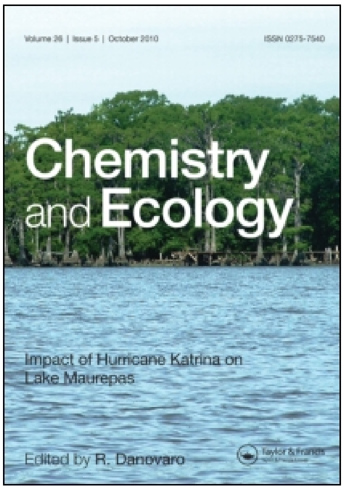

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VEHICLE-INDUCED LEAD AND CADMIUM CONTAMINATION OF ROADSIDE SOIL AND PLANTS IN ITALY[1]

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Lead and cadmium concentrations in spontaneous vegetation and in soil sampled at various distances (0–208 m) from several motorways throughout Italy were measured. Lead and cadmium concentrations appear to be correlated to distance from the motorway and to traffic levels. A comparison with data from a remote and unpolluted site shows that foliar lead concentrations can be up to 40 times higher, and foliar cadmium concentrations up to 3 times higher. Plants behave differently in their accumulation of lead and cadmium; conifers present the highest levels. Also the various receptors and compartments of the roadside ecosystem differ in their accumulation of lead and cadmium; soil and bark have consistently higher concentrations, while the leaves and twigs of trees have consistently lower levels. The data recorded by *ad hoc* introduced bio-accumulating plants (*Lolium multiflorum* L.) are consistent with those of the spontaneous vegetation. The concentrations of both lead and cadmium in *Lolium* vary from June to November, following in part the fluctuation in traffic density.

KEY WORDS: Bioaccumulation, lead and cadmium contamination, motor vehicle traffic, motorways, Italy.

INTRODUCTION

Motor vehicle traffic is one of the main anthropogenic sources of atmospheric pollutants, including sulphur and nitrogen compounds as well as trace elements such as lead, cadmium, chromium and zinc. There is evidence that such pollutants can be harmful to roadside vegetation (Flückiger *et al.*, 1978; 1979; Braun and Flückiger, 1985; Sauter *et al.*, 1987; Kammerbauer *et al.*, 1987a; 1987b; Bhatti and Iqbai, 1988; Majdi and Persson, 1989; Sauter and Pambor, 1989; Zaerr and Schill, 1991). Since the 1960s, several studies have evaluated pollution caused to areas alongside major motorways by vehicle traffic and especially due to antiknock tetraethyl lead and tetramethyl lead added to gasoline. Spontaneous vegetation, crops, the soil and small mammals, used as biological indicators, show that the concentrations of lead decrease as the distance from the highway increases and in

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soil samples taken at greater depths. This decrease can also be affected by the characteristics of the receptor, by the chemical, physical and biological properties of the soil, as well as by traffic density, age of vehicle and engine load (Daines *et al.*, 1970; Motto *et al.*, 1970; Lagerweff and Specht, 1970; Page *et al.*, 1971; Ganje and Page, 1972; Quarles *et al.*, 1977; Wheeler and Rolfe, 1979; Kingston *et al.*, 1988; Piron-Frenet *et al.*, 1994). Most of the findings concerning lead dispersal near point emission sources and motorways apply also to cadmium–emitted by attrition of tyres and oil (Lagerweff and Specht, 1970; Little and Martin, 1972)-although cadmium deposition rates are always considerably lower than for lead (Bergkvist *et al.*, 1989).

There are, however, only very few data available for Italy (Sapetti and Arduino, 1973; Levi-Minzi *et al.*, 1976) where laws regulating lead content in gasoline have been in force only since 1989, and where motorway traffic increased by 70% in the period 1982–1991 (Autostrade SpA, unpublished). In 1986 emissions in Italy from vehicular traffic are estimated at 804 10^3 t of NO_x, 96.2 10^3 t of SO_x, 5153 10^3 t of CO and 6.4 10^3 t of lead (Ministero dell'Ambiente, 1989). Data for 1989 show a net increase of NO_x emissions (+25%), while small changes occur for SO_x, CO and lead emissions (Ministero dell'Ambiente, 1992). Data concerning cadmium emissions from vehicles are still lacking.

This survey, which is part of a broader research project on the effectiveness of plants in containing and limiting the spread of atmospheric pollutants (Batistoni *et al.*, 1989), was designed and carried out to fill some of the gaps in our knowledge concerning the levels and the extent of roadside contamination in Italy. Obviously, data on ambient exposure of the roadside ecosystem are needed for any abatement strategy as well as for the assessment of any changes in pollutant load: therefore, the aims of this survey are (a) to assess and quantify how motorways affect the dispersion of certain pollutants (Pb,Cd); (b) to compare ambient concentration levels in areas near motorways to levels at a remote site; (c) to evaluate differences (if any) between the receptors in the accumulation of lead and cadmium; and (d) to monitor the temporal trends of lead and cadmium concentrations during a 4-month observation period. Some preliminary results of this study have been summarized elsewhere (Ferretti *et al.*, 1991; Ferretti *et al.*, 1992a; Bussotti *et al.*, 1995): the objective of this paper is to detail the main findings concerning the levels and distribution (in both space and time) of the pollutants under investigation.

MATERIALS AND METHODS

Sampling Strategy

In order to assess the distribution of contaminants in areas near motorways and also their geographical distribution throughout Italy, we selected two different types of sampling sites.

Motorway sampling sites During winter, 1989, using a standardized sampling procedure (Batistoni *et al.*, 1989), we selected 135 sites scattered over about 1,000 km of motorways, so as to offer a valid representation of different geographical areas

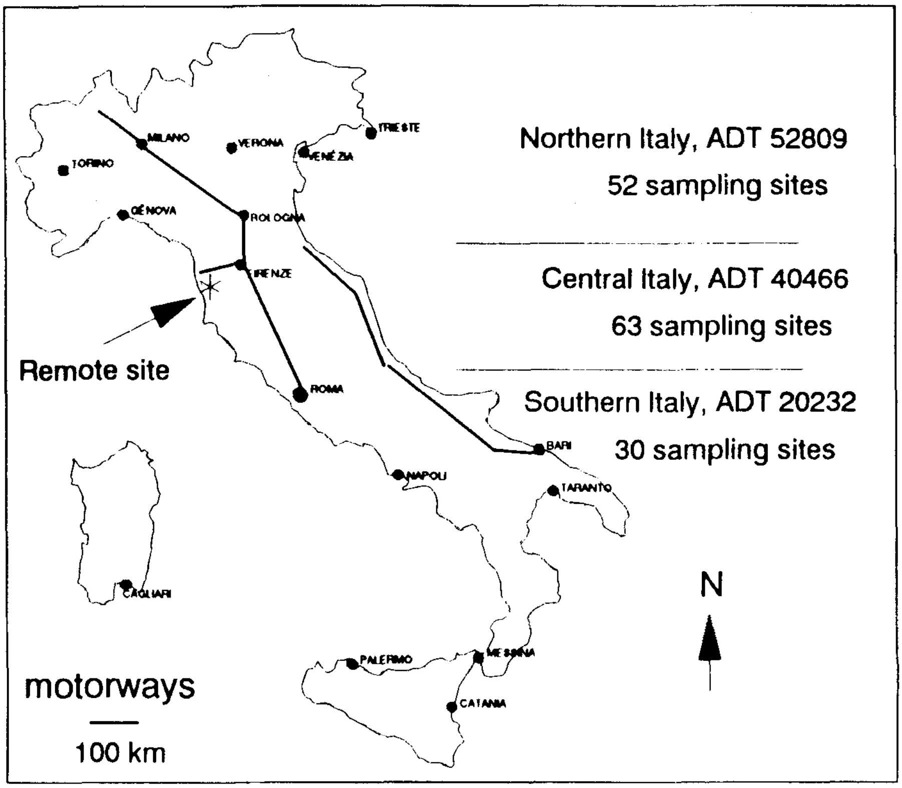

Figure 1 Geographical distribution of motorways studied: average daily traffic (ADT) and the number of sampling sites in each geographical area. The remote (control) site is also indicated.

(Northern, Central and Southern Italy) characterized by widely differing traffic densities (Average Daily Traffic, ADT, from 5,000–10,000 to 50,000–70,000 vehicles) (Fig. 1). Each sampling site was classified as to the type of road, the gradient, and the barrier planting along the road edge (if any). The number of sampling points for each site varied from a minimum of 3 to a maximum of 10, located at varying distances from the road itself (up to a maximum of 208 m from the road edge): it was from these points that samples were collected in August 1989. On motorway sites the sampling included herbaceous plants (*Graminaceae, Compositae, Leguminosae*), shrubs and trees, and soil at three different depths (0–5, > 5–10 and > 10–15 cm). We also took samples of leaves, twigs and bark from more than 100 different species of trees. Each sample (including soils) consisted of 3 sub-samples, physically mixed in the same bag. Only current leaves (< 1 year old) located in the upper third of the crown exposed to the motorways were collected. All in all, from the motorway sites we gathered 797 soil samples, 461 grass samples, 328 leaf samples, 127 twig samples, and 85 bark samples. In order to assess the trend of concentration levels during summer months, we used *Lolium multiflorum* L., a forage species used frequently as a bio-accumulator (Lorenzini *et al.*, 1988; Ferretti *et al.*, 1992b). We established three sampling sites along the A1 motorway near Firenze (Central Italy), each consisting of 16 pots (measuring 250 cm^2 each) of *Lolium* placed at four different distances from the edge of the road (1, 5, 10, and 15 m). Four identical pots growing in a greenhouse were used as control plants. Samples were taken usually every 15–20 days, from June to November 1989.

Remote site In order to evaluate the existence (if any) of increased pollutant burdens as compared to background values, we also took samples from a forest ecosystem remote from industrial emission sources (> 10 Km) and from roads (> 500 m from a road with a very low traffic density). This site lies on the eastern slopes of the Monti Livornesi (Tuscany, Central Italy, Fig. 1). In this area, the monthly average pollutant concentrations – as determined on the occasion of another investigation – are typical of background values in all cases except ozone ($SO_2 = 7.1\ \mu g\ m^{-3}$; $NO = 2.5\ \mu g\ m^{-3}$; $NO_2 = 2.8\ \mu g\ m^{-3}$; $O_3 = 76.7\ \mu g\ m^{-3}$, Ferretti *et al.*, 1992b). The sampling, three leaf samples from each of three trees from each species, covered 27 different species (see below). Only current leaves located in the upper third of the crown were collected at the same time as those from the motorway sampling sites.

Treatment of Samples

Plant samples (grass, leaves, barks, twigs) were oven-dried at a temperature of 65°C for 72 hours, while soil samples were air-dried to constant weight. Samples of leaves, grasses, bark and twigs collected in the present survey were not washed and the data we report indicate total concentrations, without distinguishing between deposited, adsorbed or absorbed quantities. Bulk concentration of metals (absorbed + deposits) is assumed to be a good and cost-effective index for a realistic estimation of the contamination levels in the roadside ecosystem, especially in large scale surveys. Each sample was finely ground, mixed accurately to obtain a homogeneous powder and stored in polyethylene (KARTELL) containers. Since the analyses were performed on solid samples, no further preparation was required. Lead and cadmium levels were measured by an atomic absorption spectrophotometer (GRÜN SM 20), ZEEMAN effect, interfaced with a precision balance (SARTORIUS Micro M 500 P): the entire procedure was handled by specific software. For the calibration we used BCR (Community Bureau of Reference) reference standards (Pb: certified value $= 25.0 \pm 1.5\ \mu g\ g^{-1}$; measured value $= 26.2 \pm 1.9\ \mu g\ g^{-1}$; Cd: certified value $= 0.10 \pm 0.02\ \mu g\ g^{-1}$; measured value $= 0.11 \pm 0.009\ \mu g\ g^{-1}$). Each measurement was replicated 3 times.

Statistics and Results

The sample points were grouped together in classes of distance from the edge of the road (see below). Since the purpose of this study was to assess contamination levels in areas near motorways, we distinguished between the various matrices. For the purposes of this survey, matrix means a receptor whose morpho-structural properties make it behave in a specific way in the capture or retention of contaminants. For example, in this study the receptor "herbaceous vegetation" is represented by a single matrix, defined GR (grass), which is the epigean part; whereas tree/shrub vegetation is represented by leaves (LV), bark (BK) and twigs (TW). We also differentiated between groups of plant species according to their characteristic features (i.e., deciduous or evergreen, conifers and broadleaves), to see if there were any differences in their lead and cadmium burdens. For each class of distance and for each matrix, our data include the descriptive statistics (minimum, 25th, 50th, 75th percentile, maximum, mean value and standard deviation). The Pearson correlation coefficient was used to evaluate the correlations between the concentration levels of the contaminants in the different matrices and distance from the road. Contaminant burdens were assessed by calculating the enrichment factors (EF),

$$\mathrm{EF} = (C_x/C_y)100,$$

i.e., the percentage ratio between the concentrations measured in a specific matrix at a specific sampling point (C_x, usually the edge of the road) and the concentration levels measured in the same matrix at another sampling point (C_y, usually the furthest point from the road and/or the remote site). We also calculated the reduction factors of the concentrations (RF),

$$\mathrm{RF} = (1 - C_y/C_x)100,$$

where C_y is the concentration measured at a distance (y) from the edge of the road, and C_x is the concentration measured at a distance x which is $\leqslant 1$ m.

We used the following abbreviations:

Matrices: BK (bark), GR (grass), LV (leaves), TW (twigs), SL1 (surface soil, 0–5 cm depth), SL2 (intermediate soil, > 5–10 cm), SL3 (deep soil, > 10–15 cm).

Classes of distance from road (metres): 0.5 (real distance 0- < 1), 2(1- < 3), 4(3- < 5), 6(5- < 7), 8.5(7- < 10), 12.5(10- < 15), 17.5(15- < 20), 30(20- < 40), 60(40- < 80), > 80(80–208).

RESULTS AND DISCUSSION

Relationship with Distance from Motorway

The data concerning lead and cadmium concentrations in samples SL1 and GR collected at different distances from the motorway edge are reported in Figures 2 and 3. Distance from the roadside affects lead and cadmium levels: despite the high variability of the data, we can notice a clearly marked decrease in mean values (and also in the median value and 75th percentile) as the distance from the motorway increases. The regressions and the relative significance level for all the different matrices are illustrated in Table I. Similar spatial trends for airborne metal dispersal have been reported for several point source emissions (Hunter *et al.*, 1987; Kansanen and Venetvaara, 1991). Soil, grass and leaves seem the most suitable matrices to use if we want to examine contamination of the environment near the Italian motorways: the bark and twig samples display a much more complex behaviour and sometimes the results can appear to be contradictory (see TW in Tables I and II).

The reduction factor (RF) of lead concentrations in GR and SL1 are between 55% and 80% within the first 15 m from the edge of the road, and increase to 80–90% at 30 m (Table II). In the case of lead, levels measured in GR and LV more than 80 m from the road are comparable to levels found in forest areas far removed from

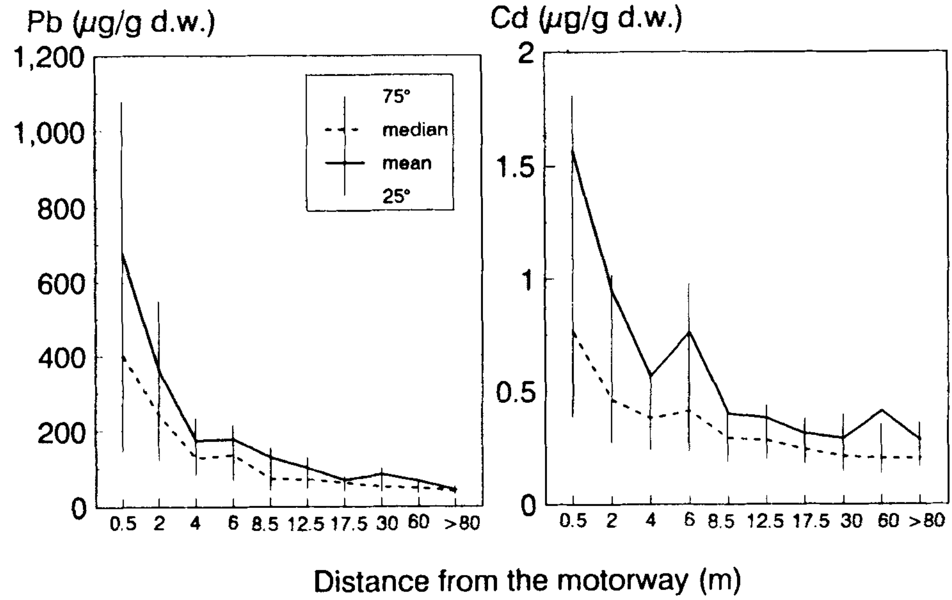

Figure 2 25th, 50th and 75th percentile and mean of lead and cadmium concentrations in surface soil samples taken at different distances from the motorway. To make the diagram easier to read, the axis lable indicating the distance is not always proportional to scale. The same applies to Figure 3 and 5.

emission sources ($< 5\,\mu g\ g^{-1}$ dw, Zöttl, 1985; Bussotti *et al.*, 1992; Ferretti *et al.*, 1993); in the soil, the mean and median concentrations are always higher than typical background levels in Italy ($26\,\mu g\ g^{-1}$, Bini *et al.*, 1988) and elsewhere ($< 25\,\mu g\, g^{-1}$, Kabata-Pendias and Dudka, 1991). In the case of cadmium samples taken more than 15 m from the roadside show levels comparable to typical

Table I Best fit regression, correlation coefficient and significance level between mean lead and cadmium concentrations (expressed in $\mu g\, g^{-1}$ d. w. on the y axis) and distance from the road (expressed in metres on the x axis) in the different matrices sampled.

Matrix	*Element*	*Regression*	*r*	*p*
SL1	Pb	$y = 416.7\, x^{-0.497}$	−0.97	<0.01
	Cd	$y = 1.027\, x^{-0.309}$	−0.89	<0.01
SL2	Pb	$y = 213.4\, x^{-0.372}$	−0.77	<0.01
	Cd	$y = 0.582\, x^{-0.287}$	−0.87	<0.01
SL3	Pb	$y = 175.9\, x^{-0.374}$	−0.89	<0.01
	Cd	$y = 0.364\, x^{-0.154}$	−0.77	<0.01
BK	Pb	$y = 101.4\, x^{-0.306}$	−0.70	<0.05
	Cd	$y = 0.35 - 0.039\, ln x$	−0.38	>0.05
TW	Pb	$y = 12.7\, e^{-0.007x}$	−0.51	>0.05
	Cd	$y = 0.14\, e^{-0.005x}$	−0.73	<0.01
GR	Pb	$y = 35.6 - 7.574\, ln x$	−0.95	<0.01
	Cd	$y = 0.21 - 0.035\, ln x$	−0.89	<0.01
LV	Pb	$y = 25.2\, x^{-0.286}$	−0.94	<0.01
	Cd	$y = 0.10 - 0.003\, ln x$	−0.46	>0.05

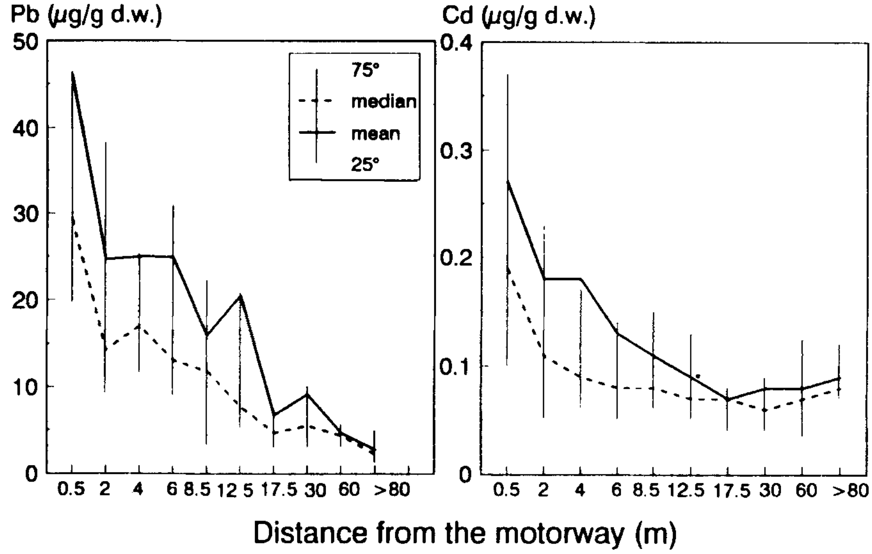

Figure 3 25th, 50th and 75th percentile and mean of lead and cadmium concentrations in grass samples taken at different distances from the motorway.

background concentrations in Italy (0.44 μg g^{-1}, Bini *et al.*, 1988) and in other countries (< 0.5 μg g^{-1}, Kabata-Pendias and Dudka, 1991).

The enrichment factors (EF) determined in GE and SL1 show a burden of lead in the roadside sampling sites that is 5.5–7.8 times higher (GR) or 9.4–20.6 (SL1) times higher than levels found at a distance of 80 m from the road; for cadmium, on the other hand, the difference is much less marked, being only about 1.3–4.3 times higher (GR samples) or 5–7 times higher (SL1 samples). This provides further confirmation that lead is still today a much more specific tracer element for motor vehicle traffic than cadmium. However, there is a close correlation between the distribution patterns of lead and cadmium concentrations in GR and SL1 samples (Table III).

Table II Reduction factors (RF, see section on Materials and Methods) of lead and cadmium at various distances from the road edge, for each of the matrices studied.

Matrix	*Distance from road edge, m*							
	2		*12.5*		*30*		*>80*	
	Pb	*Cd*	*Pb*	*Cd*	*Pb*	*Cd*	*Pb*	*Cd*
SL1	46	30	85	75	88	81	93	82
SL2	67	71	88	77	89	73	88	93
SL3	71	45	78	64	85	46	93	60
BK	61	−300	71	−21	77	15	78	−59
TW	36	−85	37	−3	−69	−34	73	41
GR	46	37	56	67	80	71	94	68
LV	29	25	59	33	66	27	80	25

Table III Pearson correlation coefficient and degree of significance between the concentrations of lead and cadmium in the various matrices sampled. Bold character indicates significance level P < 0.01.

Matrix						
SL1	SL2	SL3	BK	TW	GR	LV
0.98	**0.95**	**0.92**	0.40	0.06	**0.83**	0.46

There is little difference in the levels of lead and cadmium to be noted near different types of roads: only lead concentrations in surface soil appear to be higher near enclosed roads (for example trench-like structures, where the mean of the median values within the first 10 m from the road edge ranges from 360 to 378 $\mu g\, g^{-1}$, as opposed to completely open roads (for example, raised stretches where the mean of the median values within the first 10 m from the road edge ranges from 122 to 175 $\mu g\ g^{-1}$). This suggests that entrenched roads have a sort of "canyon effect", providing a more effective retention of the metals, partially preventing their further dispersal (Bernatzky, 1976).

Relationship to Traffic Density

In order to highlight any relationship existing between metal concentrations and traffic density (i.e., emissions), the samples were also divided according to geographical areas. For the period 1/1/89–28/10/89, average daily traffic (ADT) in Northern

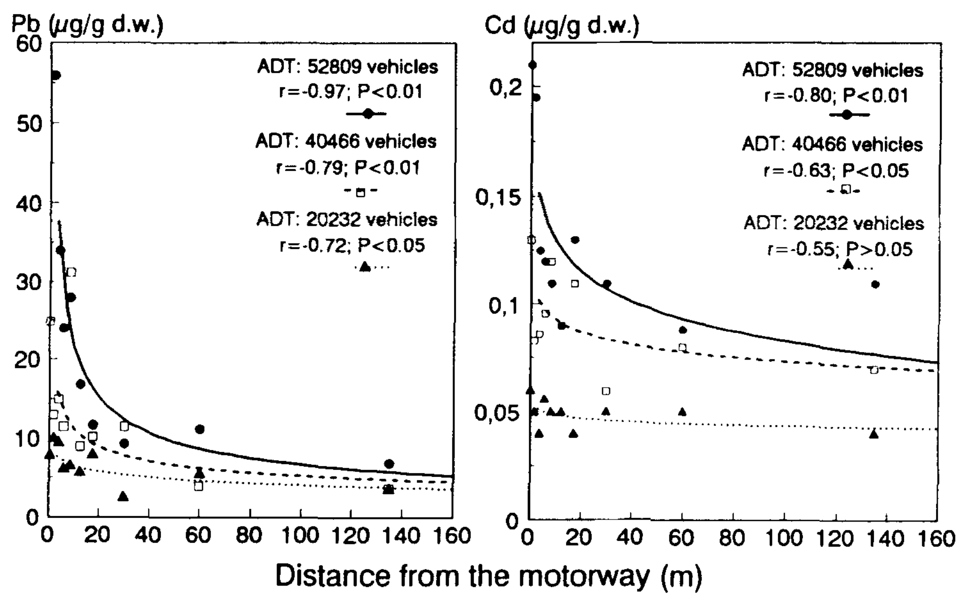

Figure 4 Mean leaf concentration levels of lead and cadmium plotted against ADT levels. The correlation coefficient and the degree of significance of the regressions are also indicated.

Italy ranged from 39,000 to 71,000 vehicles per day (mean value: 52,809); in Central Italy ADT was between 29,000 and 52,000 (mean: 40,466); in Southern Italy ADT was between 18,000 and 27,000 (mean: 20,232) (Fig. 1). Estimated lead emission from gasoline-fuelled vehicles amounted to 3.28 10^3 t/year in Northern Italy, 1.45 10^3 t/year in Central Italy, and 1.17 10^3 t/year in the South (Ministero dell' Ambiente, 1989). As an example, in Figure 4 we report leaf concentrations of both lead and cadmium according to the mean traffic levels. There is a substantial agreement between lead and cadmium concentrations and traffic density: furthermore, the typical trend of decreased concentrations at increased distance is even more pronounced in areas with greater traffic density, i.e., Northern and Central Italy. The decreasing trend was not seen for cadmium values in Southern Italy. Similar results were found in the samples of SLI and GR: generally speaking, lead and cadmium concentrations in the various matrices along the road edge are consistently higher in Northern Italy, where the traffic density is greater (see below).

Comparisons with the Remote Site

The levels of lead and cadmium in the leaves of the 27 species of trees and shrubs (Table IV) growing alongside the motorway (0–3 m) were compared to the concentrations measured in the same species at the remote site. Comparisons were made by grouping the species on the basis of their characteristic features (deciduous broadleaves, evergreen broadleaves, conifers). The mean concentrations of lead in the leaves of trees directly exposed to motor vehicle traffic vary from 9–45 $\mu g\, g^{-1}$ as

Table IV Mean lead and cadmium concentrations and the ratio between them in plants exposed and not exposed to motor vehicle traffic, divided into groups according to their basic characteristics (number of different gathering sites). Enrichment factors (EF, see section on Materials and Methods) for the motorway sampling sites are reported in brackets.

Species	*Motorway sites*			*Remote site*		
	Pb	*Cd*	*Pb/Cd*	*Pb*	*Cd*	*Pb/Cd*
DECIDUOUS BROADLEAVES ($n = 45$) *Quercus cerris: Quercus pubescens; Robinia pseudacacia; Sorbus torminalis; Castanea sativa; Ostrya carpinifolia; Fraxinus ornus; Acer campestre; Prunus* spp: *Ailanthus altissima;Crataegus* spp; *Vitis vinifera*	43.7 (2800)	0.139 (316)	0.0032	1.56	0.044	0.028
EVERGREEN BROADLEAVES ($n = 27$) *Quercus ilex; Arbutus unedo; Phillyrea spp; Myrtus communis; Viburnum tinus; Pistacia lentiscus; Nerium oleander; Pittosporum tobira; Laurus nobilis*	9.41 (697)	0.072 (103)	0.0076	1.35	0.070	0.051
CONIFERS ($n = 15$) *Pinus pinea; Pinus pinaster; Pinus halepensis; Juniperus communis; Cupressus* spp.	24.25 (3800)	0.149 (250)	0.0061	0.63	0.059	0.093

opposed to the much more homogeneous values (0.63–1.56 $\mu g\, g^{-1}$) in the controls (Table IV). We can observe differences among homogeneous groups of species: conifers and deciduous broadleaves show greater accumulation capacity than evergreen broad leaves (Table IV). Mean cadmium concentrations in the leaves of trees growing alongside the motorway are around 0.07–0.15 $\mu g\, g^{-1}$, with values that are not very different from the values at the control site (Table IV). As in the case of lead, there is a notable difference between species: evergreen broadleaves once again display a low accumulation capacity, while there is little difference between deciduous broadleaves and conifers, either in absolute terms or in accumulation capacity (Table IV). Even if leaf morphology is important, its exact role remains unclear since the deciduous broadleaves sampled in this survey sometimes have different leaf characteristics, viz. simple or composed leaf morphology (*Quercus* spp., *Castanea sativa* Mill., *Ostrya carpinifolia* Scop., *Acer campestre* L., *Sorbus torminalis* Crantz., *Prunus* spp., *Crategus* spp., *Vitis vinifera* L. on one hand; while on the other, *Robinia pseudacacia* L., *Fraxinus ornus* L., *Ailanthus altissima* Swingle), smooth (*Robinia pseudacacia, Acer* spp.) or scabrous (*Ostrya carpinifolia, Sorbus torminalis, Vitis vinifera*), hairy (*Quercus* spp.,) or hairless (*Fraxinus* spp., *Ailanthus altissima*).

However, a further stratification of the data base yields only a small number of data for each strata, making all comparisons insubstantial. The magnitude of cadmium to lead ratio at the control site is about 10 times higher than at the motorway sites (Table IV). This difference appears to be caused mainly by changes in lead levels, rather than in cadmium: motor vehicle traffic therefore appears to cause an enrichment of lead which is ten times greater than that of cadmium. This finding is consistent with our data on enrichment factors at sites near the motorway.

Monthly Variations of Lead and Cadmium Concentration Levels in Lolium Multiflorum

Figure 5 reports the seasonal trend of lead and cadmium concentrations, giving the mean value of the different sampling points located at each distance from the motorway. The spatial (lateral) distribution trend in lead and cadmium concentrations is consistent ($P < 0.05$) with the data reported for spontaneous herbaceous vegetation on a national level. In the case of lead the mean reduction is about 70% within the first 5 m from the road, 85% within the first 10 m, and 89% within the first 15 m. The level of lead concentration found in control plants ($6.78 \pm 2.72\, \mu g\, g^{-1}$ seasonal mean) is reached at a distance of 10 to 15 m from the road. As compared to controls, the enrichment factor (EF) is 694%, within the range of the values found in the spontaneous vegetation (EF = 554–785%). Levels of cadmium follow a similar trend (Fig. 5). The EF is 592%, comparable to the values typical of spontaneous grass (137–433%). The variation of concentration in relation to the date of sampling is more evident in samples collected closer to the motorway, since those sites are most influenced by changes in traffic density. If we compare the data for lead and cadmium with the data for total traffic density during the period prior to the sampling (total number of vehicles between the previous sampling and the current one), we find a positive but slightly significant correlation for cadmium ($r = 0.75$,

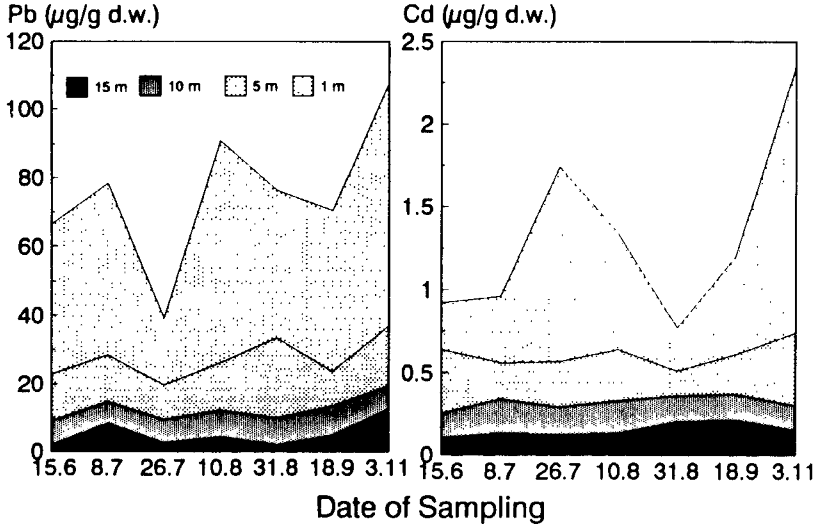

Figure 5 Variations of mean concentrations of lead and cadmium in *Lolium multiflorum* samples growing at different distances from the motorway. Each point at each distance shows the mean value for three different sampling points.

P⩽0.05) and an indicative correlation for lead ($r = 0.72$; r would need to be equal to 0.75 to have a significant value at P⩽0.05). The lack of a closer correlation may be attributed to a number of factors such as weather conditions (i.e., rainfall): according to many authors (cf. Markert, 1989) more than 90 % of leaf lead concentration is due to deposits on the leaf surface which may be sometimes removed by rain.

Preferential Accumulation Sites and Behaviour of the Matrices

Figure 6 shows the mean lead and cadmium concentrations found in the different matrices studied. The highest levels of lead were found in soil samples, especially in SL1 (surface soil). A soil profile pattern characterized by surface retention of metals is usually associated with atmospheric deposition (Hunter *et al.*, 1987). The highest levels of lead in soil samples appears to be related to the long-term exposure of surface soil to the vehicle exhausts and also to the fact that it collects both canopy leaching and stem flow from the vegetation (Mayer, 1988). Furthermore, as reported by Scanlon (1991), litterfall may contribute to soil lead. In addition, lead is bound by organic matter in soil and tends to be retained in the upper soil profile (Scanlon, 1991). The high concentration levels displayed by bark samples can be explained by long-term exposure and in some cases by the morphology of the bark: in certain species (*Robinia pseudacacia*, *Quercus cerris* L., *Q. ilex* L., *Q. pubescens* Willd. *Pinus* sp.) the bark's scabrous surface may give it a greater capture capacity. Lower concentrations were showed by grasses, leaves and twigs. The following is the order of magnitude of lead concentration levels: SL1 > SL2 > SL3 > BK > GR-LV-TW. With the exception of TW, all other receptors studied show higher levels in Northern Italy than in Central or Sourthern Italy. The observations made for lead can also be

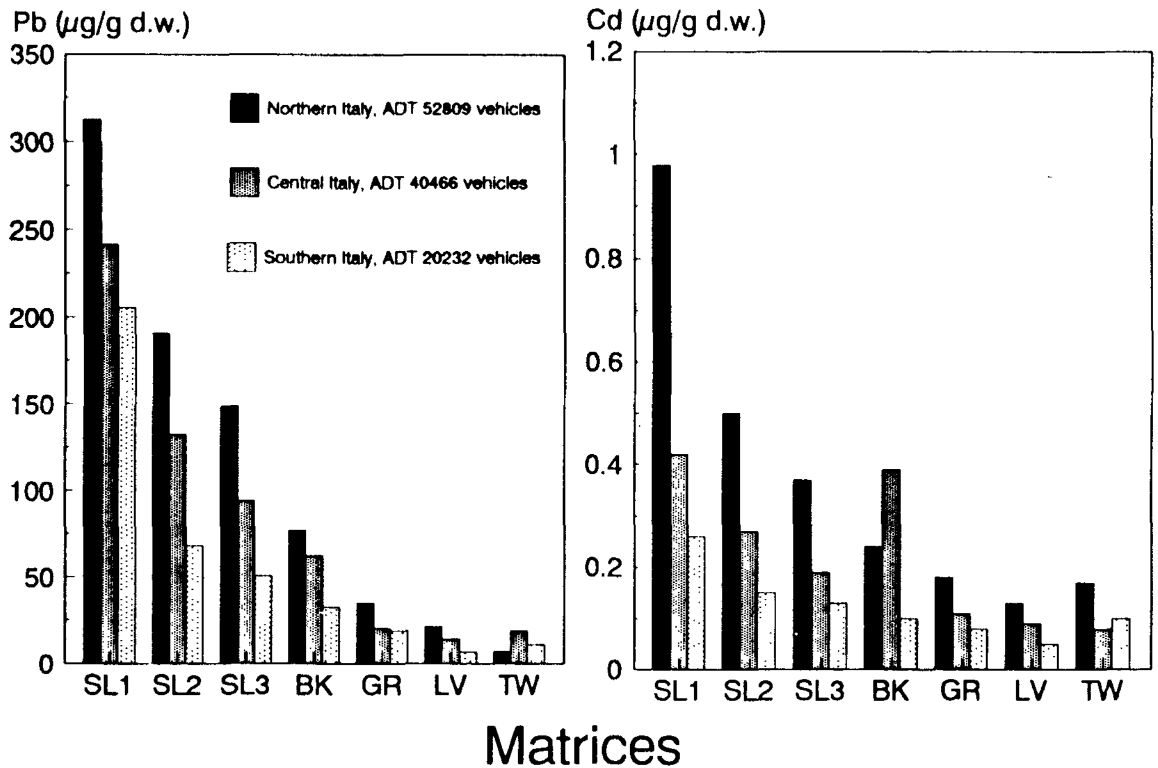

Figure 6 Mean concentrations of lead and cadmium in the various matrices sampled in different geographical areas with different levels of traffic density. Abbreviations are explained in the section on Materials and Methods.

applied to cadmium: the highest levels are found in SL1 and SL2, but there is no difference between SL3 and BK. The lowest levels of cadmium are to be found in GR, TW and LV. As a result, the concentration levels of cadmium can be placed in the following order: SL1 > SL2 > SL3-BK > GR-LV-TW. In the case of cadmium too, we find that levels are highest in Northern Italy, with the exception of BK samples. In order to assess the correlation between the various matrices, we used lead concentrations to perform a correlation analysis (Table V). There are highly significant correlations ($P \leqslant 0.001$) between SL1-SL2-SL3, GR-LV, SL1-GR, SL1-LV and TW-LV. The correlations between lead concentrations in LV and SL2, LV and SL3, LV and BK, BK and SL2, BK and SL3, were significant at $P < 0.05$. The similar behaviour of the LV, GR and SL1 samples (the receptors with the largest surface exposed to the vehicle exhausts), as well as the close interrelation between the various matrices, suggest that the main source of lead and cadmium for roadside vegetation is still atmospheric deposition.

CONCLUSIONS

The results of this survey suggest two types of spatial distribution of lead and cadmium Italy: one is a geographical distribution on a national scale (concentrations are higher in the North than in the Centre or South of Italy), and the other is local lead and cadmium levels in the soil and plants near the motorways are definitely higher than those measured in areas further away, and much higher than found at a remote site). Both these spatial distributions are consistent with traffic density, which is greater in Northern than in Central or Southern Italy. This offers further confirmation of the already known potential of plants for environmental monitoring, although standardization of biomonitoring methods is still a problem. Lead and cadmium levels vary according to the different receptors, accumulating mainly in surface soil and epigean plant organs such as bark exposed for longer periods of time. Conifers and deciduous broadleaves are the most efficient species in lead, and to a lesser extent, cadmium retention at foliar level.

Although we believe intuitively that the type of road design is important, its influence is still difficult to interpret: our data appears to suggest that enclosed

Table V Significance level of the Pearson correlation coefficient between the lead concentration levels found in the different matrices (NS = $P > 0.05$; * = $P < 0.05$; ** = $P < 0.01$).

SL1	1						
SL2	**	1					
SL3	**	**	1				
GR	**	NS	NS	1			
LV	**	*	*	**	1		
BK	NS	*	*	NS	*	1	
TW	NS	NS	NS	NS	**	NS	1
	SL1	SL2	SL3	GR	LV	BK	TW

roadways, trench-like in design, retain a greater quantity of the pollutants, thereby reducing the amount which is dispersed further afield.

The data gathered over the June-November 1989 period using *Lolium multiflorum* are consistent with the findings of our national level study of spontaneous vegetation.

The findings of this study are consistent with the data reported by many other authors since the 1960s (see Introduction). The high levels of contamination from heavy metals found in the matrices sampled near roadways offer further confirmation that motor vehicle traffic interacts with the nearby environment. However, monitoring is only a first step which can allow identification of a problem and its first assessment: in-depth studies on metal fractioning, speciation and fate in the roadside ecosystem are necessary to understand the impact of the reported interferences at ecosystem level.

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