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The Role of Evergreen Vegetation in Industrial Agglomeration Areas

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Air hygienic problems in industrial agglomeration areas mainly appear in winter when periods of weak air exchange and persistent low level temperature inversions within high pressure areas cause high concentrations of polluted air.

Aerosols and SO_2 are immissions which can entail the formation of SO_2-smog in mid-latitude industrial areas in the winter half of the year. During this season, deciduous trees in public parks, for example, cannot improve city air quality because of the absence of green leaves.

In this connection one must ask whether evergreen vegetation can aid the improvement of air quality in agglomeration areas during months when air pollution concentrations are higher than in summer.

There are many ways in which evergreen plants can improve air quality in winter (e.g., the social function of green leaves, filtering aerosols, absorption of CO_2 and gaseous pollutants and the production of oxygen by photosynthesis). For these reasons, evergreen vegetation should have received more attention than it has up to the present in planning public gardens in cities for, under certain climatological conditions, different species of evergreen vegetation can also grow in the winter season.

In industrial areas the intensive regional association of a high population density and air pollution gives rise to a frequently noted air hygienic dilemma. On the one hand air layers near the ground must serve as an absorption-, carrier- and exchange medium of gaseous and particle pollution foreign to the atmosphere, on the other hand, air layers of the troposphere should guarantee a permanent supply of clean air, essential to life, to the population.

This problem appears to be a focal point of public interest, especially when high concentrations of air pollution are caused by episodically developing weather conditions which are characterized by several days duration of calm weather and high pressure.

Such periods of weak air exchange mainly occur within high pressure areas induced by lack of wind and persistent, low level temperature inversions. Under these circumstances an undiminished continuous emission of pollutants in winter can result in the formation of SO_2-smog [7], whose noxious effects have frequently caused acute injuries to the health of industrial area populations.

This fact is proved by numerous examples of severe air pollution in various industrial areas within recent decades (compilation in ref. 8). However, not only these, fortunately, relatively seldom appearing peak loads of air pollution, but also the long-term prevailing cases especially which can be classified as "normal" basic concentrations of emission, are unhealthy, and detract from human welfare since their air pollution concentrations are still essentially high as compared with areas of clean air.

How far the process of air pollution has already advanced can be shown by a comparison in Table 1 between "unpolluted" and "polluted" air in respect of frequently appearing immissions.

For example, in heavily polluted agglomeration areas SO_2 concentrations are 520 times higher than in unpolluted areas, while in the case of dust there can be increases of up to 35 times compared with unpolluted areas.

These immission concentrations which are called long-term loads in industrial areas do

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TABLE 1

Comparison between an "unpolluted" and a "polluted" atmosphere (from Kuttler [8] after Georgii, completed)

Spurenstoff	Unbelastet	Belastet	Erhöhung um den Faktor
Staub Dust	0.01 - 0.02 mg/m^3	0.07 - 0.7 mg/m^3	7 - 35
Schwefeldioxid SO_2	0.001 - 0.01 mg/m^3	0.05 - 5.2 mg/m^3	50 - 520
Kohlendioxid CO_2	310 - 330 ppm	350 - 700 ppm	1.1 - 2.1
Kohlennoxid CO	1 ppm	5 - 200 ppm	5 - 200
Stickoxide nitrogen oxides	0.001 - 0.01 ppm	0.01 - 0.1 ppm	10
Kohlenwasserstoffe Hydrocarbons (gesamt) (total)	1 ppm	2 - 20 ppm	2 - 20

not always occur at the same height, just as with peak loads; they deviate considerably according to the kind of pollution and the season. The different degrees of pollution by the nowadays nearly ubiquitous SO_2 and dust immissions are shown in Figs. 1 and 2.

A comparison of the pollution data in summer (April - September) and winter (October - March) shows that the SO_2 immission loads in summer (x = 0.13 mg/m^3) are only about half as concentrated as those in winter (x = 0.23 mg/m^3).

Dust pollution (Fig. 2) is also higher during the heating-intensive cold period of the year (winter mean x = 0.248 mg/m^3) than it is during the summer (summer mean x = 0.181 mg/m^3). These increased immission concentrations during the winter are caused, mainly, in two ways: on the one hand during the heating period there is — in addition to the continuous year-round-pollution by industry and motor traffic — a further important air hygienic load caused by domestic heating, which is mainly released at lower heights

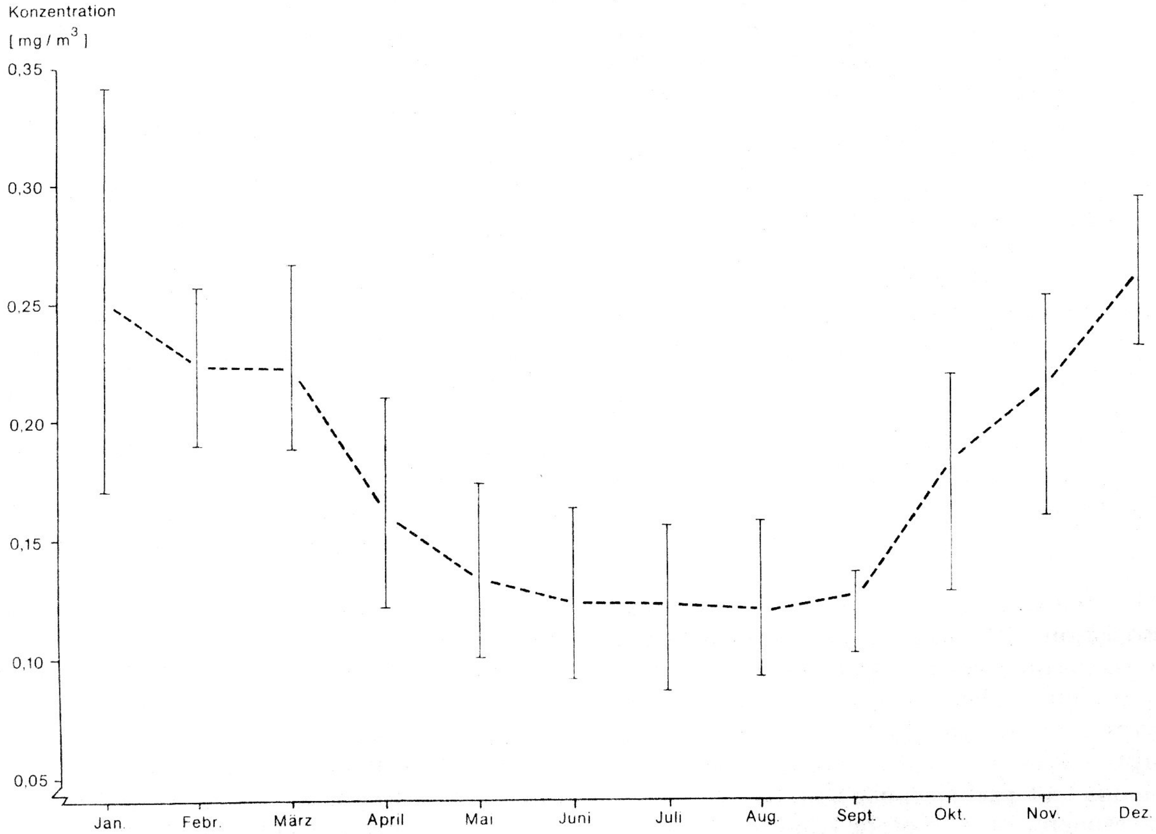

Fig. 1. Annual course of SO_2 concentrations in an urban area (after Kuttler 1979b).

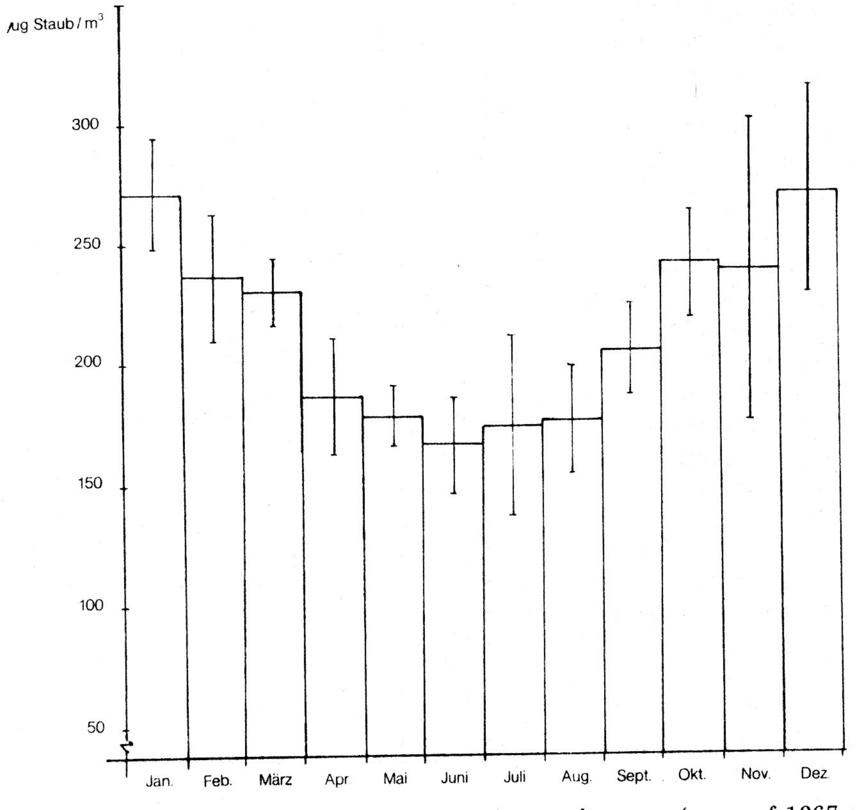

Fig. 2. Annual course of dust concentration in an urban area (mean of 1967 - 1972; calculated and drawn from data after de Haar 1979).

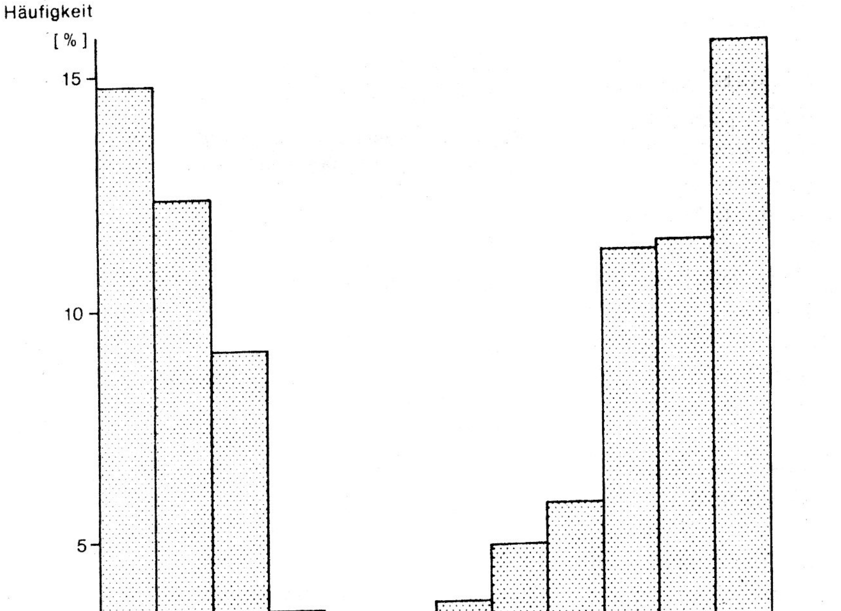

Fig. 3. Annual course of frequency of temperature inversions in an urban area (after Kuttler 1979b).

above ground. On the other hand, an enrichment of immissions near ground level is induced meteorologically by calm weather with low level inversions formed under high pressure conditions.

Figure 3 shows the seasonal cycle of inversions with its unequal dispersion with regard to the summer and winter months.

Nearly 70% of all inversions develop in winter, 30% during the summer. However, there is not only a higher frequency of occurrence of temperature inversion layers during the winter months, but also an increase in its duration. Figure 4 shows that inversions of several days duration occur more frequently during the cold season of the year as a result of stable, cold anticyclones.

From these arguments it is evident that air layers near the ground — the ecosphere of man — are heavily loaded by an increased air pollution, especially in the winter months.

Although high immission concentrations have decreased considerably within recent years, a further improvement in air quality in densely populated industrial regions is still desirable, especially in winter.

In this connection, inner urban and downtown green areas play an important role in solving urban climatic and air hygienic problems.

Summarizing the welfare effects of urban green areas under two headings [1], on the one hand a "protection function" can be developed with regard to improving comfort in the urban environment; on the other hand, plants are able to carry out a "social function", too, which implies, for instance, the recreation utility, the positive psychological effect of chlorophyll and its aesthetic worth.

Plants fulfill these main functions according to a classification by Kratzer [6], supplemented, as follows:

— public parks within avenues of trees, separated plazas, woods, greens, and promenades;

— green areas for special purposes with play- and sports grounds, urban parks, cemeteries, botanical gardens;

— green areas used by individuals with common gardens, private parks, back gardens, commercially used horticultural or agricultural areas.

Green areas do not only influence the quality of the air in a passive manner, since they create no dust by themselves, but also in an active way by filtration of the air streaming through the leaves.

A comparison of various kinds of trees with regard to their particle pollution filtration capacity reveals which quantities of dust can be filtered from the atmosphere near the ground (Table 2).

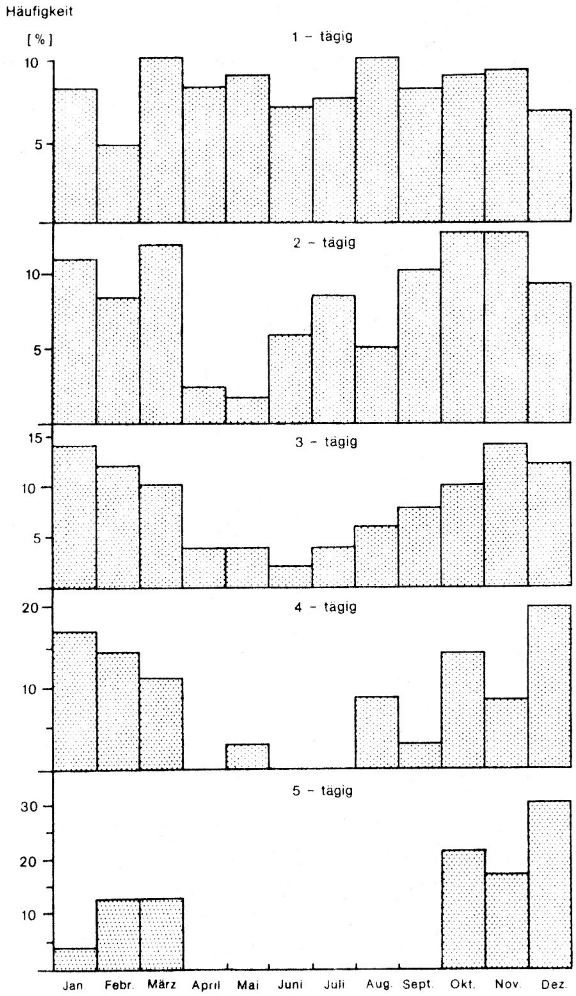

Fig. 4. Annual course of temperature inversions in an urban area (one day and several days duration; after Kuttler 1979b).

TABLE 2

Dust filtration of trees (after Keller 1971)

Tree	Staubmenge mg/g Blatttrockengewicht	Staubfang (kg/ha)
Beech	70	280
Oak	90	540
Pine	30	420
Mountain fir	200	1000

By comparison with other trees, a pine-tree has a filtration capacity of *ca.* 4 times that of a beech, of *ca.* twice that of an oak and of *ca.* 2.5 times that of a spruce. This importance of increasing roughness near the ground of plants in order to improve the air quality is shown in Table 3, in accordance with the results of laboratory experiments [13]. It allows a comparison of sedimentation quantity data for air pollution with regard to smooth areas and of trefoil planted areas, and it is clearly obvious that there are essentially higher data for planted soil (*cf.* Table 3).

TABLE 3

Deposition velocity and sedimentation quantity for different kinds of substrate (after Horbert [13])

Substrate	Deposition velocity (cm/s)	Deposition amount (kg/ha day)
Smooth surface	0.03	0.25
Soil	0.04	0.35
Grass	0.1	0.86
Clover	0.24	2.1

Apart from this, the height of the specific sedimentation rates gives an idea of the particle deposition velocity.

In addition to these results, Horbert (in ref. 13) found that "sedimentation on coniferous trees is higher by a factor of 1.5 to 10 than sedimentation on oak trees or other deciduous trees".

Even in the case of gaseous air pollution, a filtration effect within the framework of a "dry deposition" can be noticed which, for example, shows an essentially higher filtration rate in a spruce forest than in a beech forest (*cf.* ref. 14).

Even though public parks improve the air quality of the urban environment, areas planted with deciduous trees, shrubs or other summer green vegetation cannot meliorate air quality in a season of increased air pollution because of their lack of green leaves in winter. In this connection, therefore, one has to ask whether evergreen vegetation* can improve air quality in agglomeration areas during the winter months when pollution concentrations are higher than in summer.

Due to lack of research in this field, unfortunately, quantitative statements on the influence of evergreen vegetation on the urban environment are not yet possible.

In a qualitative manner, however, it can be stated that evergreen species not only filter particle pollution, but also have, amongst others, the effect of diminishing traffic noise. Apart from this, these plants can absorb CO_2 and gaseous pollutions, and can deliver oxygen during the course of photosynthesis unless certain limiting values in the strength of luminous intensity and ground temperature are exceeded.

Although the efficiency of deciduous trees and shrubs should not be overestimated (Bernatzky, ref. 2), to my knowledge, no detailed information exists so far about the relative importance of the absorption of pollutants during photosynthesis in winter by urban parks with evergreen vegetation. In addition to this, for instance, in the case of the Rhein–Ruhr zone, the largest industrial area in central Europe, no data are available about the proportions of deciduous to evergreen vegetation in green areas of cities (Petsch, personal communication). In principle, regeneration of air for respiration just at that time would be of great benefit to densely populated urban areas. Conditional on sufficient luminous intensity* the growth of evergreen plants, their absorption of CO_2 and other pollutants, as well as the delivery of

*Almost all conifers (except larch, marsh cypress), boxtree, ivy, holly, *arbor vitae*, privet, cranberry, blueberry, rhododendron, cotoneaster, etc.

*In addition to air temperature, the radiation intensity determines the efficiency of photosynthesis. According to Pisek (ref. 11), the net assimilation efficiency is reduced to *ca.* 1/3 of its initial value if the luminous intensity diminishes from 30000 Lux to 3000 Lux. It should be taken into consideration, however, in this connection, that the optimum temperature is shifted to higher temperature ranges in consequence of an increased luminous intensity. This means that at lower temperatures a plant can reach its photosynthesis maximum at lower luminous intensities than those prevailing in winter. A comparison with the average sums of global radiation (converted into Lux) from the Karlsruhe station shows that even in the winter months average values do not fall below 3000 Lux: Oct. (12700), Nov. (4500), Dec. (3400), Jan. (3600), Febr. (9000), Mar. (15500), Apr. (21800). Conversion of measurements after Hann-süring [4] according to the relation 1 Lux = 1146×10^{-5} cal cm^{-2} min^{-1}.

TABLE 4

Temperature limits of net assimilation for different kinds of plants

No.	Plant	No of days with T_L** < TM_N								
		TM_N*	Jan.	Feb.	Mar.	Apr.	Oct.	Nov.	Dec.	Σ year
1	*Buxus sempervirens* (Gem. Buchsbaum) Boxtree	−2.0	11.6	9.3	4.9	0.7	0.6	4.7	8.1	39.9
2	*Quercus ilex* (Steineiche) Oak									
3	*Vaccinum vitis - idaea* (Preiselbeere) Cranberry	−3.5	9.8	7.3	3.0	0.3	0.2	3.2	6.3	30.1
4	*Olea europea sativa* (Ölbaum) Olive	−4.5	8.3	5.7	1.8	—	0.1	2.0	5.0	22.9
5	*Pinus cembra* (Zirbelkiefer) Siberian fir	−5.0	6.9	4.6	1.1	—	—	1.1	3.9	17.6
6	*Rasengräser* lawn	−6.0 to −6.5	5.7	3.6	0.8	—	—	0.6	2.9	13.6
7	*Picea excelsa* (Fichte) Pine									
8	*Pinus silvestris* (Waldkiefer) Scotch fir	−7.0 to −7.5	4.4	2.9	0.6	—	—	0.3	2.2	10.4
9	*Viscum album* (Mistel) Mistletoe									
10	*Arbutus unedo* (Erdbeerbaum) Strawberry tree									
11	*Laurus nobilis* (Edler Lorbeer) Bay									
12	*Abies alba* (Weisstanne) White fir									
13	*Hedera helix* (Efeu) Ivy									
14	*Taxus bacata* (Eibe) yew									

*TM_N = minimum temperature for net assimilation (°C).
**T_L = air temperature.
Source: Pisek *et al.* (1967); Stählin *et al.* (1972).

oxygen, are mainly determined by the prevailing air temperature.

In this connection, the minimum temperature of net assimilation is of importance, because at an air temperature below this limiting value photosynthesis will stop.

Therefore, knowledge of these limiting values is of great importance in determining the efficiency of photosynthesis of evergreen vegetation in winter. For this reason, minimum temperature data of the net assimilation of some evergreen species which have been analysed are given in Table 4.

These measurements show that the wood-pine, the white-fir, the ivy and the yew tree still deliver oxygen and absorb pollutants, as well as CO_2, within the course of their net assimilation at a temperature down to −7.5 °C. Whereas, for instance, spruce and (in green areas frequently wide-spread) lawn grass can still assimilate at temperatures down to −6.5 °C, the olive tree (to −4.5 °C) and the box tree (to −2.0 °C) stop production of surplus oxygen much earlier. In order to determine on how many days and in which months the air temperatures remain below the specific temperature limits for a delivery of oxygen and absorption of CO_2, the number of days has been computed on which the air temperature (T_L) remains below the minimum temperature of net assimilation (TM_N)*.

The frequency of minimum temperatures of plant net assimilation with very low values (Nos. 8 - 14 in Table 4) shows that in the Central European climatic zone these plants do not produce surplus oxygen in the course of their photosynthesis on only 10 days within a year.

*The compilation of the frequency of temperature minima was achieved according to data of the Münster station [10]. In the case of the high agglomeration area of the Rhein–Ruhr zone, temperature measurements as well as frequency dispersions should be even more favourable as a result of the urban-climate-effect, which means that the number of days in which $T_L < TM_N$ will be less.

Other examples (Nos. 4 - 7) also show that there is still sufficient time for the process of net assimilation in the winter months. Only plants with a relatively high minimum temperature stop the supply of oxygen especially in January and February, on about one-third of all days (Nos. 1 - 3 in Table 4), whereas in March and April net assimilation is interrupted on only a few days.

The distinctive diminution of the number of days with $T_L < TM_N$ from February to April, and its slow increase from October to December, is striking. This shows that interruption of assimilation of evergreen plants is almost entirely restricted to the two months January and February, and within these months, only to a few days. This restricted and sporadically appearing winter rest of evergreen vegetation, which can be interrupted by a warmer winter day [11] increases its air hygienic value in urban green areas compared with deciduous vegetation.

Lawn grasses (No. 6 in Table 4) — predominating in many urban parks — contribute only slightly to oxygen production in winter [12]. In the same way, its value as a dust filter of aerosols is assessed as very low in those cases when grass is cut short and perhaps even covered by snow.

There is a handicap in using evergreen conifers in urban green areas because of their great sensitivity to SO_2 and aerosols. In the Ruhr industrial area especially these problems are obvious. During recent decades, however, attempts have been made to cultivate resistant species for this region, with the aim of replanting the Rhenish–Westphalian industrial area with conifers (especially spruce and pine).

Meanwhile, for some border regions which suffer less from immissions, various conifers have already been recommended for cultivation [14], for example, Japanese larch (*Larix leptolepis*), the Weymouth-pine (*Pinus strobus*) and the Serbian spruce (*Picea omorika*)*.

Conifers, however, represent only *one* group of evergreen vegetation which could be used for cultivation in urban green areas. Even though for the time being this group of plants cannot yet be applied efficiently to improve air quality in its entirety due to its sensitivity to prevailing immissions loads, in my opinion it would be useful to determine whether other evergreen trees and bushes could be planted in agglomeration areas more than at present, in order to improve the air quality in winter.

*In this connection the black pine (*Pinus nigra*) should also be mentioned.

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