BRYOPHYTE AND LICHEN INDICATORS OF AIR POLLUTION IN CHRISTCHURCH, NEW ZEALAND

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SUMMARY: In the winters of 1968 and 1969 a survey was made of the growth and distribution of bryophyte and lichen species within communities on tree trunks, stone walls, non-metallic roofs and soil in Christchurch, New Zealand. The survey was stimulated by European and Scandinavian work which has shown that high levels of urban and industrial air pollution have caused severe reductions in the distribution of normally-abundant cryptogams. The present survey has demonstrated that a similar, but at present less severe, reduction in bryophyte and lichen flora occurs in Christchurch. Removal of sensitive species through their inability to grow at even moderate levels of winter pollution is considered the most likely cause.

An initial transplant experiment indicates that damage to sensitive mosses like *Hypnum* and *Brachythecium* may occur within 3 months of exposure to city air. Gilbert and others have shown that, in northern England, sensitive mosses and lichens begin to die when the average winter sulphur dioxide level reaches 50 μg./m.^{3} of air. This relationship has been confirmed in Christchurch, a moderately polluted city.

Numbers of species and the area covered by sensitive mosses, hepatics and lichens reduce sharply along a broad transect into the centre of Christchurch from the west. Further work should display the distribution patterns of sensitive species. However, the information reported here demonstrates the possibility of using changes in selected mosses and lichens to indicate the trends in winter sulphur dioxide pollution in the city.

Many of the genera and species of bryophytes and lichens prominent in the English survey were also found to be common in Christchurch. Introduction on plants and building materials during colonial times is considered likely.

INTRODUCTION

In Europe and North America, several botanists have described the sparse moss, liverwort and lichen communities in and around cities and industrial areas (Barkman, 1958). These moss and lichen "deserts" may be caused by reduced light, high temperatures, human disturbance and drought. However, recent surveys have implicated air pollution in the damage or death of many mosses, lichens, vegetables and trees (Fenton, 1960; Gilbert, 1965, 1968; Skye, 1958, 1965, 1968; Webster, 1966; Challenger, 1967; Laundon, 1967).

An exhaustive review of the effects of air pollution on plants and soil was compiled by Webster (1966). He included physiological research by Zimmerman, Thomas, Bleasdale, McCune and others which demonstrated that many plants are very sensitive to such gaseous chemicals as sulphur dioxide, hydrogen fluoride, nitrogen dioxide and photo-oxidised hydrocarbons (PAN). Sensitive plants become affected in towns and industrial zones when air pollutants remain at, or above, critical concentrations for short periods. Other species appear to be little affected, even in heavily-polluted air.

Damage to plants caused by air pollution may now be separated from such urban influences as increased temperature, aridity and reduction of sunlight by smoke palls. The severity of damage to sensitive plants has been used by Challenger (1967), Gilbert (1965, 1968) and Skye (1958, 1968) to assist the measurement of pollution levels. Among macroscopic plants, bryophytes and lichens appear to be most sensitive to atmospheric pollutants such as sulphur dioxide.

Casual observations in 1968 indicated that the distribution of mosses and lichens in Christchurch might follow the pattern described by Gilbert (1965, 1968) in Newcastle-on-Type, England. The ecology of cryptogams has been little studied in areas of New Zealand disturbed by European culture. In addition, there is no information concerning the effects of air pollution on plant life in this country. Despite possible errors in species-identification and sampling methods this first survey is directed towards the need for such information.

METHODS OF STUDY

The survey was made during the winters of 1968 and 1969 in an effort to reveal the distribution patterns of all lichens, mosses and liverworts on tree trunks, stone walls, non-metallic roofs and soil. A broad, semi-circular transect was traversed from central Christchurch for 11 miles towards the west. Sampling was confined to a wedge-shaped area of city widening into the countryside and bounded by compass bearings north-west and south-west. Choice of area and selection of sites were determined by the availability of suitable trees, parks and walls and the pattern of winter air pollution (Anon., 1966). The winter climate is marked by frequent calm periods and temperature inversions which trap smoke and gases at a low level. A succession of incipient smogs causes smoke and sulphur dioxide to build up to moderately high concentrations. Figure 1 is a view of Christchurch from the Port Hills during one such period in June 1969.

FIGURE 1. *A mixture of ground fog and smoke over Christchurch at 10.30 a.m. on a morning in June 1969. The temperature inversion layer is approximately 100 ft. deep.*

Search for communities

Trees, stone walls and lawns were selected within concentric mile-wide zones radiating westwards from the centre of highest pollution. The concentric zones were related to isopleths of average winter atmospheric concentrations of sulphur dioxide as measured by Wilkinson and others in a survey of air pollution in Christchurch from 1959 to 1964. (Anon., 1966). More recently, Pullen (1970) has made accurate daily measurements of sulphur dioxide and smoke during the winter of 1969 within four of the zones.

Only mature undamaged trees growing in groups or parkland areas were included in the survey. Those most frequently encountered were species of elm (*Ulmus*), oak (*Quercus*) and ash (*Fraxinus*). Their bark supports a rich assemblage of epiphytes in sheltered rural situations. Other large trees often sampled were linden (*Tilia*), plane (*Platanus*), sycamore (*Acer*), chestnut (*Castanea*) and walnut (*Juglans*). The conifers, beech (*Fagus*) and birch (*Betula*), though abundant, were omitted from the survey as their bark was rarely colonised by epiphytes.

Stone walls were sampled if they were more than 10 years old, unpainted and without signs of recent disturbance. Most of the walls chosen surrounded gardens or parks and some belonged to stone or brick buildings. Mortared basalt, bricks and concrete were the most common wall materials sampled. Moss and lichen grows luxuriantly on these materials, especially on shaded southern aspects. A few granite walls were included. On these most lichens were growing on the cementing mortar.

Bryophyte communities on soil were found mainly in moist, shaded lawns and park grassland. The records include a number of communities on soil beside water channels in city streets.

Lichens and bryophytes are abundant on slate, tile and asbestos roofs in suburban and country areas around Christchurch. Quantitative records have not yet been obtained for such roofs. However, a list of prominent species growing on southerly aspects of high roofs has been compiled from an examination of examples found in both city and country.

The bryophyte and lichen flora

All species were listed for each example of the different communities. The total number of species in each community was then related to the average winter sulphur dioxide level for every mile or two-mile zone.

Cover values

Estimates were made of amount of the surface of tree trunks and walls covered by all bryophyte and lichen species and expressed as a percentage. On trees a chain of decimetre-square wire quadrats was hung down the basal 1.5 metres of trunk of north and south aspects. Visual estimates of projected cover by each species were made as described by Hoffman and Kazmierski (1969). On walls cryptogam cover was again estimated within decimetre-square quadrats, 20 of which were placed to include both sheltered and exposed surfaces. Results have been tabulated according to increasing distance from the city centre.

Transplant experiment

Pieces of bark or stone bearing thalli of several mosses and lichens known to differ in sensitivity to sulphur dioxide were placed in boxes of soil. A set of transplants was retained as control at Lincoln College and two other sets were placed in Riccarton, an inner suburb of Christchurch. The Riccarton series of transplants were set in the open at ground level and at four feet above ground. This site was within a residential area and 300 yards from a continuous air pollution monitoring station set up by the Department of Health.

The boxes of transplants placed in position in June, were occasionally watered during two and a half months' exposure to the winter air. In late August each group of transplanted thalli was given a score according to amount of visible damage.

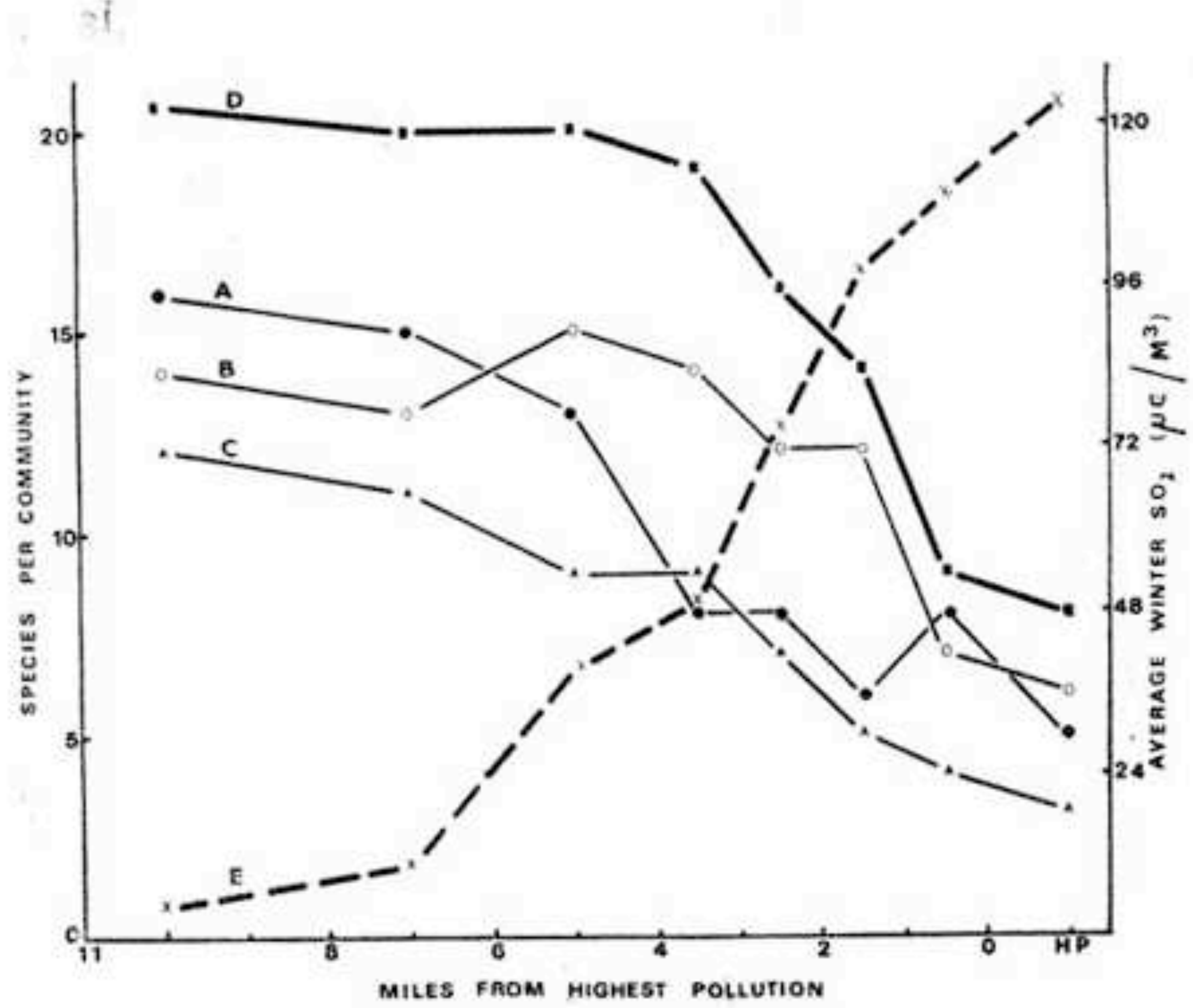

FIGURE 2. *Number of bryophyte species in relation to the average winter sulphur dioxide concentration in Christchurch: (A) in grassland, (B) on stone walls, (C) on tree trunks, (D) all communities, (E) average* SO_2 *concentration.*

This 1–5 scoring system was used by Gilbert (1968) in a more extensive bryophyte transplant experiment in Newcastle-on-Tyne.

RESULTS

Flora of the different communities

The total number of species in each community along the transect is shown in Figures 2 and 3 for bryophytes and lichens respectively. Average winter sulphur dioxide levels are plotted on the graphs to allow direct comparisons. Species numbers for both bryophytes and lichens fall sharply as pollution during winter increases towards the inner suburbs.

In general, cryptogams found in the central area are distributed throughout the region. Consequently, the reduction in species diversity within Christchurch is due to the removal of many of those abundant in rural communities. Though few species are restricted to one type of substrate, the curves for total species in all communities fall very sharply between five miles and one mile from the centre of highest pollution.

Lichen and bryophyte cover

Average values for per cent cover are given for bryophytes and lichens on trees (Tables 1 and 2) and on walls (Tables 3 and 4). The data are arranged according to distance from the most polluted area.

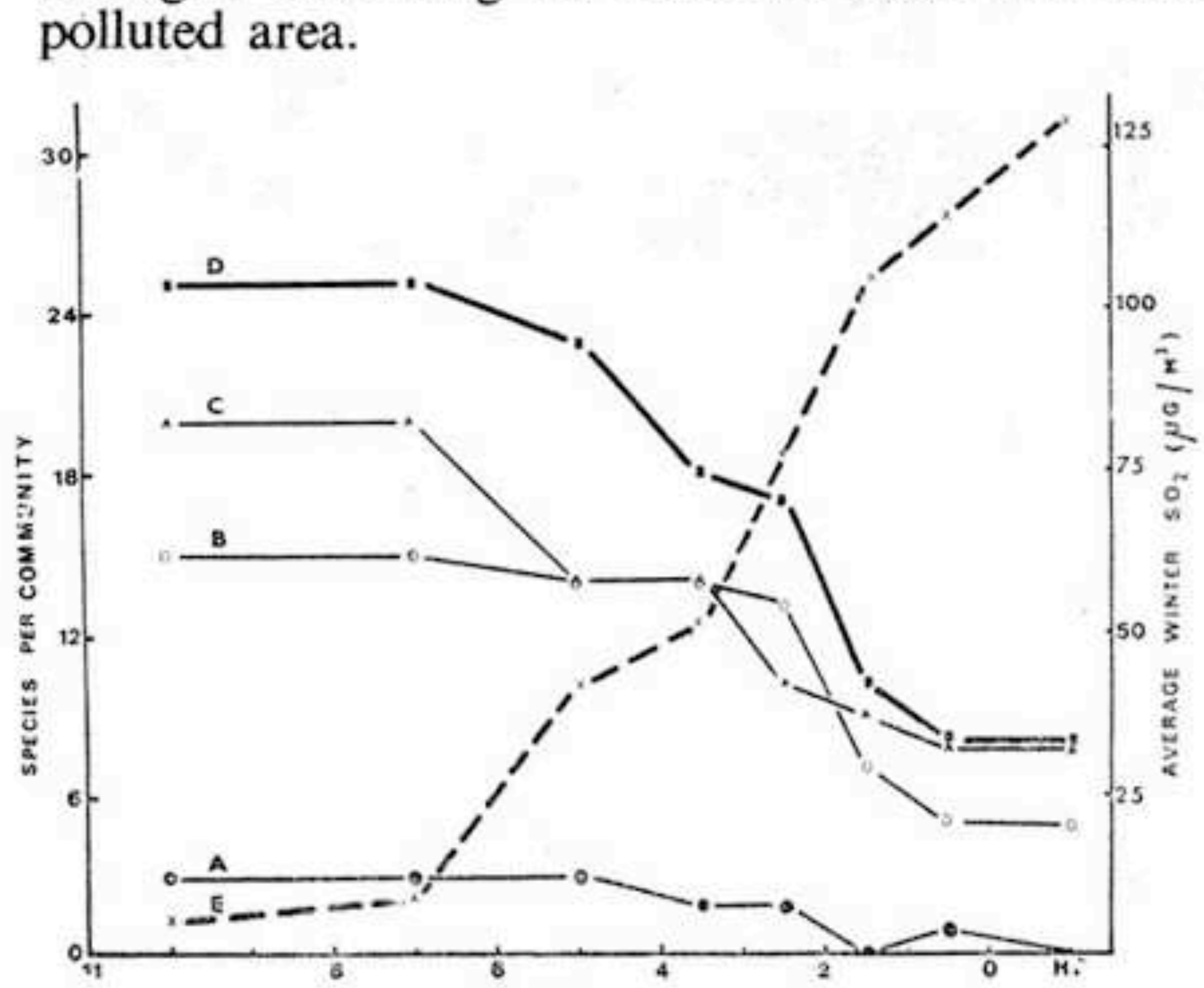

FIGURE 3. *Number of lichen species in relation to average winter sulphur dioxide pollution in Christchurch: (A) in grassland, (B) on tree trunks, (C) on stone walls, (D) all communities, (E) average* SO_2 *concentration.*

TABLE 1. *Average percentage cover by bryophytes on basal 1.5 metres of tree trunks.*

	Miles from area of highest pollution															
	8–10		6–8		4–6		3–4		2–3		1–2		0–1		HP	
No. of trees sampled	12		16		12		19		22		15		8		23	
Av. winter SO_2 (μg./m.^{3})	5		10		40		50		75		100		110		125	
Aspect	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.
Encalypta vulgaris	0.2															
Brachythecium rutabulum	*		0.7													
Tortula princeps	0.1		1.4	2.0												
Bryum rubrum	*		0.5		*		*									
Campylopus sp.	0.1		0.1		*		0.2									
Rhynchostegiella muricata	0.5	*	0.5		*		0.1		*							
Lophocolea spp.	0.1	*	0.3		0.3	0.3	0.1		0.2	*						
Hypnum cupressiforme	5.5	0.2	3.2	0.2	1.6	*	1.3	*	*		0.2					
Tortula muralis	0.6	1.7	2.8	0.3	0.1	0.1	0.5	0.9	0.3	0.4	*		*			
Ceratodon purpureus	0.1	*	1.6	0.1	*		0.2		0.3	*	0.3	*	0.3	*	0.1	*
Pohlia cruda	*		*		*		0.1		0.1	*	0.1	*	*		*	
Bryum argenteum	*		*		*		*		*		0.2	*	0.4	*	0.1	0.1
Total cover	7.0	1.9	11.1	2.6	2.0	0.4	2.5	0.9	0.9	0.4	0.8	*	0.7	*	0.2	0.1
Dead gametophytes	*		*	0.1			0.1	*	0.1	*	*		*		*	

S. = South aspect. HP = area of highest pollution.
N. = North aspect. * = species present but negligible cover.

TABLE 2. *Average percentage cover by lichens on basal 1.5 metres of tree trunks.*

	Miles from area of highest pollution															
	8–10		6–8		4–6		3–4		2–3		1–2		0–1		HP	
No. of trees sampled	12		16		12		19		75		100		110		125	
Av. winter SO_2 (μg./m.^{3})	5		10		40		50		22		15		8		23	
Aspect	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.
Leptogium tremelloides	1.2	0.2	*													
Ramalina ecklonii	1.0	0.1	0.6	0.2	0.1	*	*	*								
Parmelia conspersa	0.1	*	4.0	0.2	*		*		*							
Usnea ciliifera	0.1	*	*		*		*		*							
Physcia alaenia	0.4	0.9	1.6	0.4	2.4	0.6	2.1	0.6	*							
Graphis adscripta	1.0	1.1	8.8	8.5	2.8	4.2	2.1	2.2	0.2							
Teloschistes velifer	0.3	0.4	1.2	1.2	*	*	*	*	*	*						
Physcia planthiza	2.4	1.4	1.5	1.5	2.5	0.3	0.1	0.4	*	0.1						
Cladonia spp.	*		*		*		*		*		*					
Physcia regalis	6.5	4.1	18.3	6.6	7.5	2.7	13.2	6.0	1.0	*	1.2					
Xanthoria parietina	0.5	0.2	0.4	0.3	4.6	*	*	*	0.1	*	*	*	*	*	*	*
Caloplaca sp.	0.1		0.3	*	*	*	0.1	*	*	*	*	*	*	*	*	*
Physcia adscendens	0.4	0.3	1.0	0.4	1.0	0.2	0.1	0.1	5.6	2.1	0.1	*	0.1	*	0.3	*
Lecanora varia	*	*	0.1	0.8	*	*	0.3	0.2	0.1	*	*	*	2.1	0.4	0.5	0.1
Buellia punctata	0.1		0.2	0.1	0.1	0.2	0.1	0.3	4.1	2.1	1.1	0.1	0.6	0.3	0.5	1.3
Rinodina exigua	*		0.6		0.1		0.7		1.9	0.4	1.9	0.4	4.7	*	3.9	*
Total cover	13.4	8.7	38.6	20.2	21.1	8.2	18.8	9.8	13.0	4.7	4.3	0.5	7.5	0.7	5.2	1.4
Dead thalli	0.1	0.1	1.0	0.5	0.5	0.1	0.3	0.3	1.6	0.8	1.0	0.5	0.6	0.3	0.2	0.2

Changes in species composition and species cover are clearly related to position on the transect. There are marked reductions in total bryophyte and lichen cover on tree trunks within Christchurch city. Furthermore, species diversity and cover values are generally higher on the southern aspects of trees than on the sunny north sides. On the other hand, total cover on stone walls does not show a downward trend towards the city centre. Species apparently resistant to sulphur dioxide pollution appear able to increase in cover with the reduction or disappearance of sensitive species.

TABLE 3. *Average percentage cover by bryophytes on stone walls.*

	Miles from area of highest pollution							
	8–10	6–8	4–6	3–4	2–3	1–2	0–1	HP
Av. winter SO_2 ($\mu g./m.^3$)	5	10	40	50	75	100	110	125
No. of walls	4	3	3	5	7	6	4	5
Tortriguella papillata	0.1	*	0.7					
Bryum blandum			*					
Brachythecium rutabulum	*	*	1.7	0.5				
Campylopus sp.				*				
Bryum rubrum	*	*	*	*	0.2			
Hypnum cupressiforme	2.0	2.0	4.4	0.7	*			
Lophocolea spp.						0.3		
Tortula princeps	1.9	0.4	1.1	*	0.1	0.2		
Rhynchostegiella muricata	1.0	1.0	3.4	0.2	0.2	1.5		
Lunularia spp.	0.6	*	0.3	0.6	0.5	0.1		
Bryum laevigatum						*		
Grimmia pulvinata	5.8	3.0	2.6	0.2	0.3	0.9	*	
Pottia macrophylla	*		*	*	0.2	0.3	1.3	*
Funaria hygrometrica	0.1	0.3	0.3	0.1	0.3	0.1	*	*
Bryum argenteum	0.5	0.9	0.1	1.3	2.6	4.3	1.3	3.0
Pohlia cruda	1.3	0.1	0.6	1.5	3.2	3.7	1.1	2.7
Ceratodon purpureus	6.0	1.3	3.5	6.1	9.6	5.2	6.3	4.6
Tortula muralis	7.5	6.0	7.4	7.4	13.2	15.1	20.6	10.2
Total cover	24.7	15.6	25.9	18.7	30.4	31.6	30.6	20.5
Dead gametophytes	2.0	1.0	1.0	2.0	2.5	3.6	5.5	9.1

TABLE 4. *Average percentage cover by lichens on stone walls.*

	Miles from area of highest pollution							
	8–10	6–8	4–6	3–4	2–3	1–2	0–1	HP
Av. winter SO_2 ($\mu g./m.^3$)	5	10	40	50	75	100	110	125
No. of walls sampled	4	3	3	5	7	6	4	5
Parmelia perlata	2.2	1.3						
Stereocaulon caespitosum	1.0	1.5						
Ramalina ecklonii	0.1	0.1						
Teloschistes velifer	0.1	0.4						
Physcia planthiza	*	0.3						
Ramalina sp.	*	0.3						
Sticta aurata	*	0.3						
Parmelia conspersa	1.4	9.6	0.1	0.2				
Physcia regalis	0.3	0.4	*	*				
Physcia alaeina	0.1	1.7	0.1	*				
Placopsis sp.	0.3	0.6	0.3	0.3				
Usnea ciliifera	*	*	0.1	0.1	0.1			
Leptogium tremelloides	0.1	0.4	*	1.2	*	*		
Xanthoria parietina	3.1	0.3	0.3	0.1	0.1	0.1	0.1	*
Diploschistes cinerarensis	1.0	0.5	0.7	0.5	0.4	*	0.4	1.0
Cladonia spp.	0.1	1.7	0.1	0.1	2.2	0.6	5.5	2.6
Physcia adscendens	1.3	3.1	0.5	0.5	0.7	*	0.5	0.4
Lecanora varia	2.5	3.3	0.5	1.6	1.4	2.5	1.8	2.6
Buellia punctata	1.5	3.3	2.4	3.6	3.8	2.5	4.3	2.8
Caloplaca sp.	7.5	5.7	5.9	4.4	3.0	2.4	2.7	10.5
Rinodina exigua			0.3	*	0.9	0.4	*	0.1
Total cover	22.6	34.6	11.3	12.6	11.7	8.5	10.2	19.9
Dead thalli	1.2	1.0	0.1	0.3	1.0	1.5	3.0	2.4

Cover values for epiphytes prominent on trees and walls have been graphed against distance in Figures 4, 5, 6 and 7. Some reduction in sensitive species tends to occur at sulphur dioxide concentrations of up to 50 ug/m^3. Where this winter level is exceeded, mosses such as *Hypnum cupressiforme, Brachythecium rutabulum* and *Tortula princeps* and the lichens *Physcia regalis, Parmelia* *conspersa, Ramalina ecklonii* and *Xanthoria parietina* are drastically reduced in cover, or absent. The distribution of *Graphis adscripta* gives it the appearance of being a sensitive species. This is notable, for *Graphis* is a very small crustose lichen. All the other sensitive types have large surfaces and fruticose or foliose growth forms.

The microlichens, *Rinodina, Lecanora* and *Buellia* and mosses, *Bryum argenteum, Pohlia cruda* and *Ceratodon purpureus* appear unaffected by city conditions and tend to increase in cover there. Cover by *Tortula muralis* and *Caloplaca* sp. is greatly increased on walls in central areas, though concentrated on mortar and concrete. Dead thalli, especially gametophytes of moss, were much more abundant in the inner city, particularly on basalt and granite building stones.

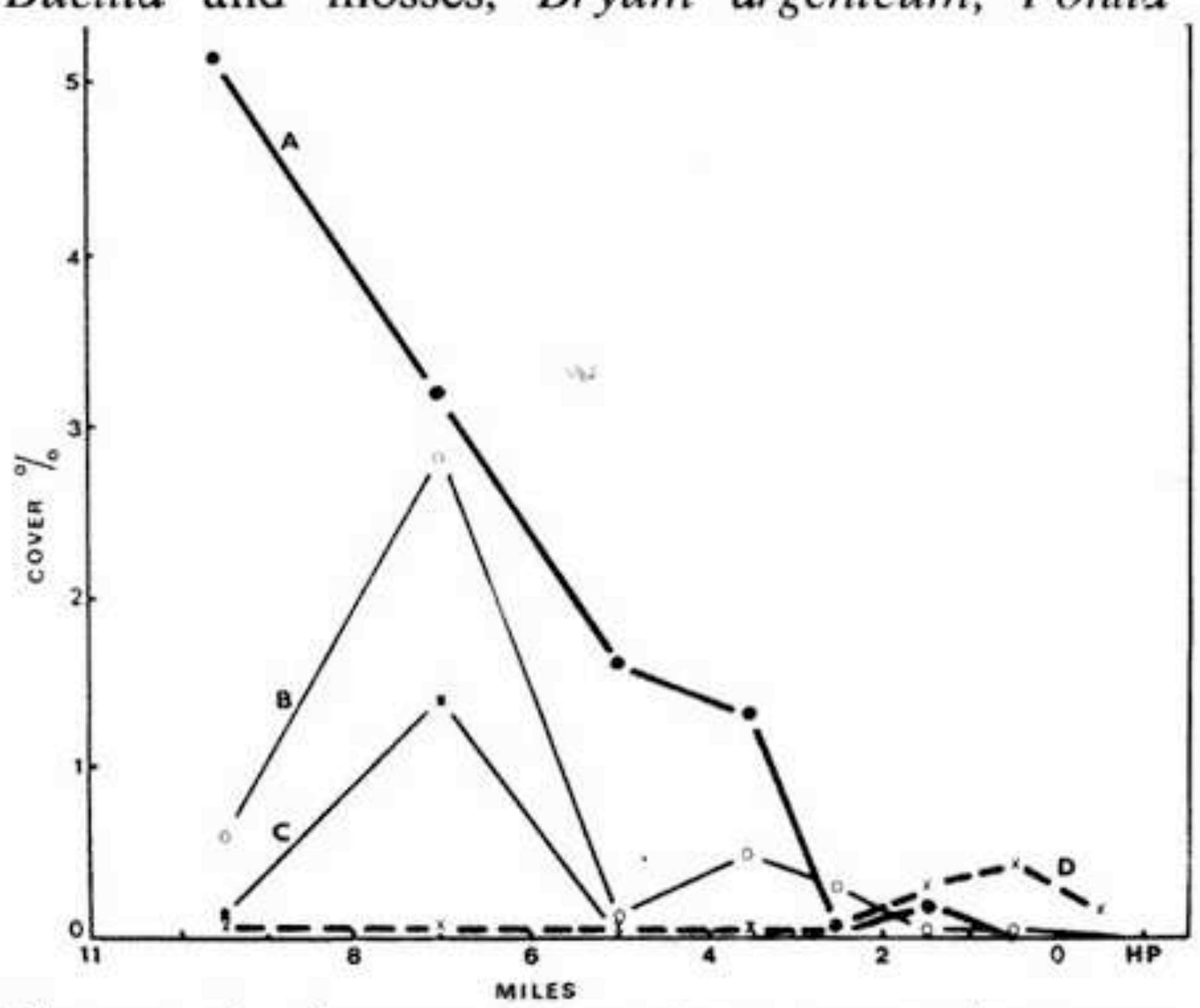

FIGURE 4. *Average percentage cover by moss species prominent on tree trunks:* (*A*) Hypnum cupressiforme, (*B*) Tortula muralis, (*C*) Tortula princept, (*D*) Bryum argenteum.

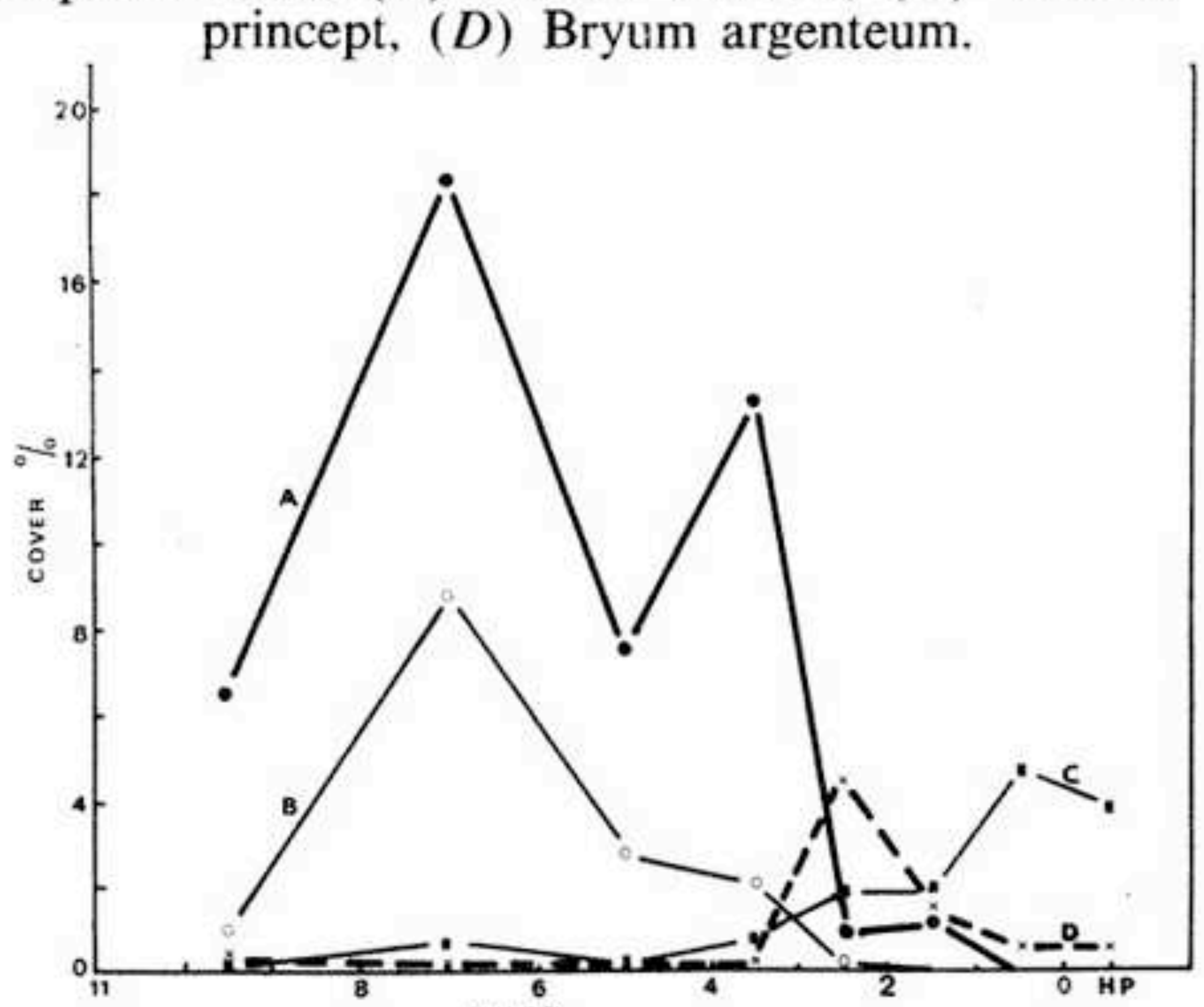

FIGURE 5. *Average percentage cover by lichens prominent on tree trunks:* (*A*) physcia regalis, (*B*) Graphis adscripta, (*C*) Rinodina exigua, (*D*) Buellia punctata.

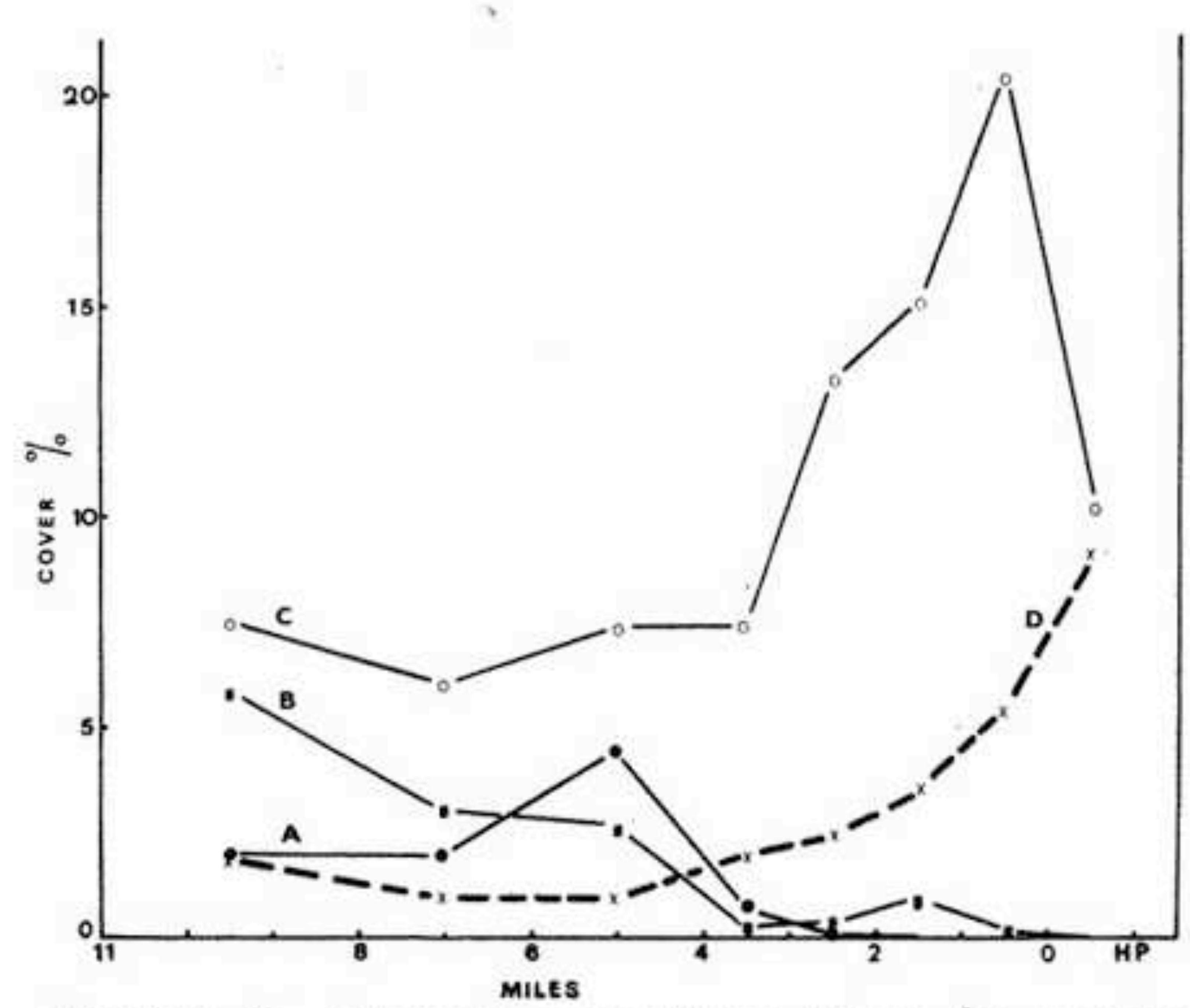

FIGURE 6. *Average percentage cover by mosses prominent on stone walls*: (*A*) Hypnum cupressiforme, (*B*) Grimmia pulvinata, (*C*) Tortula muralis, (*D*) *dead gametophytes of all species.*

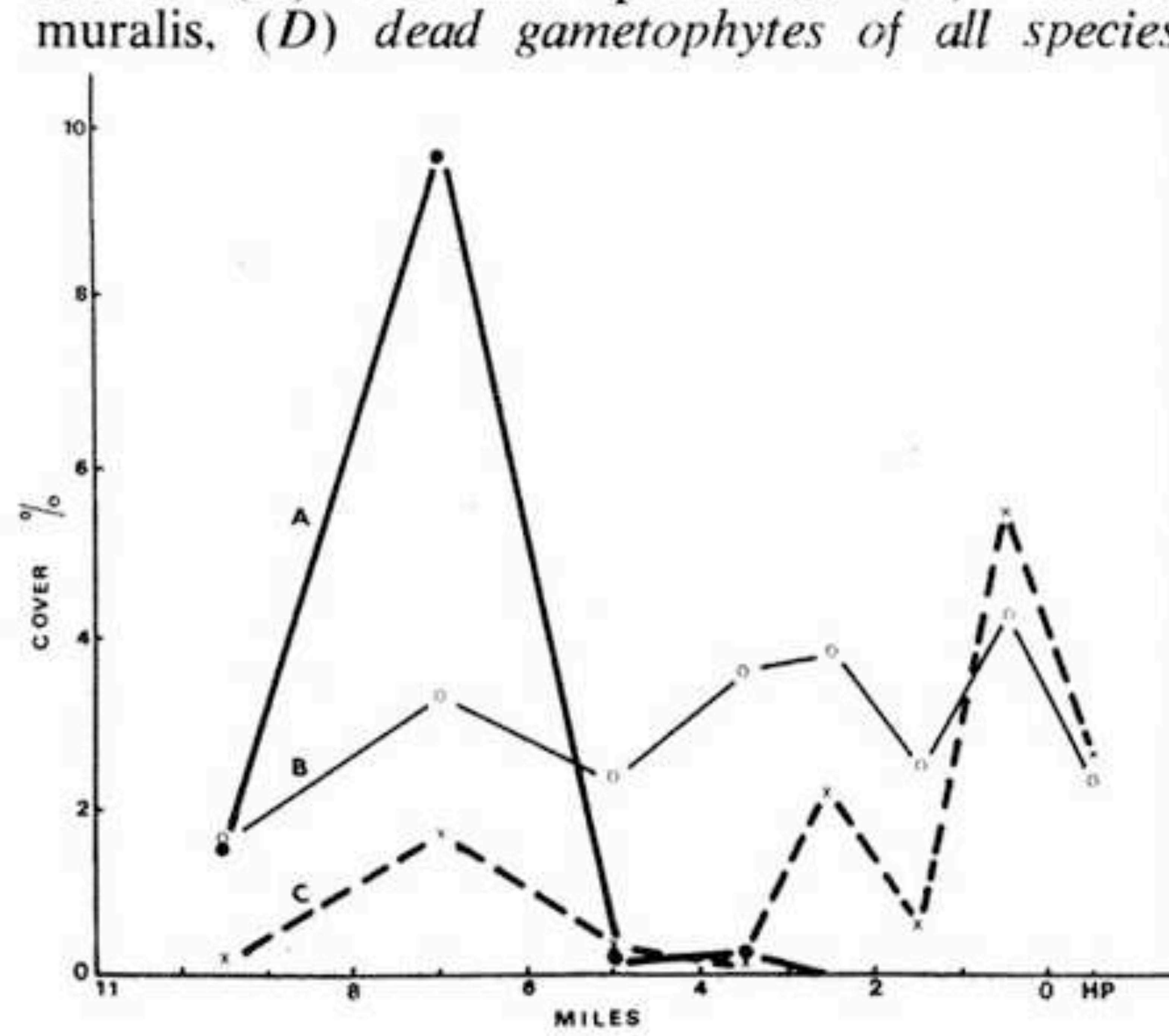

FIGURE 7. *Average percentage cover by lichens prominent on stone walls:* (*A*) Parmelia conspersa, (*B*) Buellia punctata, (*C*) Cladonia *spp.*

FIGURE 8. *The southern aspect of an oak tree at Lincoln College in rural Canterbury showing the extensive growth of epiphytes. The chief species in this community are the lichens* Physcia regalis Teloschistes velifer *and* Ramalina ecklonii.

FIGURE 9. *A luxuriant community of cryptogams on a basalt wall at Tai Tapu in rural Canterbury. The moss species* Grimmia pulvinata *and* Tortula muralis *account for most of the cover; the prominent lichens are species of* Parmelia.

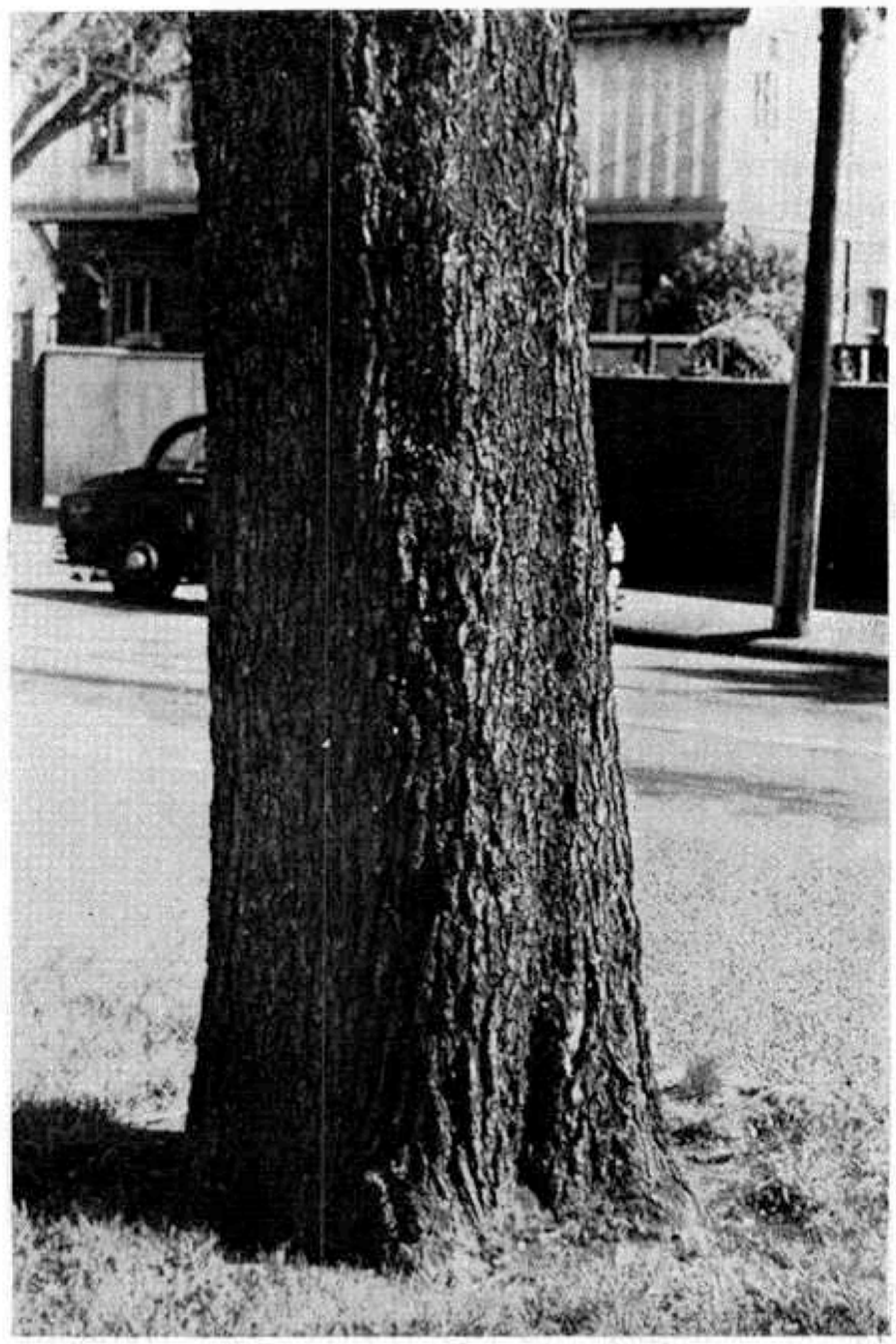

FIGURE 10. *The southern side of an elm tree near the centre of Christchurch city. Epiphytes have been reduced to small colonies of* Physcia adscendens, Buellia, Rinodina *and the mosses* Bryum argenteum *and* ceratodon purpureus.

The derivation of average cover values for epiphytes on trees has obscured their vertical distribution patterns. Cover by sensitive species is progressively restricted from the top of the trunk and branches to near the ground as the concentration of winter sulphur dioxide rises.

Figures 8 and 9 give the appearance and nature of the communities on southern aspects of rural trees and rock walls. The relative absence of epiphyte and the darkened colour of tree bark in polluted areas of the city is evident in Fig. 10.

Roof communities

The remarkable feature of roof communities is the almost complete absence of mosses and lichens within the city. The luxuriant growth of *Parmelia conspersa* on shaded aspects of high slate roofs in the country, is typified by the example in Figure 11. Steep-sloping roofs of imported slate favour the growth of foliose lichens, whereas mosses appear abundantly on corrugated asbestos and ceramic tiles. Roof communities on southerly aspects of buildings in rural areas have a fairly uniform and extensive cover which includes the following species:

LICHENS	*BRYOPHYTES*
Parmelia conspersa	*Bryum argenteum*
Parmelia perlata	*Ceratodon purpureus*
Parmelia olivacea	*Tortula muralis*
Physcia regalis	*Tortula princeps*
Physcia adscendens	*Pohlia cruda*
Xanthoria parietina	*Hypnum cupressiforme*
Teloschistes velifer	*Rhynochostegiella muricata*
Lecanora varia	
Caloplaca sp.	
Buellia punctata	
Ramalina ecklonii	

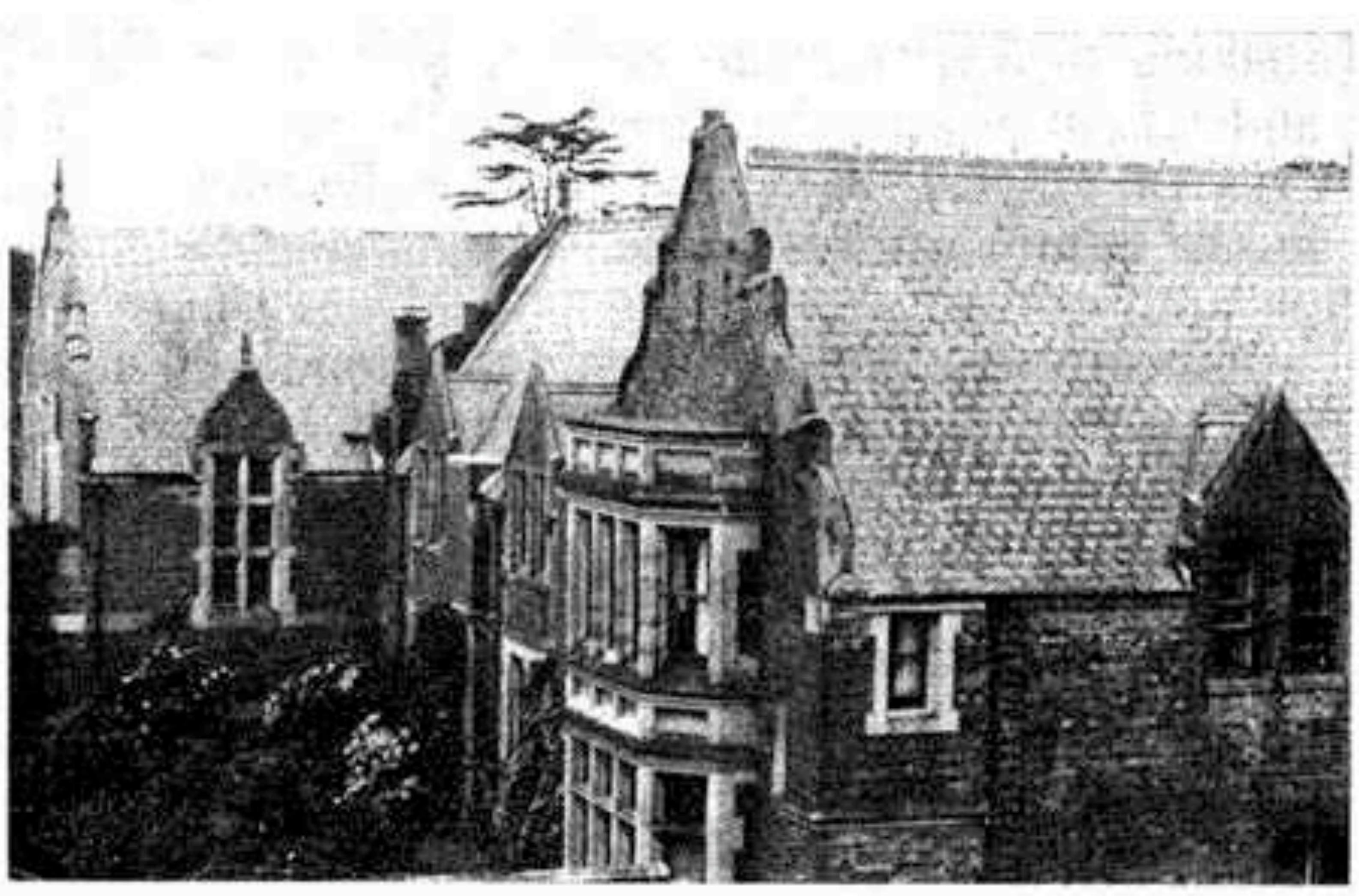

FIGURE 11. Parmelia conspersa *covering the sheltered aspects of a 90-year-old slate roof at Lincoln College, 11 miles from Christchurch. Similar roofs within the city are almost devoid of cryptogams.*

Each species is capable of dominating local areas of roof. Roofs of the inner city have a very reduced cover and simple composition and include the following hardy species:

LICHENS	*BRYOPHYTES*
Physcia adscendens	*Bryum argenteum*
Buellia punctata	*Pohlia cruda*
Lecanora varia	*Ceratodon purpureus*
Caloplaca sp.	*Tortula muralis*
Xanthoria parietina	

Transplant experiment

Table 5 gives the average scores for the appearance of transplanted mosses and lichens. After 10 weeks' exposure during winter there was severe deterioration in the condition of several species transplanted to Riccarton. Those species thought to be very sensitive to atmospheric sulphur dioxide showed the greatest degree of vegetative deterioration. However, there was little change in gametophytes of *Grimmia pulvinata* at either site. This species, considered by other workers to be moderately sensitive, behaved like the resistant moss *Ceratodon purpureus*.

TABLE 5. *Average condition of transplanted mosses and lichens in August after 10 weeks' winter exposure.*

	RICCARTON		LINCOLN
Average SO_2 (μg./m.^{3})	75		10
Height transplants above ground	4 ft	4 in.	2 ft
MOSSES:			
Brachythecium sp.	2.1	2.6	5.0
Hypnum cupressiforme	2.8	4.0	4.6
Tortula princeps	3.5	3.8	4.2
Tortula muralis	4.2	4.4	5.0
Grimmia pulvinata	4.7	5.0	5.0
Ceratodon purpureus	5.0	4.4	5.0
LICHENS:			
Physcia regalis	2.8	3.3	4.8
Ramalina ecklonii	3.3	4.3	4.8
Parmelia conspersa	4.8	4.8	5.0
Xanthoria parietina	3.0	4.6	5.0
Physcia alaeina	5.0	4.0	5.0

Scores

1=thallus brown, flaccid — dead.
2=all surface brown, devoid of chlorophyll colony still alive.
3=all exposed shotes or margins strongly bleached.
4=loss of chlorophyll from exposed tips.
5=virtually no damage.

Scores for appearance of lichen thalli were less conclusive though they tended to conform to the pattern shown by mosses. Thalli of *Ramalina ecklonii* and *Physcia regalis*, in particular, began to degenerate within 10 weeks at the Riccarton site.

Plant damage on sensitive species was much less severe at ground level in Riccarton. Measurements of sulphur dioxide relative to height above ground in Newcastle (Gilbert, 1968) showed that the gas concentration falls sharply from six inches to ground level. Moss and lichen damage would be much less severe at four inches from the ground than that at four feet if atmospheric sulphur dioxide were the cause of the observed deterioration.

DISCUSSION

A number of the most abundant bryophytes and lichens in lowland Canterbury are almost entirely missing from a large area of Christchurch city. The area of reduced cryptogam communities coincides with that of moderate to high winter air pollution. Gilbert (1968) has shown that in Newcastle, England, sensitive mosses and lichens begin to die when the average winter sulphur dioxide level reaches 50 ug/m^3 of air. A similar relationship appears to be present in Christchurch. Studies of air pollution in Christchurch (Anon., 1966; Pullen, 1970) have firmly established that winter levels of sulphur dioxide are comparable to those recorded by Gilbert for the outskirts of Newcastle.

Results of the present survey, though incomplete, confirm the conclusions of Gilbert (1965, 1968), Skye (1958, 1968) and others. In particular, it appears that bryophytes and lichens may be the most sensitive macroscopic plants to gaseous air pollution. Consequently, where pollution levels are only moderate and may rise or fall, the reactions of sensitive cryptogams might be used to indicate changes.

There is remarkable similarity between species lists for tree, wall and grassland communities of lichens and mosses in northern England and Canterbury, New Zealand. Most of the mosses and lichens may have been introduced during the early years of settlement. Certainly, introduced trees in the South Island carry many of the epiphytic species normally found in the northern temperate region. Some indigenous epiphytes such as species of *Menagazzia, Lophocolea* and *Lepidozia* were recorded on European trees near areas of native forest. An ecological study will be reported elsewhere of some epiphytic moss and lichen communities on introduced and native trees.

The result of cover estimation for species on trees in Tables 1 and 2 may be compared with those obtained by Hoffman and Kazmierski (1969) in forests of the Olympic Peninsula, Washington, Skye (1958) in Sweden and by Barkman (1958) in Europe. In all these studies exposure or aspect effects are very evident on different moss and lichen species. For most species on trees in Christchurch, reduction in cover occurs earliest and most severely on drier more exposed northerly aspects of the trunks. A number of bryophytes are confined almost entirely to the sheltered, moist habitats of bark on southern aspects.

Hoffman and Kazmierski commented that microclimatic variations might modify the sensitivity of epiphytes to air pollution. The modifying effect of shelter and alkaline substrata in allowing sensitive mosses and lichen to survive in polluted atmospheres, was described in detail by Gilbert (1968). Observations in Christchurch support his conclusion that in sheltered, moist areas of trees and grassland and on mortar and limestone, sensitive species are carried in further towards the centre of the city. The reasonably resistant moss, *Tortula muralis*, exhibits much more gametophyte production when on limestone, mortar and concrete within the areas of highest atmospheric sulphur dioxide. Sensitive species such as *Hypnum, Lophocolea, Physcia regalis* and *Ramalina ecklonii* reappear in the Botanic Gardens and other wooded parks of the central city. There is a striking similarity in the reduction of air pollution and return of sensitive species in the large wooded area of Hagley Park and that in Jesmond Dene in the centre of Newcastle.

Atmospheric sulphur dioxide is rapidly oxidised to sulphate in the moisture films of high pH on alkaline materials like mortar and concrete. The mosses *Grimmia* and *Tortula* when growing on these media are able to tolerate reasonably high sulphur dioxide levels. The removal of gametophytes of all moss species, sensitive and resistant alike, from the bark of most trees in the city, possibly results from the absence of any such modifying effect. Again, much of the recent death in moss gametophytes (Figure 6) was recorded on building stones where a reasonably acid pH would be expected.

Results of the initial transplant experiment are in accord with those of Gilbert's more detailed study with some of the same mosses. Severe damage to thalli of sensitive species, in particular *Hypnum cupressiforme* and *Brachythecium* spp., may occur within three months of exposure to city air in winter. Death of gametophytes appears to be cumulative, from leaf tips and apices downward. This indicates that the average level of pollution during winter is a reasonable guide to the likelihood of biological damage. The resistant species *Ceratodon purpureus* was relatively unaffected in the same conditions of transplanting. The making of other more detailed transplant and physiological experiments is considered worthwhile.

CONCLUSION

Though mosses and lichens have been used as indicators of air pollution in England and Sweden, their great sensitivity makes them less effective in large areas of seriously polluted atmosphere. In the Northern Hemisphere extensive industrial and city areas have virtually become moss and lichen deserts. In these places considerable pollution damage is now occurring to trees and herbaceous plants. Sensitive species among these, including gladioli, roses and conifers, are now being used as indicators.

The level of air pollution in Christchurch is, so far, only moderate. Any significant increase will have further drastic effects on moss and lichen communities before measurable damage occurs to the city's beautiful trees and gardens. Decreases in winter sulphur dioxide levels within central city areas should be accompanied by a return of sensitive mosses and lichens to sheltered aspects of trees, walls and lawns. The detection of such changes will be possible after the completion of the study reported here. An essential part of any future work will be the detailed recording of distribution patterns of sensitive indicator species within city localities.

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