.948	0.880
	41	-0.173	-0.795	0.789
	42	-0.253	-0.428	1.065
	43	-0.010	-0.814	0.379
	44	0.252	-0.277	0.868
	45	-0.268	-0.265	1.495
	46	-0.451	-0.314	3.452
	47	-0.701	-1.015	0.750
	48	0.338	-0.100	0.951
	49	0.535	0.123	2.140
	50	-0 002	-0.496	1.790
	51	0.564	-0.265	2.231
	52	-0.159	-0.354	1.198
	53	0.219	0.014	2.283
	54	0.241	0.824	2.986
	55	-0.100	0.465	1.230
	56	-0.057	0.049	1.696
	57	-0.264	0.155	2.310
	58	-0.249	1.090	1.457
	59	-0.316	1.705	2.431
	60	-0.216	1.527	2.173
	61	0.653	0.941	-1.313
	62	0.427	1.302	-1.352
	63	0.441	0.752	-0.424
	64	0.813	1.369	-0.333
	65	0.683	0.462	0.164
	66	0.702	0.059	0.498
	67	1.010	0.171	0.185
	68	-0.725	-0.072	-0.540
	69	-0.849	0.312	-0.355
	70	-0.588	-0.174	-0.773
	71	-0.478	-0.256	-0.504
	72	-0.213	-0.127	-0.481
	73	-0.316	-0.524	-0.535
	74	0.512	-0.673	-0.111
	75	4.270	-1.620	0.043
	76	2.154	-1.021	-0.276
	77	0.595	-0.918	-0.697
	78	0.168	-0.535	-0.835
	79	-0.508	-0.613	-0.545
	80	-0.179	0.150	-0.377
	81	-0.276	0.688	-0.217
	82	-0.923	-0.476	0.356
	83	-0.561	0.207	-0.786
	84	-0.466	-0.296	-0.365
	85	-0.524	-0.615	-0.162
	86	-0.317	0.308	-0.663
	87	0.137	0.106	-0.476
	88	1.204	0.377	-0.415
	89	2.552	-0.246	-0.323
	90	0.042	0.139	-0.627
	91	0.061	0.622	-0.895
	92	0.667	0.896	-1.236
	93	-0.388	1.972	-1.044
	94	-0.419	1.562	-0.234
	95	0.651	1.007	-1.255
	96	0.648	0.377	-1.159
	97	0.269	0.601	-0.334
	98	0.184	-0.069	-0.821
	99	0.166	-0.252	-1.003
	100	0.075	-0.285	-0.922
	101	0.668	-0.224	-0.882
	102	1.732	-0.270	-0.303
	103	2.471	0.043	-0.100
	104	0.911	0.116	-0.476
	105	0.156	-0.022	-0.581
	106	-0.263	-0.047	-0.362
	107	-0.235	0.169	-0.678
	108	-0.161	-0.404	-0.645
	109	-0.130	-0.065	-0.315
	110	1.707	-0.728	-0.777
	111	0.515	-0.638	0.036
	112	-0.050	0.735	-1.102
	113	1.158	-0.336	-0.286
	114	1.465	-0.397	-0.637
	115	-0.337	0.837	0.525
	116	-0.499	0.967	1.024
	117	0.576	0.368	-1.082
	118	0.656	-0.077	-0.197
	119	0.043	0.002	-0.106
	120	1.897	-0.254	-0.198
	121	1.618	0.675	0.176
	122	1.603	0.283	0.862
	123	2.642	0.528	1.001
	124	2.290	1.168	0.200
	125	2.941	-0.240	-0.039
	126	2.646	-0.484	-0.292
	127	0.850	1.330	-0.392
	128	1.295	1.374	-0.249
	129	1.375	1.430	0.292
	130	-0.741	5.010	-0.790
	131	-0.044	3.652	0.311
	132	-1.023	0.242	2.164
	133	-0.984	-0.828	0.191
	134	-0.857	-0.189	0.259
	135	-0.740	-0.113	0.768
	136	-0.807	-1.381	2.046
	137	-0.784	-0.869	1.155
	138	-1.036	-0.846	2.653
	139	-0.903	-0.444	2.708
	140	-1.705	0.618	2.761
	141	-1.121	-0.324	1.418
	142	-0.050	0.630	0.323
	143	0.071	0.145	-0.168
	144	-0.015	0.657	-0.676
	145	1.547	0.392	-0.325
	146	0.394	1.795	0.278
	147	-0.072	0.335	0.543
	148	-0.842	0.758	0.290
	149	-0.591	-0.183	0.547
	150	-0.466	0.958	-0.450
	151	-0.517	1.511	-0.599
	152	-1.052	1.465	-0.174
	153	-1.067	2.042	0.134
	154	-0.875	1.140	-0.580
	155	-1.015	-0.496	-0.844
	156	-1.160	-0.504	-0.589
	157	-0.178	0.921	-0.816
	158	0.202	0.768	-0.293
	159	0.033	0.321	-0.690
	160	0.196	0.645	-0.161
	161	0.085	0.301	-0.659
	162	-0.040	-0.082	-0.150
	163	-0.153	0.630	-0.836
	164	-0.456	2.387	-0.514

When the estimated factor scores of all receptor points are calculated (Tab. 9) and the scores marked on map with symbols, the main sources corresponding to the factors are exposed (Figs 47 - 49). The combined information of factor scores gives more condensed information from the air pollution and emission sources than concentration maps of individual elements.

In Figs 47-49 the factor scores are divided into four categories (limits: -0.5, 0, 1 and 4).

The greatest scores of the traffic factor are without exception on the sides of main roads (Fig. 47). The higher values of points 110, 113 and 114 are caused by busy traffic to the harbour and industrial areas. The control points were situated just by the side of the street.

Corresponding receptor points situated far off traffic ways get the lowest factor scores as expected. The influence of source depends on wind direction and traffic intensity.

Most receptor points with highest scores on factor 1 are situated on the east and north side of the main streets because the dominating wind direction is from south or southwest (Fig. 5). Very high scores occur near the beginning of eastern motorhighway where the traffic intensity is nearly 50 000 vehicles per day. Besides traffic, the power plants load the area. It seems to be one of the most polluted regions in the City of Helsinki.

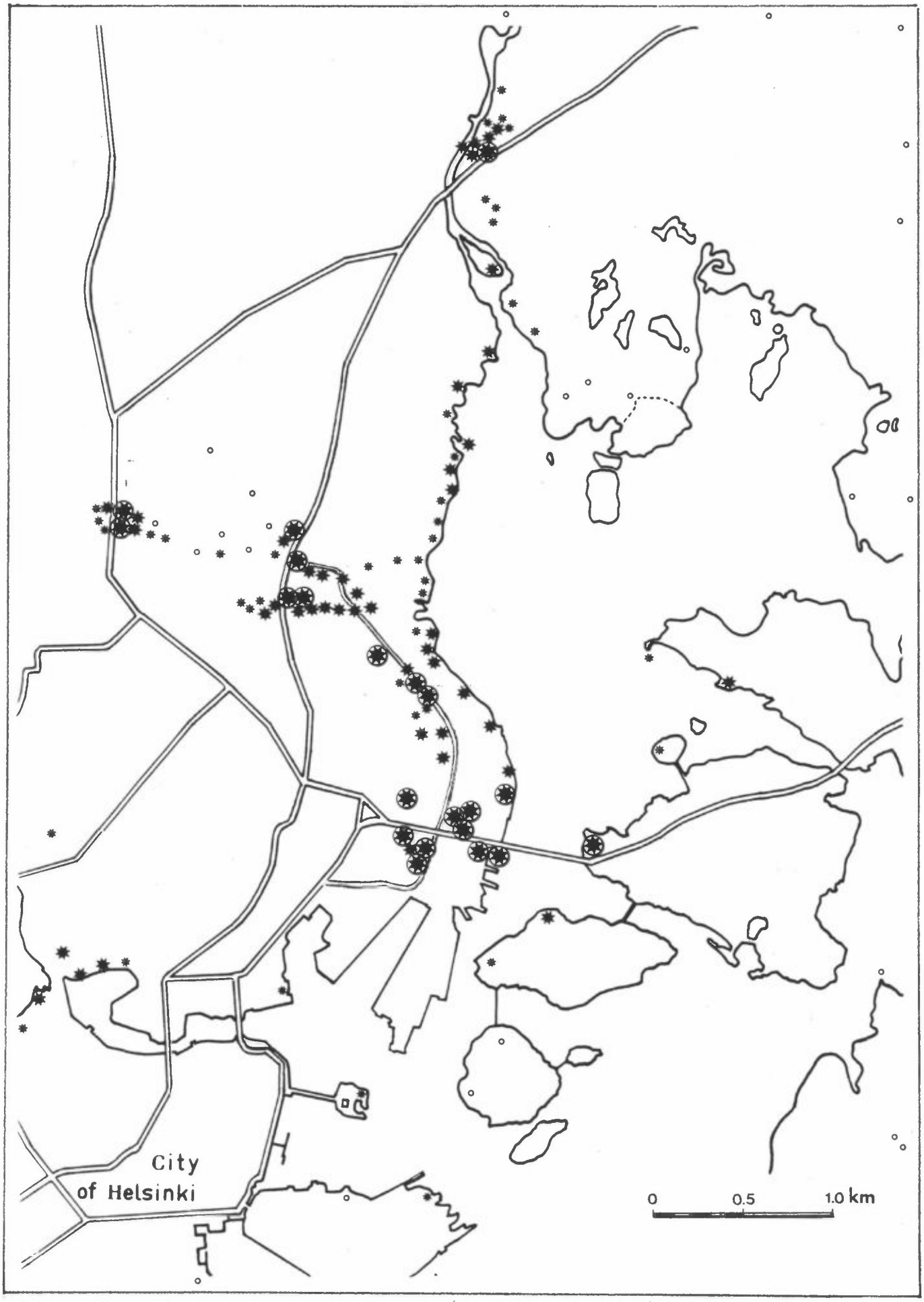


Fig. 47. The scores of factor 1 (traffic factor) indicated in four levels (limits: -0.5, 0, 1 and 4).

The maximum values on factor 2 (the energy-factor) are situated near power plants (Fig. 48). For instance in the nearest vicinity of coal-fired power plant Hanasaari there are 7 receptor points with very high scores. Equal amount of high values are to be found in the nearest surroundings of Kyläsaari incinerator. Hanasaari uses some heavy oil and it seems possible that these high factor scores have something to do with heavy oil. Also many ships visiting the harbour use oil as fuel and have some influence upon the high values in receptor points 130 and 131 (see Fig. 7). The high score in point 164 is also influenced by nearest oil-fired reserve power plant that is in function on cold winter days only.

The pattern of cadmium and zinc in factor 3 is clear. All of the greatest factor scores are situated downwind north east from the Kyläsaari incinerator where great emission values have been measured (Fig. 49). Also the receptor points far away on higher hills get high scores. That is an evidence of longer transport as formerly supposed. For instance the values of receptor point 132 were in all former studies high, too, but it was supposed that the main emission source was the north-east highway. Fig. 47 and Tab. 9 , however, showed that the high loadings of factor 3 are not repeated in factor 1.

7.4. Relative accumulation in selected sites

To calculate relative heavy metal accumulation in moss bags, representative receptor points were tested. The

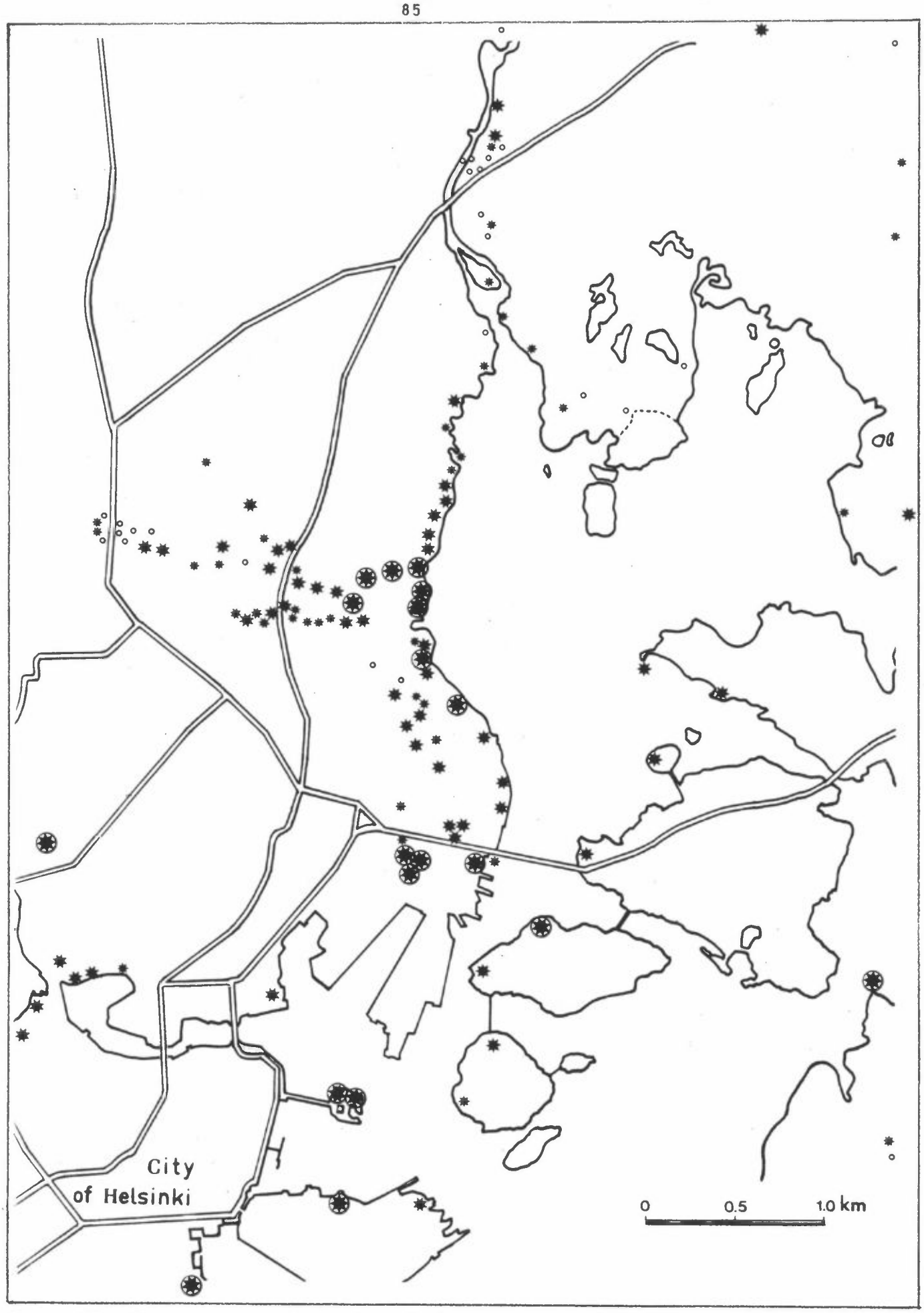


Fig. 48. The scores of factor 2 (energy_factor) indicated in four levels. Limits as in Fig. 47.

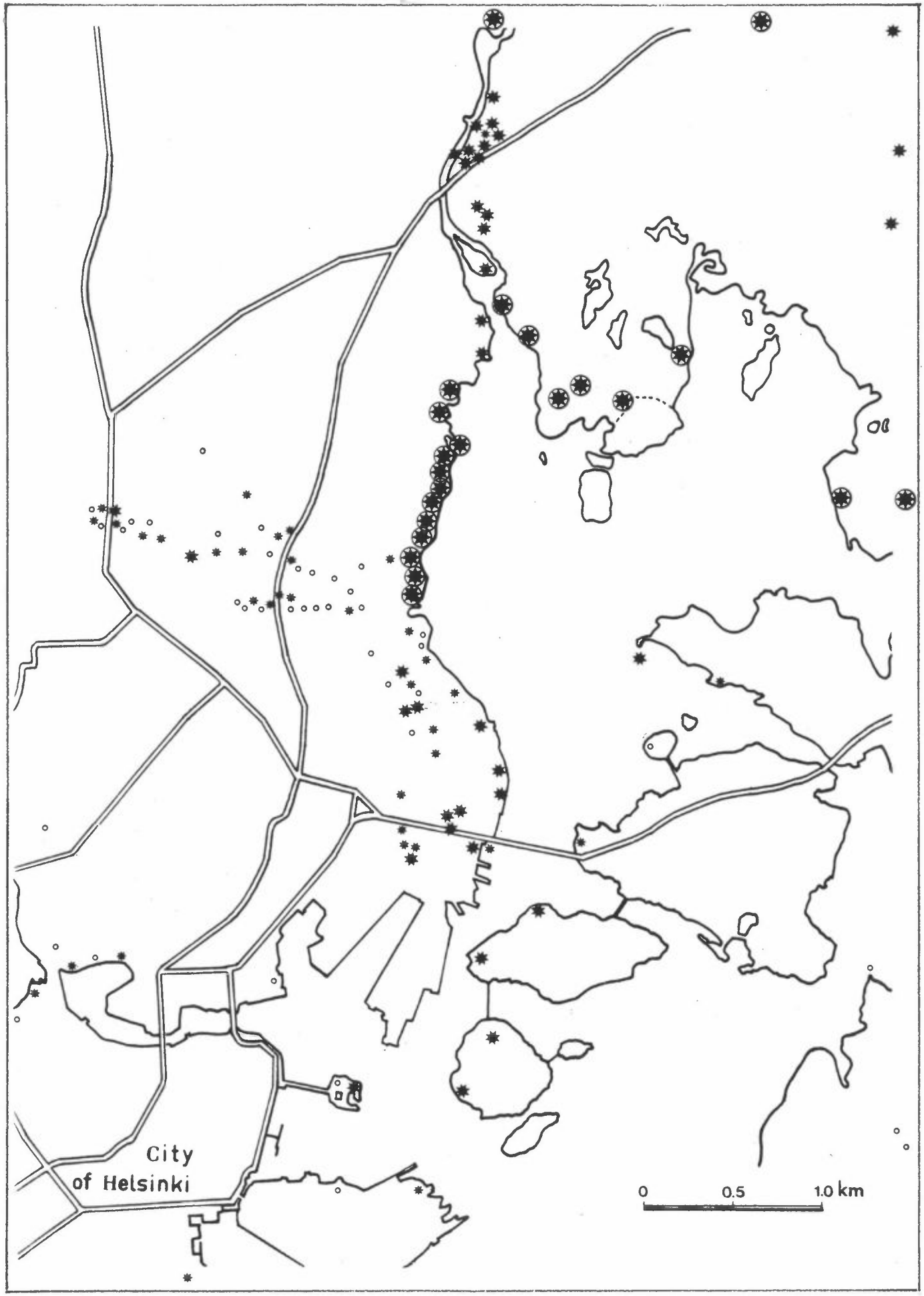


Fig. 49. The scores of factor 3 (incinerator factor) indicated in four levels. Limits as in Fig. 47.

starting point is a hypothesis that the key emission sources in study area are traffic, energy supply and garbage burning. The influence of other sources is supposedly relative small.

For all these factors, characteristic receptor points were selected. In this study, the indicator point for traffic, n:o 75, was located in the middle of the street Mäkelänkatu between lanes (see Fig. 7). The traffic density in this point is on an average 33 200 vehicles per day.

The indicator point for energy supply, n:o 129, is situated about 400 meters downwind from the greatest power plant in the city. This 580 MW power plant supplies most of the energy requirement of the inner city.

The indicator point for garbage burning, n:o 59, was selected 300 m downwind from the incinerator.

For these representative points relative values of each metal and ash were calculated by dividing mean monthly accumulation by the city background values (receptor point 68-70 in the middle of the Central Park). The results are indicated in Tab. 10.

Tab. 10. Relative accumulation values of heavy metals and ash in selected receptor points.

Element	Pb	Cd	Cr	Cu	Fe	Ni	Zn	V	Ash
Factor									
1. Traffic	4.9	3.6	3.0	4.2	7.1	2.1	2.1	1.0	10.4
2. Energy	3.3	4.3	2.6	4.6	5.5	6.6	3.4	3.1	5.8
3. Inciner.	3.2	8.0	3.0	3.7	3.1	3.4	3.8	2.9	3.1

Although Tab. 10 is based on mean accumulation values of three selected receptor points only, it gives a similar pattern (underlined values) than the PCA model of the total material. A superior indicator of traffic at least in winter conditions seems to be the ash. Also the iron values are prominent.

The energy factor does not show as well as in PCA, but highest values are anyway related to nickel. It is possible that in the neighbour area there are too many other emission sources with a disturbing effect, because the results are somewhat different from the sorted factor loadings (cf. Tab. 8). In the vicinity of the incinerator Cd values as well as zinc are stressed.

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NORWEGIAN INSTITUTE FOR AIR RESEARCH

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TITTEL
Regional extent and relative proportions of different metal emissions in Helsinki air studied by the moss-bag technique.

PROSJEKTLEDER
A. Mäkinen

NILU PROSJEKT NR.
O-8052

FORFATTER(E)
Anti Mäkinen

TILGJENGELIGHET*
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OPPDRAGSGIVERS REF.

OPPDRAGSGIVER (NAVN OG ADRESSE)
Nordisk Ministerråd (NMR-MIL 4)
Sekretariatet, St. Olavs plass
Oslo 1

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TITLE

ABSTRACT (max. 300 characters, 7 lines).Trace metals were analysed in 600 moss bag samples located in and around Helsinki. Accumulation of ash, Cd, Cr, Cu, Fe, Pb, Ni, V, and Zn over 5 months (Oct-Mar) was analysed with a AAS flame method. Largest amounts of metals were found near a refuse burning plant and near main streets with daily traffic of up to 50 000 vehicles. The relative contribution of different sources was estimated with a factor analytic method. The factors traffic, energy and incinerator factory showed significant loadings.

*Kategorier: Åpen - kan bestilles fra NILU A
Må bestilles gjennom oppdragsgiver B
Kan ikke utleveres C