EFFECTS OF LIMESTONE DUST ACCUMULATION ON COMPOSITION OF A FOREST COMMUNITY

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ABSTRACT

Two sites in southwestern Virginia were sampled to determine the effects of dust accumulation on structure and composition of a forest community. The sites were similar in all respects except for dust accumulation. One site, the control, had essentially no dust accumulation, whereas the other had heavy accumulation from limestone processing plants.

When compared with the control site, significant changes in structure and composition were found to have occurred in the seedling-shrub and sapling strata of the experimental site. Dominance in the tree stratum was also shown to be changing. Leading dominants in the control site were Quercus prinus, Q. rubra, *and* Acer rubrum, *whereas those in the dusty site were* Quercus alba, Q. rubra, *and* Liriodendron tulipifera. *Species expected to assume ultimate dominance in the experimental site, if dust accumulation continues, are* L. tulipifera, Acer saccharum, *and, possibly,* Quercus muehlenbergii. *This is the first known attempt to assess the long-term effects of dust accumulation on structure and composition of forest communities.*

INTRODUCTION

The effects of particulate air pollutants on vegetation have been studied, mainly under laboratory conditions. This research was concentrated on the major effects of leaf incrustations, namely interference with light absorption, reduction in net photosynthesis, and resultant reduction in growth. Some investigators, however, have expressed doubts as to whether results of laboratory research can be applied directly to effects of dust accumulation in natural vegetation (Darley, 1969).

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Darley (1966) and Darley & Middleton (1966) have reviewed and summarised the research on dusts from cement-kilns. Similar research on effects of lime dust has been reported by Heck *et al.* (1970). The research reviewed by these workers dealt with the short-term effects of dust on individual plants under controlled conditions and gave no indication of how a plant community reacts to prolonged accumulation of dust.

The paper reports the results of field investigations on effects of accumulated limestone dust on the structure and composition of a forest community in southwestern Virginia, USA.

MATERIALS AND METHODS

Big Stony Creek in Giles County, southwestern Virginia, flows through an area of the Allegheny mountains rich in high-grade limestone. The region is in the Ridge and Valley province of the Appalachian highlands, and the forest is part of the oak–chestnut association of the eastern deciduous forest of North America, as described by Braun (1950).

Two sites in the Big Stony Creek valley were selected for this study (Fig. 1). One receives heavy dust fall from nearby limestone quarries and processing plants. The other, a control site, receives little, or no, dust. The sites are similar in all other respects. Both are at mid-slope with a northern exposure at 640 to 670 m in elevation. Slope aspect ranged from 280° to 305°, and gradient between 30 and 75%. The areas are underlain by marine sedimentary rocks of Middle Ordovician to Early Devonian age. The Martinsburg formation and other undifferentiated limestones constitute the primary geological group being mined in the dusty site. Tonoloway limestone underlies much of the control site (Eckroade, 1962). None of the soils in Giles County, Virginia, have been mapped and, therefore, the actual soil type is not known. Chemical and physical properties indicate that the soils in both areas are of Frederick, Lodi, or Groseclose loams or silt-loams. Soils in both sites are clayey and shallow with a prevalence of cobbles and limestone outcrops. Neither site showed any evidence of appreciable disturbance from recent fire or cutting. The sites are close enough together to allow the assumption that changes in macroclimate are consistent for both.

Suspended particulate matter was sampled on a General Metals high-volume sampler. The air flow rate average was 1·3 m^3/min. Dust fall was sampled with standard dust fall buckets 19 cm in diameter. Table 1 summarises the Virginia State air quality standards for both dust fall and suspended particulate matter, and indicates quantities and particle sizes for both categories for Kimballton, Virginia, which is adjacent to the dusty site. This area is zoned for residential and commercial use. Dust has accumulated at this rate since 1967 when the limestone plant drastically increased production. This plant has been in operation since

1945. The main components of the effluent are calcium carbonate, calcium oxide, carbon dioxide and water vapour. The oxide reacts quickly with water vapour and carbon dioxide to form more carbonate.

Quantitative data on the composition of the vegetation in each area were obtained with a stratified random sample. A belt transect, 30 m wide and 600 m long, was located parallel to the contour of the slope in each area. Each transect

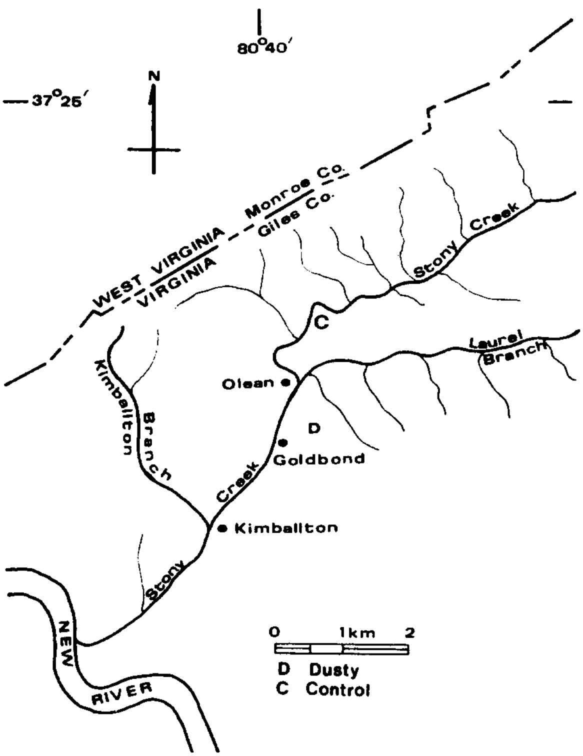

Fig. 1. Location of study area in Giles County, Virginia, showing the control site and the experimental dusty site.

was divided into twenty equal sections or strata. A 5 × 20 m quadrat was placed in each stratum at random, perpendicular to the contour of the slope. A 20 m tape was laid out, and an area 2·5 m on either side sampled. The species and diameter of every tree 5 cm DBH (diameter breast height, 1·37 m) and greater were recorded. Stems less than 5 cm DBH were also tallied but diameters were not recorded.

Woody plants were classified into three canopy classes. These were trees (10+ cm DBH), saplings (5–9·9 cm DBH) and seedlings and shrubs (< 5 cm DBH). Herbaceous vegetation was not sampled. From field data, density and relative

TABLE 1

DUST ACCUMULATION IN KIMBALLTON, VIRGINIA, COMPARED WITH AIR QUALITY STANDARDS OF THE COMMONWEALTH OF VIRGINIA*

Suspended matter limits—μg/m³/24 h Residential zone: 75 Other land uses: 150				*Dust fall limits—Metric tons/km²/month* Residential zone: 21 Other land uses: 42			
	Min.	*Amount Median*	*Max.*		*Min.*	*Amount Median*	*Max.*
Kimballton, Va.: (3 Feb. 1970– 8 May 1970)†	158	824	2428	Kimballton, Va.: (Nov. 1968– June 1970)†	274	426	718
Particle size:		0·5 to 5+ μ		Particle size:		10 to 150+ μ	

* Air Quality Standards Relative to Dust and Fumes, Report to the Governor, 1 July 1968 (revised 1 February 1969).

† Dates indicate sample periods for the Kimballton, Virginia, area.

density were computed for seedlings and shrubs. Importance values were calculated for saplings and trees. Importance values are half the sum of relative density and relative basal area, and have a maximum value of 100.

RESULTS

From observations of vegetation in the area between the control and dusty sites, it is believed that the community on the dusty site is limited to the immediate area around the pollution source, and that differences in composition and structure of the forest in the two sites are due largely to differences in dust accumulation.

The most obvious structural difference between the two sites studied is in total density of woody stems; seedlings, shrubs, saplings and trees. The control site has 11,305 stems/ha, whereas the dusty site has only 7,595 stems/ha. The sites also differ in pattern of species distribution.

The dominant trees of the control site are *Quercus prinus, Q. rubra*, and *Acer rubrum*. The trees are tall, straight, and moderately-spaced. The sapling stratum is of uniform height and distribution. The great abundance of saplings and seedlings indicates favourable conditions for reproduction of trees (Table 2). Herbs are localised in areas under openings in the usually dense canopy.

Density of trees in the community is 1135 trees/ha with a total basal area of 62·9 m^2/ha. *Q. prinus* dominates the community (Table 4) with a density of 400 trees/ha and a basal area of 18·34 m^2/ha. The larger trees are 60 to 80 years old. Although *Q. rubra* has a higher density, 265 trees/ha, as compared with 155 trees/ha for *A. rubrum*, and the mean basal area of *Q. rubra* is lower (2·76 dm^2) than that of *A. rubrum* (3·67 dm^2), these trees are important associates and occur throughout the site.

TABLE 2

DENSITY OF SEEDLINGS AND SHRUBS (<5 cm DBH) IN THE CONTROL (C) AND DUSTY (D) TRANSECTS

Species	*Density (No./ha)*		*Species*	*Density (No./ha)*	
	C	*D*		*C*	*D*
Acer pennsylvanicum	660	30	*Pinus pungens*	—	—
A. rubrum	740	160	*P. rigida*	—	—
A. saccharum	10	845	*P. strobus*	45	—
Aesculus octandra	5	5	*Platanus occidentalis*	—	—
Betula alleghaniensis	25	—	*Prunus serotina*	—	—
Carya spp.	140	235	*Quercus alba*	—	15
Castanea dentata	25	20	*Q. coccinea*	45	—
Cercis canadensis	75	915	*Q. muehlenbergii*	—	40
Cornus florida	890	1110	*Q. prinus*	735	30
Fagus grandifolia	20	—	*Q. rubra*	520	80
Fraxinus americana	75	350	*Q. velutina*	—	15
Hamamelis virginiana	1315	195	*Rhododendron maximum*	470	25
Juniperus virginiana	5	100	*Robinia pseudoacacia*	110	85
Liriodendron tulipifera	25	125	*Sassafras albidum*	855	175
Magnolia acuminata	120	105	*Tilia americana*	80	105
Nyssa sylvatica	325	85	*Tsuga canadensis*	220	—
Ostrya virginiana	320	1075	*Ulmus rubra*	5	55
Oxydendrum arboreum	335	90	*Viburnum acerifolium*	345	—
			V. prunifolium	—	185

TABLE 3

DIFFERENCES IN COMPOSITION OF THE SAPLING STRATUM (5–9·9 cm DBH) BETWEEN THE CONTROL AND DUSTY TRANSECTS. *IV* = IMPORTANCE VALUE BASED ON RELATIVE DENSITY AND RELATIVE BASAL AREA

Control		*Dusty*	
Species	*IV*	*Species*	*IV*
Acer rubrum	28·30	*Acer rubrum*	16·94
Quercus prinus	14·55	*Carya* spp.	15·81
Quercus rubra	14·30	*Cornus florida*	9·27
Tsuga canadensis	13·20	*Ostrya virginiana*	6·67
Carya spp.	6·40	*Cercis canadensis*	6·23
Cornus florida	6·30	*Fraxinus americana*	5·55
Oxydendrum arboreum	4·20	*Liriodendron tulipifera*	4·91
Nyssa sylvatica	2·35	*Oxydendrum arboreum*	4·85
Sassafras albidum	1·70	*Quercus rubra*	4·63
Tilia americana	1·55	*Acer saccharum*	4·21
Magnolia acuminata	1·50	*Juniperus virginiana*	3·87
Ostrya virginiana	1·20	*Quercus alba*	3·43
Betula alleghaniensis	1·00	*Robinia pseudoacacia*	2·88
Pinus strobus	0·85	*Quercus prinus*	2·75
Quercus coccinea	0·85	*Sassafras albidum*	2·52
Acer pennsylvanicum	0·70	*Aesculus octandra*	1·80
Fagus grandifolia	0·70	*Nyssa sylvatica*	1·74
		Quercus muehlenbergii	1·14
		Platanus occidentalis	0·81

Saplings are uniformly distributed, and most are of the three dominant tree species (Table 3). Other characteristic saplings are *Tsuga canadensis*, *Carya* spp., *Cornus florida* and *Oxydendrum arboreum* (Table 3). Seedlings of the leading dominants are abundant, along with *Hamamelis virginiana, Cornus florida, Sassafras albidum* and *Acer pennsylvanicum* (Table 2).

Dominant trees in the dusty site are *Quercus alba, Q. rubra* and *L. tulipifera* (Table 4). In general appearance this site is untidy, with a tangled growth of seedlings and shrubs, few saplings, and a prevalence of *Smilax* spp. and *Vitis* spp.

TABLE 4

DIFFERENCES IN COMPOSITION OF THE TREE STRATUM (10+ cm DBH) BETWEEN THE CONTROL AND DUSTY TRANSECTS. *IV* = IMPORTANCE VALUE BASED ON RELATIVE DENSITY AND RELATIVE BASAL AREA

Control		*Dusty*	
Species	*IV*	*Species*	*IV*
Quercus prinus	40·15	*Quercus alba*	16·45
Quercus rubra	20·15	*Quercus rubra*	13·28
Acer rubrum	13·50	*Liriodendron tulipifera*	13·21
Quercus coccinea	7·10	*Acer saccharum*	7·71
Pinus pungens	3·05	*Quercus prinus*	7·21
Liriodendron tulipifera	2·80	*Carya* spp.	6.46
Tilia americana	2·55	*Acer rubrum*	5·63
Nyssa sylvatica	2·30	*Robinia pseudoacacia*	4·87
Quercus alba	1·85	*Quercus muehlenbergii*	3·82
Pinus strobus	1·50	*Quercus velutina*	3·76
Magnolia acuminata	1·40	*Quercus coccinea*	3·53
Carya spp.	1·30	*Fraxinus americana*	3·18
Robinia pseudoacacia	1·20	*Nyssa sylvatica*	1·28
Tsuga canadensis	1·20	*Tilia americana*	1·23
Sassafras albidum	1·00	*Cercis canadensis*	1·11
Betula alleghaniensis	0·95	*Prunus serotina*	1·10
Aesculus octandra	0·60	*Platanus occidentalis*	0·84
		Tsuga canadensis	0·80
		Aesculus octandra	0·78
		Pinus rigida	0·71
		Sassafras albidum	0·41
		Cornus florida	0·38
		Oxydendrum arboreum	0·37
		Ulmus rubra	0·36

With the exception of *L. tulipifera*, which thrives in localised areas in the site, trees have necrotic leaves, peeling bark, and appear to be in a generally poor condition. Accumulation of dust on trunks, branches, and leaves heightens this impression. There are few herbs except in open areas with little accumulated dust.

Density of trees in the dusty community is 835 trees/ha with a total basal area of 23·3 m^2/ha. *Q. alba* dominates the site (Table 4). Trees of this species have a density of 110 trees/ha and a basal area of 6·43 m^2/ha. The largest trees are 100 years old. *Q. rubra* and *L. tulipifera* are co-subdominants, each with 90 trees/ha. *Q. rubra* has a basal area of 5·32 m^2/ha and *L. tulipifera* 5·27 m^2/ha.

Saplings occur locally throughout the site and none of the leading dominants is of importance in this stratum. Species characteristic of the sapling stratum are *A. rubrum, Carya* spp., *C. florida*, and *Ostrya virginiana* (Table 3).

Seedlings of the leading dominants appear in the lowest stratum of the community. Although their density is lower than that of other species, these seedlings are more abundant than saplings of the dominants. Seedlings and shrubs which characterise the stratum and, due to their tangled growth habit, are the most obvious form of vegetation in the dusty site are *C. florida, O. virginiana, Cercis canadensis* and *Acer saccharum* (Table 2).

None of the species present in one site and absent from the other is of major importance in the composition of these communities (Tables 3 and 4). *Viburnum prunifolium* adds to the tangled appearance of the dusty site since it grows in thickets associated with *Juniperus virginiana. Quercus muehlenbergii* is a known calciphile and occurs on soils with a pH not less than 7·0 (Fowells, 1965). Trees of this species occur in areas of heavy dust accumulation. *Platanus occidentalis* and *Prunus serotina* are thought to be adventives from lower elevations along Big Stony Creek. Restriction of other species to one site or the other is probably due to variations of microclimate and topography in the site.

The sites are similar in the relative numbers of stems in each stratum. In the control site, 84·4% of the individuals are seedlings or shrubs, 5·5% are saplings, and 10·1% are trees. In the dusty site, 82·4% are seedlings or shrubs, 6·9% are saplings, and 10·7% are trees. Tables 2 to 4 show that the sites are markedly dissimilar in density of seedlings and in relative importance of species in the sapling and tree strata. These data indicate the changes that have occurred in the dusty site. In addition, species composition of the strata differs markedly and indicates the changes that have occurred. In the control site, 97% of the species are in the seedling-shrub stratum and 55% in both the sapling and tree strata. In the dusty site, however, 84% of the species occur in the seedling-shrub stratum, 59% in the sapling stratum, and 75% in the tree stratum. Of the thirty-one species in the control site, one (*Q. alba*) is not represented as a seedling or sapling. Four species are present as seedlings and trees, but not as saplings. These are *Pinus pungens, L. tulipifera, Robinia pseudoacacia* and *Aesculus octandra.* All other trees are also present in the lower two strata of this community. In the dusty site, five of the thirty-two species are not represented in the seedling-shrub stratum. These are *Quercus coccinea, P. serotina, P. occidentalis, T. canadensis,* and *Pinus rigida,* which all appear as trees. *P. occidentalis* is the only one which occurs as a sapling. This species, however, is to be found mainly in damp areas at lower altitudes along Stony Creek and is not particularly important in the structure of the dusty site. Three species (*Quercus velutina, Tilia americana* and *Ulmus rubra*) occur as seedlings but are not present in the sapling stratum. From the data it is apparent that certain species have increased in abundance, namely, *C. florida, O. virginiana, C. canadensis, A. saccharum* and *L. tulipifera.* These species have significantly higher densities in the seedling-shrub and sapling strata of the dusty site, compared with the control site. Apparently these species are filling niches vacated by species unable to tolerate dust.

The control site has an abundance of shrubs, good reproductive efficiency in all strata, and is assumed to be undergoing normal succession. The experimental site, however, shows disruptions in structure and composition, as a result of dust accumulation. Reproductive efficiency of some species has apparently decreased and the course of succession has been altered.

DISCUSSION

In a review and summary of research on ecosystem dynamics, Odum (1969) states that a result of the accumulation of toxic pollutants in the biosphere is simplification of the structure of both plant and animal communities. In a plant community, structure is determined by sampling various strata within the community. Each stratum comprises a particular life-form; *e.g.* herbs, seedlings, saplings, and trees. Buell & Martin (1961) used this method to determine the changes in structure due to competition in two adjacent plant communities. In this study a similar sampling procedure was used to indicate changes in structure of a plant community due to the accumulation of limestone dust.

It appears that dust accumulation favours some species and limits others. *A. saccharum*, for example, is significantly more abundant in all strata of the dusty site than in the control site where it is present only as seedlings. *L. tulipifera, C. florida, O. virginiana, V. prunifolium* and *C. canadensis* also seem to be favoured by limestone dust accumulation.

If the dust accumulation goes on, however, it is unlikely that conifers or acidiphiles will continue to be found in the dusty site. Woodwell (1970) has shown that when a late successional oak-pine forest was exposed to chronic irradiation, five well-defined zones of modification of vegetation were established. Conifers occurred only in the zone farthest from the radiation source where exposure was lowest. In the present study, there are few trees and saplings and no seedlings of any coniferous species present in the dusty site. Density of *Rhododendron maximum*, an acidiphile, has also decreased as compared with the control site (470 as compared with 25 stems/ha).

Most of the trees in the dusty site were established there before heavy dust accumulation, and have tolerated the dust. The most significant changes in structure have occurred in the seedling-shrub and sapling strata. Reproduction of some trees has decreased or ceased entirely. In future, species such as *Q. coccinea, Q. velutina* or *T. americana*, may not be found in the dusty site. Structure of the community is changing at the present time, and if dust accumulation continues *L. tulipifera, A. saccharum* and, possibly, *Q. muehlenbergii*, will become the leading dominants (Tables 2 to 4).

Dust accumulation started in 1945, but has been heaviest only since 1967 when the industry increased production. Compared with the age of dominant trees, 25 years is, indeed, a short period. The reported changes that have occurred over this time indicate successional trends that will continue for many years. Because the site is still changing, the full range of effects of chronic dust accumulation on structure and composition of forest communities could not be determined.

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REFERENCES

BRAUN, E. L. (1950). *Deciduous forests of eastern North America.* New York, Hafner Publishing Co., Inc. 596 pp.

BUELL, M. F. & MARTIN, W. E. (1961). Competition between maple-basswood and fir-spruce communities in Itasca Park, Minnesota. *Ecology*, **42**, pp. 428–9.

DARLEY, E. F. (1966). Studies on the effect of cement-kiln dust on vegetation. *J. Air Pollut. Control Ass.*, **16**, pp. 145–50.

DARLEY, E. F. (1969). Symptomatology of particulate injury to vegetation. In *Handbook of effects assessment, vegetation damage*, ed. N. L. Lacasse & W. J. Moroz. Center for Air Environment Studies of The Pennsylvania State University, V1–V4.

DARLEY, E. F. & MIDDLETON, J. L. (1966). Problems of air pollution in plant pathology. *A. Rev. Phytopathology*, **4**, pp. 103–18.

ECKROADE, W. M. (1962). *Geology of the Butt Mountain Area, Giles County, Virginia.* Master of Science thesis in geology, Virginia Polytechnic Institute, Blacksburg, Virginia.

FOWELLS, H. A. (1965). Silvics of forest trees of the United States. *Forest Serv. Handb. Wash.*, No. 271.

HECK, W. W., DAINES, R. H. & HINDAWI, I. J. (1970). Other phytotoxic pollutants. In *Recognition of air pollution injury to vegetation: a pictorial atlas*, ed. J. S. Jacobson & A. C. Hill. Air Pollut. Control Ass. TR-7 Agr. Committee, Inf. Rep. No. 1, F1–F24.

ODUM, E. P. (1969). The strategy of ecosystem development. *Science, N.Y.*, **164**, pp. 262–70.

WOODWELL, G. M. (1970). Effects of pollution on the structure and physiology of ecosystems. *Science, N.Y.*, **168**, pp. 429–33.