LICHENS AS AIR POLLUTION ASSAYS ON THE WESTERN CAPE COAST.

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ABSTRACT.

A pollution survey was done in Milnerton industrial area along three transects, the coastal road, the R27 road, and the N7 road. In this project lichens were used as pollution monitors and their availability, abundance and percentage cover were used to estimate the level of pollution. Lichen specimens were collected from St. James, which is far from the pollution source and put in the vicinity of the Caltex oil refinery for four month after which they were analysed for their fluorescence and chlorophyll content.

In all transects, lichen species richness and percentage cover increased with distance from the oil refinery, suggesting that indeed lichens are sensitive to pollution and are therefore good air pollution bio-monitors. The fruticose growth forms especially *Teloschistes* and *Usnea* were shown in this study to be the most sensitive to pollution because none of them was recorded close to the oil refinery.

Photosynthetic pigment analyses revealed that Parmelia and Xanthoria are affected differently by pollution. Parmelia showed chlorophyll a and b injury under high pollution conditions while Xanthoria showed high carotenoid injury. The results of this study indicate that the atmosphere in the Milnerton industrial area is heavily polluted, with the Caltex oil refinery being the main pollution source.

INTRODUCTION.

Industrial expansion in countries with uniquely diverse biota, on the one hand, and Third world level of investment in scientific research on the other, leads to formidable and often intractable environmental management dilemmas (Rutherford et al., 1993).

The amount and complexity of toxic pollutants in the environment has increased alarmingly (Kozlowski and Mudd, 1975). Prior to 1940, the major recognized pollutants were particulate matter and sulphur dioxide in smoke but now we have to cope with an array of environmental pollutants including gases, particulates, agricultural chemicals and radioactive material in the atmosphere. These toxic substances affect man's food supply and health because they enter food chains of higher animals, alter reproductive capacity, cause or aggravate eye and respiratory diseases, corrode metals and building materials. Air pollution is associated with a number of respiratory diseases, largely in aggravating existing disorders such as emphysema, bronchitis, and asthma (Treshow and Anderson, 1989). Environmental pollution therefore promises to be one of the problems which require the most urgent attention.

Accumulation of toxic substances in the biosphere is causing serious changes to the structure and function of ecosystems (Kozlowski and Mudd, 1975). Reductions in productivity, as well as the outright demise of forest, are well documented around smelters and other sources of pollution (Treshow and Anderson, 1989). Growing plants are usually susceptible to pollution with reduction in photosynthesis and growth often occurring before symptoms of injury. Yield of virtually all important field crops are greatly depressed by air pollution. In heavily

polluted areas such as the Los Angeles basin, it has become necessary to abandon many citrus groves and farms (Kozlowski and Mudd, 1975).

Plants can therefore be good indicators of pollution. However, the earliest scientific studies did not concern human health or the demise of forests near smelters, instead, they involved the response of lichens (Treshow and Anderson, 1989). These are a composite organism made up of two unrelated entities, a fungus and algae living together in one plant like structure. In sunlight with adequate moisture, the algae partner which contain chlorophyll does the work of converting atmospheric carbon dioxide to sugar, the main food for the partnership (Hawksworth and Rose, 1976). The fungal partner provides the main structure of the lichen including a place within its tissues where algal cells reside, receive water and are protected from ordinary environmental hazards (Treshow and Anderson, 1989). Lichens are able to withstand harsh conditions, but their poikilohydrous nature makes them extremely sensitive to air pollution as they take nearly all of their moisture and nutrients from the atmosphere. In this process, lichens can accumulate and concentrate pollutants into their thalli. Their sensitivity is heightened by the fact that unlike higher plants, lichen never shed their toxin laden parts (Le Blanc and Rao, 1975).

One of the pollutants is sulphur dioxide, which when reacted with water leads to formation of acid rain. This cause very low pH values at which photosynthesis is disrupted because chlorophyll can be irreversibly oxidised or converted to phaeophytin (Hawksworth and Rose, 1976, Le Blanc et al., 1975, Treshow and Anderson, 1989).

a) chlorophyll*a* → chlorophylla^{+}

b) chlorophyll*a* + $2H^{+}$ → phaeophytin*a* + mg^{++}

Biomonitoring is advantageous in that unlike the alternative physio-chemical methods which

record the concentration of toxic elements in the atmosphere, it records cummulative effects of pollutant. This method has been adopted by many European countries which have gone so far as establishing an extensive biomonitoring system to detect industrial pollutants such as fluoride, sulphur dioxide and nitrogen dioxide (Saunders, 1985).

Treshow and Anderson (1989) cited a Finnish lichenologist, W. Nylander, who made a list of lichens growing on tree trunks in the Luxembourg gardens in Paris. He noted that lichens were poorly developed or sterile. Three decades later, L'Abbe Hue could find no lichens in the same areas.

In South Africa little seem to have been done in air pollution biomonitoring. There have been some studies in Cape Town, including the work in Kuilsriver, Milnerton and Stellenbosch both of which showed biomonitoring to be useful (Botha et al. 1991; Davis, 1991; Goliath, 1988). The industrial complex in Milnerton, Cape Town is one area faced with pollution problems but, surprisingly, few pollution investigations have addressed vegetation impacts and susceptibility (Rutherford et al., 1993). It is unclear to what extent pollution may have promoted the current local dominance of introduced Australian species of *Acacia* and *Eucalyptus* and the loss of indigenous species diversity. In a study by Botha et al.(1991) species of *Eucalyptus* generally showed good correspondence between visible symptoms of leaf injury and foliar fluoride concentrations, while *Acacia* species showed no clear relationship.

The aim of this study was to determine the level of pollution around Milnerton in Cape Town using lichens as pollution monitors. The Caltex refinery plant is the suspected pollution source. An adjacent fertilizer factory may also be a source.

The objectives include the following.

1) to determine the level of air pollution produced by the refining plant by looking at the lichen species growing in this area and comparing them with herbarium specimens collected in the area some years back.

2) To investigate the relationship between distance from the oil refinery and the presence and abundance of lichens.

3) To find out which lichen species are more sensitive to pollution.

4) To determine the rate of accumulation of pollutants by comparing the results of this study with that of previous research.

5) To provide a basis for, and to stimulate, future research along these lines.

The following predictions were tested in this study:

a) Fewer species of lichens will be present near the refinery plant (due to disappearance of sensitive species).

b) Species that occur near the refinery plant will be poorly developed.

c) Percentage cover and frequency of each species will be lower near the refinery plant.

MATERIALS AND METHODS.

Two approaches were used in this study: a descriptive survey of lichen abundance and experimental transplanting of lichens from control sites to sites in the vicinity of the oil refinery. Firstly, lichen distribution in relation to the presumed pollution source was surveyed. Sampling was done every kilometer within a radius of 13km and beyond this, sampling was done every two kilometers. In each site, time spent and distance covered for

survey was the same. The following aspects were considered in the survey: Lichen species diversity, growth forms, and percentage cover. Since very little background information on lichens exist in this area, several controls were necessary to separate the effects of pollution and other causes of variation in lichen distribution.

Possible non-pollution determinants of lichen distribution included :

a) Local climatic variation, affected particularly by distance from the sea.

b) The substrates on which lichens were growing.

c) Removal of vegetation by fire.

I attempted to control for these factors by

a) Sampling along three transects at different distances from the sea which would correct the effects of moisture availability.

b) Considering lichens only on the bark and noting any variation in abundance of lichens on different species. This was done to correct for effects of substrate availability on lichen distribution.

c) Restricting the sampling as far as possible, to strandveld species that do not burn readily. In case of Australian *Acacia* dominated areas, recently burnt stands were avoided (see appendix 5 for sites location..

A survey was also done towards the south as far as St. James. This was primarily aimed at investigating lichen species diversity in the fynbos. In each site, lichen species, percentage cover, and growth forms were recorded.

Automobile exhaust fumes also emit measurable amounts of pollutants. It was therefore

necessary to control for this factor. I did this by having all sample sites close to roads, to ensure that lichens were exposed to similar amounts of these pollutants.

Numerical values were used to designate the extent of cover and frequency of occurrence of lichens at different sites. The values used are as follows:

Numerical value	Extent of cover and frequency.
1	Very rare, very low cover, lichens on less than 5% branches.
2	Rare, low cover, lichens on 5-20% branches.
3	Frequent, medium cover, lichens on 20-35% branches.
4	Common, high cover, lichens on 35-55% branches.
5	Abundant, high cover, lichens present on more than 55% branches.

Experimental samples collected in June from St. James far from the pollution source, were placed at varying distance from the Caltex oil refinery for four months (June to September). St. James was chosen as a control site because it is far from the pollution source and hence effects of pollution are minimal. Species collected were: *Parmelia* sp. and *Usnea* sp. Two replicates were put in each site. Thalli were marked, using pins on edges of foliose specimens to measure their growth rate. The samples were recollected after four month (in September). Colour change, growth rate, fluorescence and photosynthetic pigment content

were determined.

Fluorescence measurements.

Fluorescence was measured by a chlorophyll fluorescence measurement system PSM, Biomonitor AB. Specimens were put in the dark overnight before measurements were taken. Because specimens were dry and unresponsive, they were first sprinkled with water. Two parameters within the fast phase of fluorescence induction of the Kautski response were measured. Firstly, the non-variable fluorescence (F_0) when a large majority of photosystem II (PSII) reaction centres are open and photochemical quenching is maximal. Secondly, the maximal fluorescence (F_m) when the reaction centre traps for excitation energy are said to be closing. These two parameters were used to calculate the variable fluorescence (F_v), $F_v = F_m - F_0$, the ratio F_v/F_m, which represents the quantum yield or the efficiency of photochemistry in PSII (Bolhar-Nordenkampf *et al.*, 1989).

Photosynthetic pigments analyses.

Photosynthetic pigment analyses were done for experimental transplant specimens with *Parmelia*, while *Xanthoria* was used for non-experimental specimens collected from different sites along the suspected pollution gradient. This was done to investigate photosynthetic pigments degradation by sulphur dioxide.

Chlorophylls and carotenoids were extracted with ammoniacal acetone (81.8% $(CH_3)_2CO$, 18%H_2O and 0.2% NH_4OH) and their concentrations determined spectrophotochemically. The samples were homogenized twice in 20 ml of extractant and put in bottles wrapped with

light shielding foil to avoid light reaction of photosynthesis. The extract was then centrifuged for 12 minutes after which their spectra were recorded at 470 nm, 647 nm, 663 nm and 710 nm. The following formulae were used to calculate the concentration of chlorophylls and carotenoids:

Chlorophyll*a* (C_a)= $12.25A_{663} - 2.04A_{647}$

Chlorophyll*b* (C_b)= $21.5A_{647} - 5.1A_{663}$

Chlorophyll$_{(a+b)}$ = $7.15A_{663} + 18.71A_{647}$

Carotenoids (C_{x+c}) = $1000A_{470} - 1.82Ca - 85.02Cb/198$

A, is the absorbance at a specific wavelength, and other values are extinction coefficients (adopted from Lichtenhaler, 1987).

RESULTS.

Identification of lichens was done according to Hawksworth and Rose (1976). The following species were found:

LEPROSE	CRUSTOSE	FOLIOSE	FRUTICOSE
Lepraria	*Lecanora*	*Candelaria*	*Ramalina*
	Pertusaria	*Parmelia*	*Teloschistes*
		Physcia	*Usnea*
		Xanthoria	

Coastal road survey.

The results show that *Xanthoria, Lecanora* and *Parmelia* can grow in close proximity to the oil refinery.

crustose *Pertusaria* was recorded beyond a radius of 10.5km from the oil refinery. The fruticose *Teloschistes, Ramalina* and *Usnea* were first recorded beyond radii 11.5Km,

12,5Km and 13.5km respectively. The highest number of lichens species range from 7-8 and this was recorded 11.5 km away. (see Appendix 1). A strong correlation ($r^2 = 0.67$) between species number and distance from the refinery was found (Figure 2).

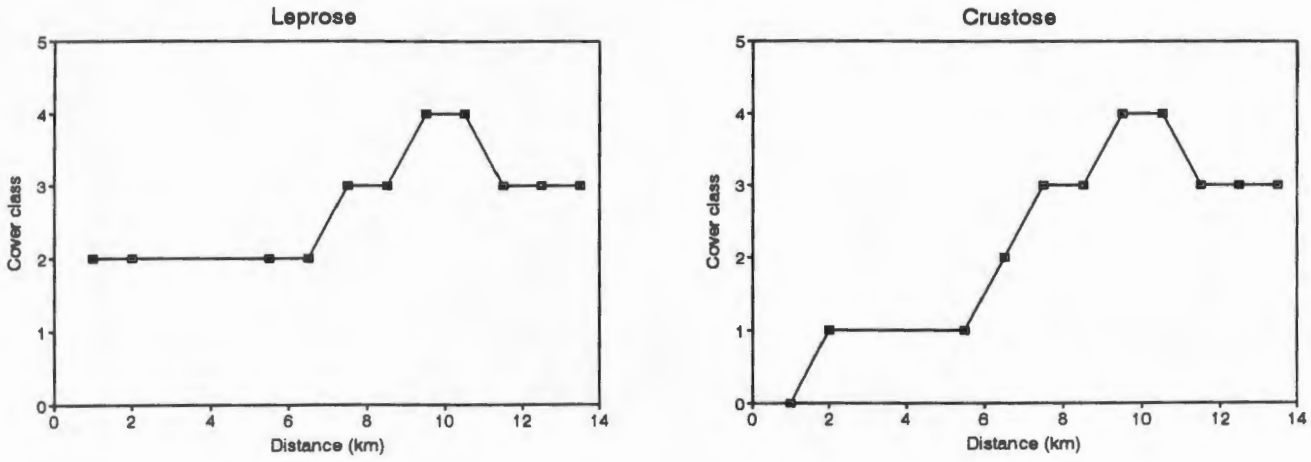

Figure 1. Percentage lichen cover for Leprose and Crustose along the coastal road transect as a function of distance from the oil refinery.

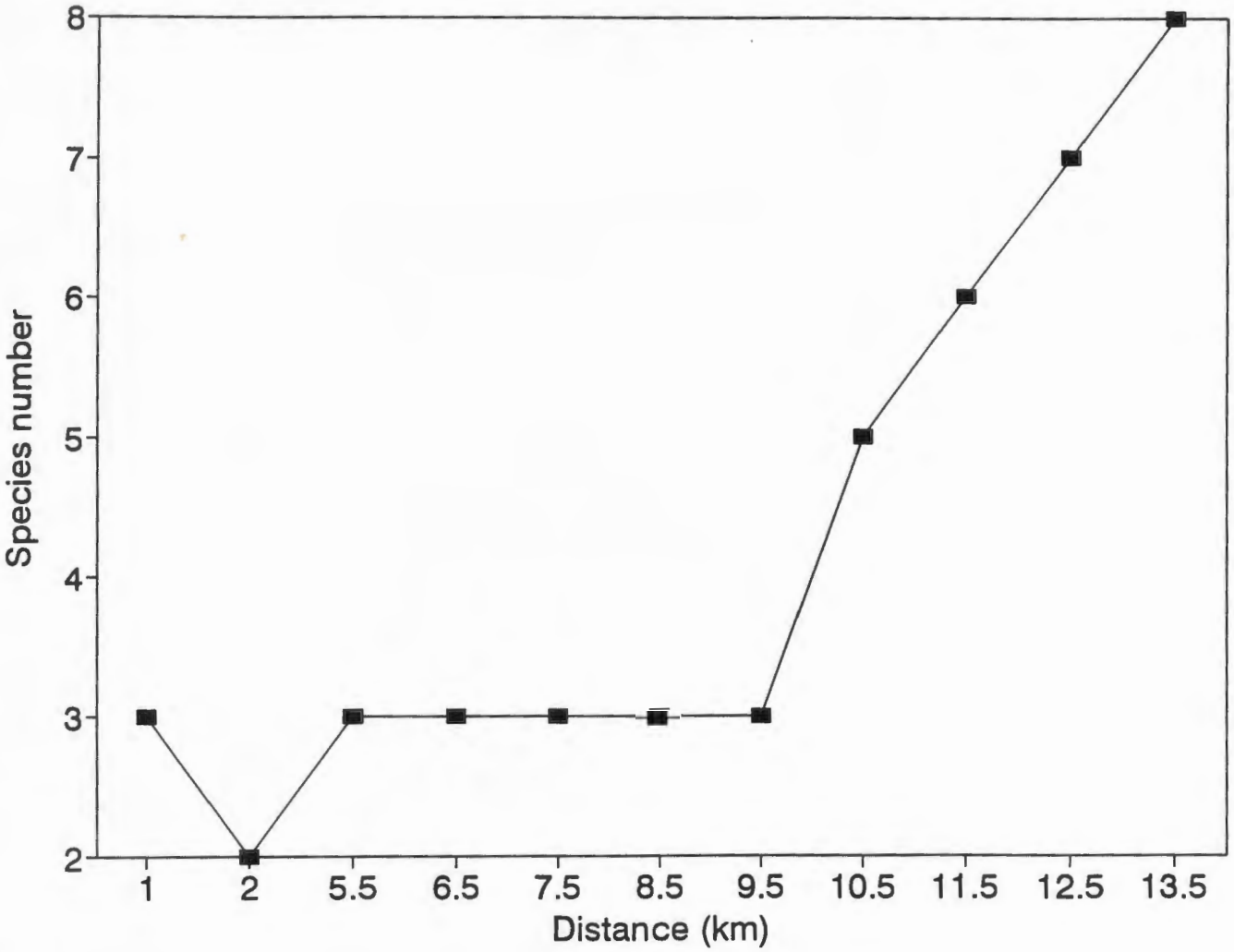

Figure 2. Lichen species richness as a function of distance from oil refinery along the coastal road transect ($r^2 = 0.67$).

R27 road survey.

A strong positive correlation (r^2 = 0.52) was found between distance from the pollution source, number of species and growth forms (see Figure 3). For species occuring close to the pollution source, (ie *Lepraria* and *Lecanora*) there was a significant increase in abundance and percentage cover (from being very rare with low degree of cover at 4Km to being abundant with very high degree of coverage 29Km away) with increasing distance from the pollution source (see Figure 4). Fruticose *Teloschistes* was recorded 12.5Km from the refinery where it was very rare with a very low degree of cover (see Appendix 2). Another fruticose species, *Usnea* was recorded 31Km from the pollution source. The highest number of lichen species (10 species) was recorded 31 Km away from the refinery.

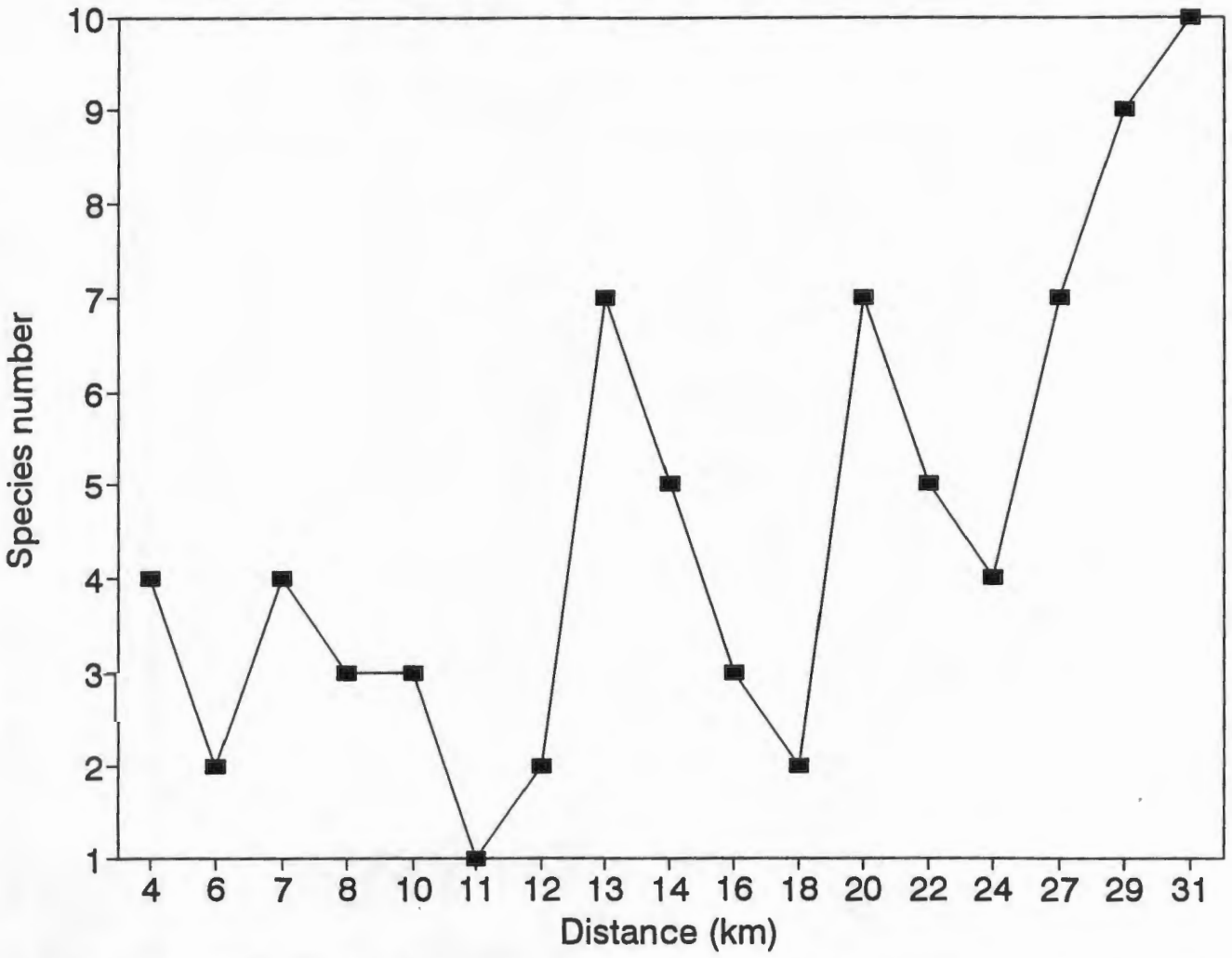

Figure 3. Lichen species richness as a function of distance from the pollution source along the R27 road (r^2 =0.52).

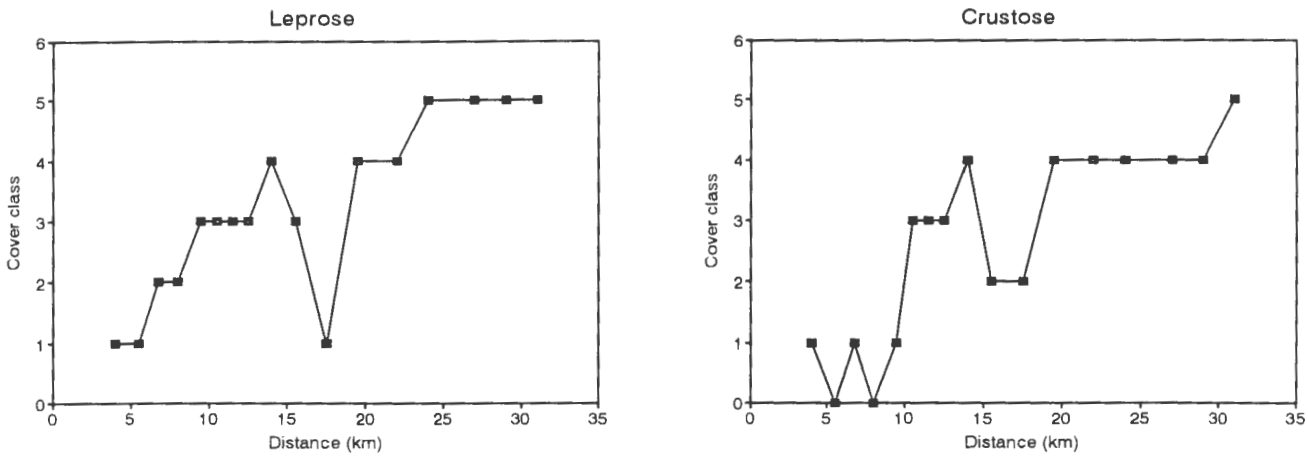

Figure 4. Percentage lichen cover for leprose and crustose as a funcion of distance from the pollution source along the R27 road.

N7 road survey.

Unlike the coastal road and the R27 road, the N7 road in the area surveyed is dominated by Australian *Acacia*. Lichen species diversity was found to be poor along this transect and percentage cover was also low (Figure 5).

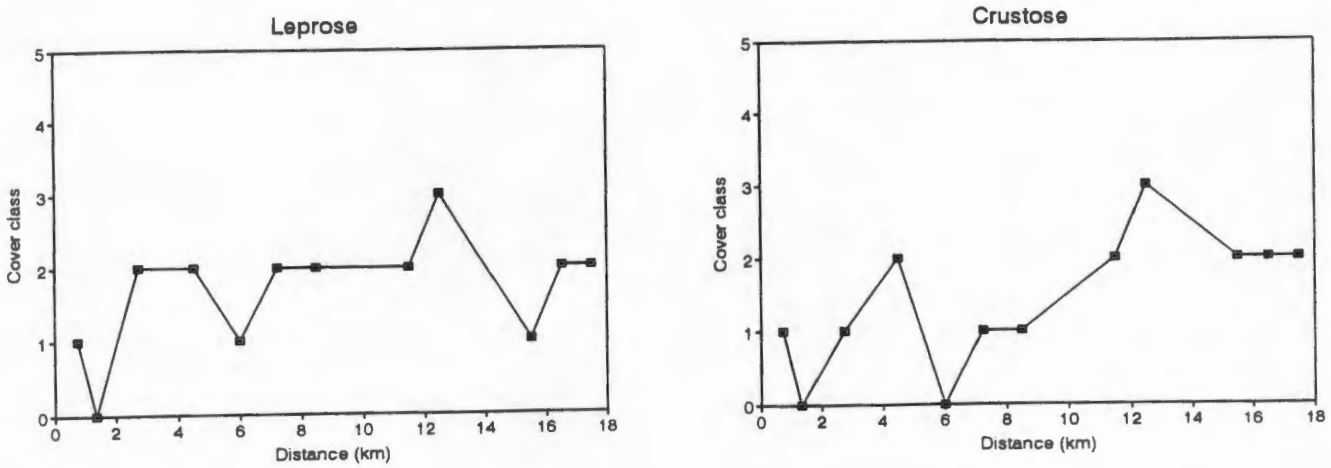

Figure 5. Percentage lichen cover as a function of distance from the pollution source along the N7 road.

The fruticose *Ramalina* was recorded within a radius 0.75 Km (see Appendix 3). The highest number of lichen species was 8, and occurred beyond 8.5 Km from the refinery. There was a poor correlation between distance from the pollution source and species number (r^2 =0.23) (see Figure 6).

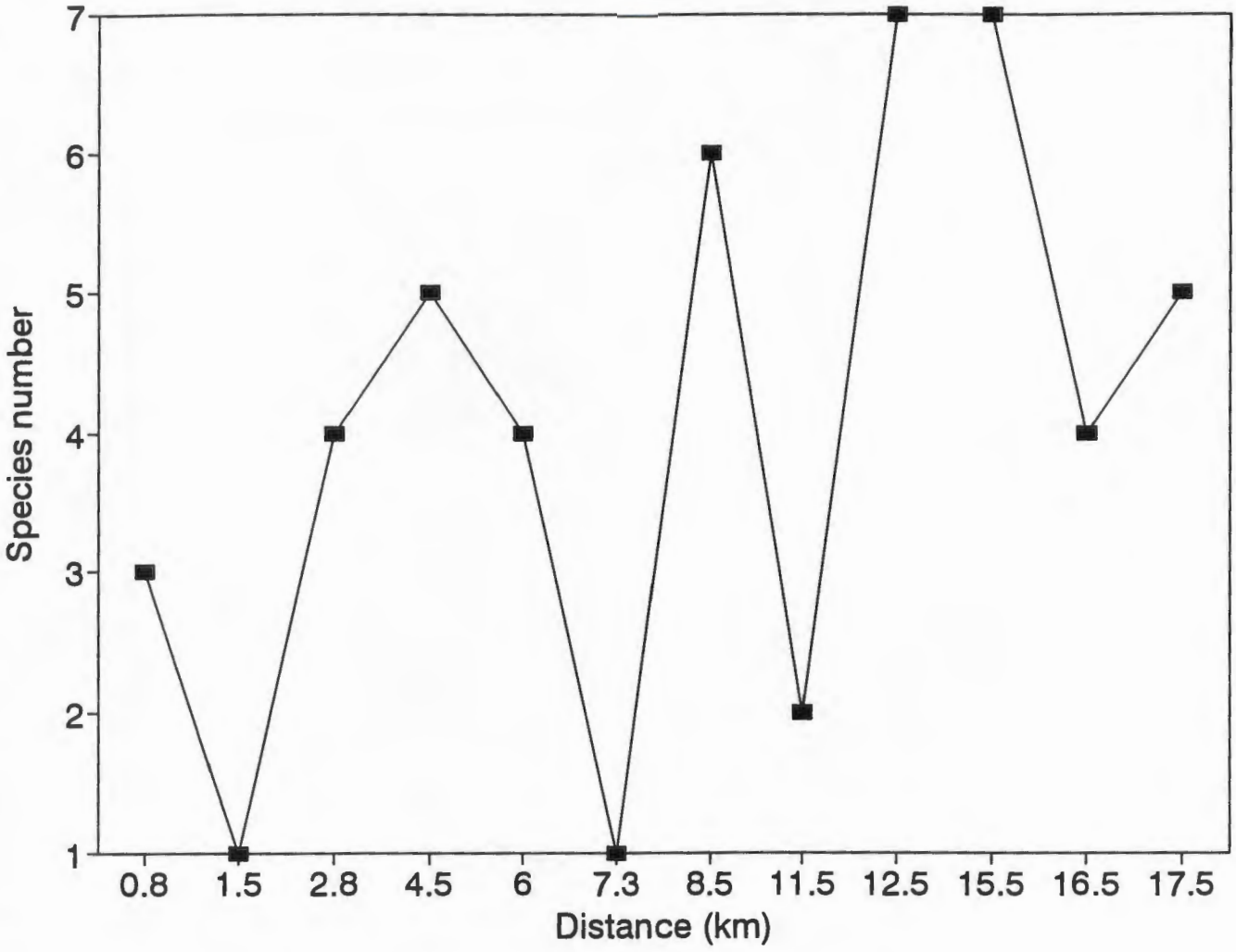

Figure 6. Lichen species richness as a function of distance from the pollution source along the N7 road.(r^2 = 0.23)

Comparison of species diversity in three different transects.

Results of the three surveys indicated greater lichen diversity along the R27 road and the coastal road. The survey along the southern transect (fynbos) (which includes site 1-19) revealed low lichen species diversity in the fynbos. The species recorded were *Xanthoria, Parmelia, Lepraria*, and *Lecanora*. The only fruticose species (*Cladonia)* was recorded at Tygerberg Hill.

Ranking of species according to sensitivity.

Results obtained from the three different transects suggest the following order of pollution resistance:

Lepraria > *Lecanora* > *Xanthoria* > *Pertusaria* > *Parmelia* > *Ramalina* > > *Teloschistes* > *Usnea.*

This indicates that leprose species are more tolerant whereas the fruticose species are the most sensitive.

Experimental samples.

Visual changes in the colour of the experimental specimens were observed only for greenish grey *Parmelia* which had turned yellow by the time the specimens were recollected. The texture of the greyish green *Parmelia* had changed from soft, to hard and leathery. All the *Usnea* specimens died, with whitish skeletons remaining.

Pin marking showed that no growth had occurred throughout the experimental period.

Instead, some thalli were detached from the substrate, suggesting that the species might be senescing.

Fluorescence analyses.

Fluorescence results are tabulated for *Parmelia* and *Xanthoria* (see Appendix 4). There was a great variation in fluorescence values for specimens collected from the same site. Generally fluorescence values did not differ much between sites and there was no regular trend.

Photosynthetic pigment analyses.

There were significant differences in carotenoid injury for *Xanthoria* between sampling sites ($p < 0.001$) with those sites closer to the oil refinery exhibiting high caretonoid injury (Figure 7). Chlorophyll a and b content on the other hand, were recorded to be high for specimens put closer to the pollution source (Figures 7) and low for those further away from the pollution source.

For Parmelia, specimens at 4 and 5 km from the pollution source exhibited higher chlorophyll a and b injury than the specimens put in the vicinity of the oil refinery (see Figure 8). However, specimens put 8km away from the pollution source showed higher chlorophyll a and b content. Caretonoid pigment appeared to be more degraded in sites far from the pollution source (Figure 8).

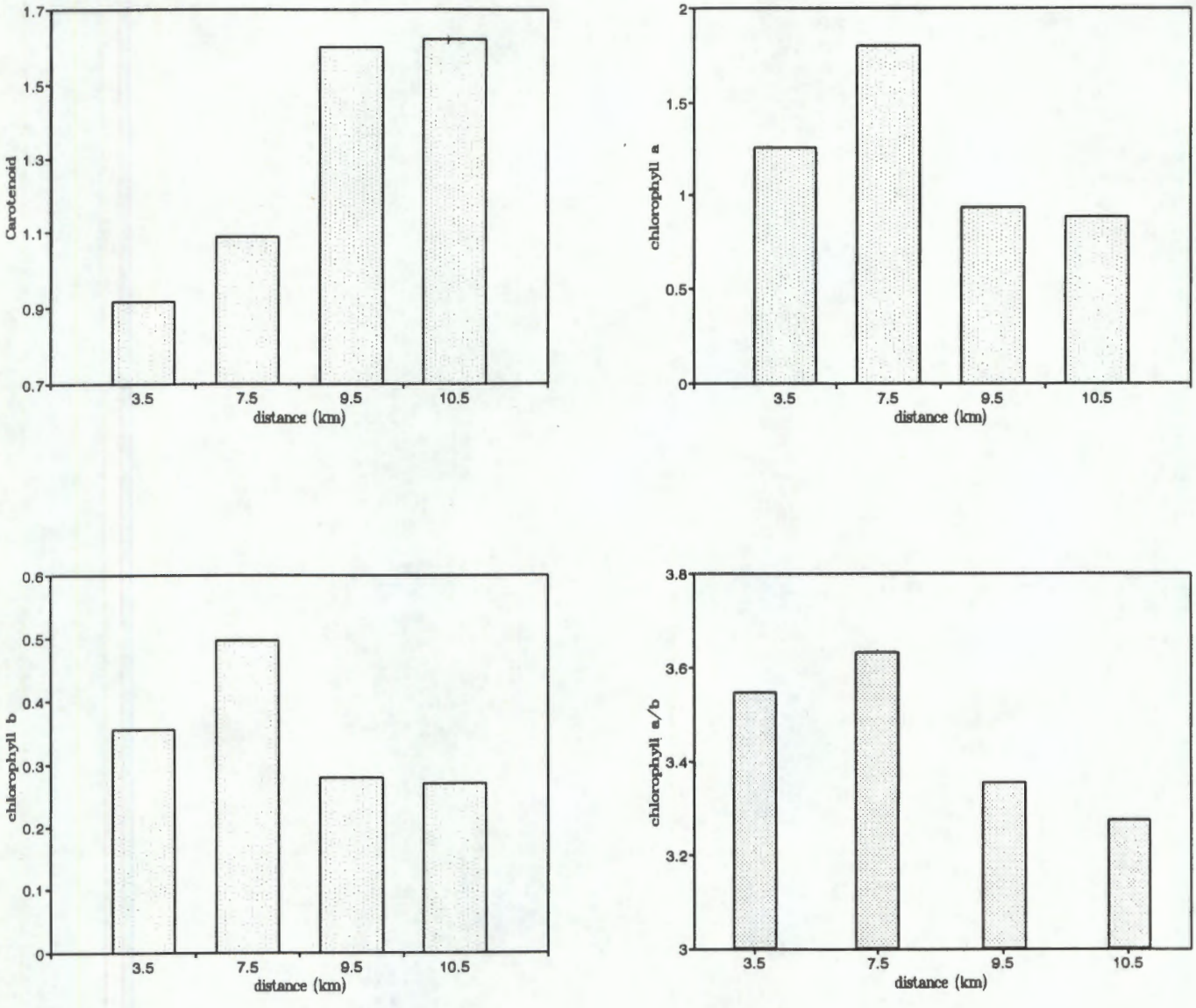

Figure 7. Photosynthetic pigment content of Xanthoria (in micromol per gram dry mass) as a function of distance from the oil refinery. One way anova showed variations to be significant between different sites. In all cases, $p < 0.001$ and $SE < 0.1$.

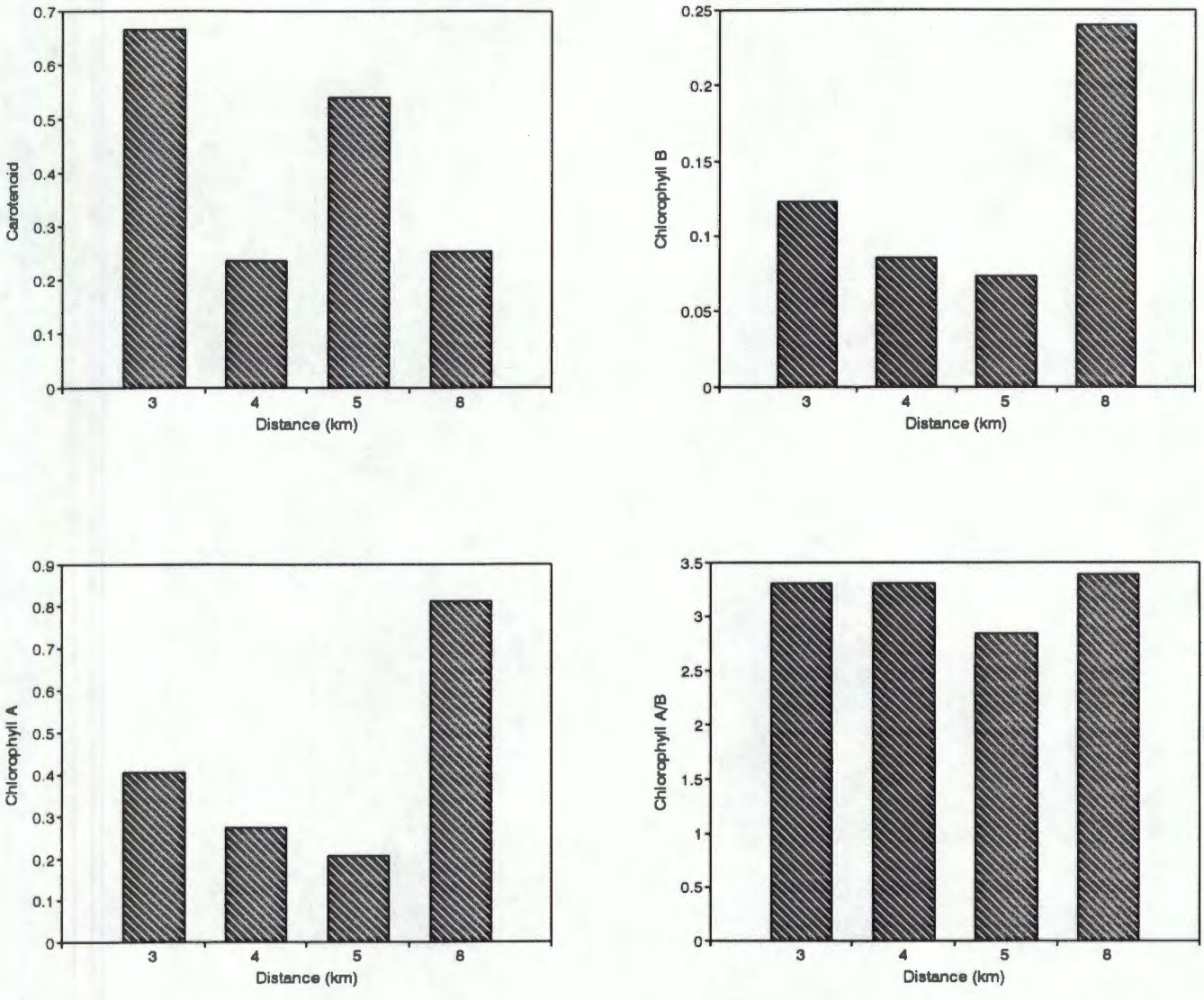

Figure 8. Photosynthetic pigment content of Parmelia (in micromol per gram dry weight) as a function of distance from the oil refinery. One way anova showed variations to be significant between different sites. In all cases $p < 0.044$ and $SE < 0.055$.

Discussion.

Among the many organisms in the world that have been affected by air pollution are lichens, modest plant-like organisms that are reminiscent of mosses, liverworts, mould growth or even bird droppings in some settings (Treshow and Anderson, 1989). As already mentioned, there are many factors influencing the occurrence of lichens. Results of sampling of three transects indicated moisture (as a function of distance from the sea) has a minimal effect on lichen species distribution, but differences among transects were observed.

In both transects, as the pollution source was approached, lichen species diversity decreased. These patterns of lichen diversity were consistent with those of European studies. It was reported that lichens species diversity declines as heavily polluted areas are approached (Hale, 1967). There are fluctuations however, in species diversity along the R27 and the N7 roads. This might be explained by wind patterns since sites near the hill, like site 60 (11.5 km along R27) and site 47 (11.5 km along N7 road) have very low species diversity, while sites shielded from pollution by the hill, like site 48 (12.5km along the N7 road) show high lichen species richness. On the other hand, sites along the coastal road may not be expected to show this fluctuations because the sea breeze is more likely to blow pollutants inland. According to earlier research (Hawksworth and Rose, 1976 , Le Blanc and Rao, 1975), this kind of distribution is directly related to the levels of sulphur dioxide in the atmosphere. The correlation between the levels of sulphur dioxide, species diversity and distance from the pollution source has been confirmed in many studies including those by Davies (1991) and Goliath (1988).

The results of this study also suggests that lichen percentage cover increases with increasing distance from the pollution source (see Figures 1 and 4) . The highest percentage cover was recorded at the furthest site (31 Km) where all lichen species were common. This demonstrates amongst others, the inhibitory effect of high pollutant concentration on multiplication of lichen cells (Le Blanc and Rao, 1975). It can therefore be expected that percentage cover be poor in heavily polluted sites.

Crustose and leprose species appear to be the most pollution tolerant species, followed by foliose species whereas the fruticose growth forms are more susceptible to pollution. This is in agreement earlier research including that of Davis (1991), de Wit (1978) and Goliath (1988) which indicate that the interplay of two factors: avoidance and tolerance render the lichen species either tolerant or sensitive. Avoidance includes the reduction of assimilation through limiting wettability of the thallus by a powdery surface, as in crustose forms and reduction of toxic ions through the buffering capacity of the thallus (Hawksworth and Hill, 1984). Some of these leprose and crustose species are toxitolerant, taking advantage of reduced competition whereas others are toxiphilous, being actively stimulated metabolically by certain pollutants in urban or industrial environments (Le Blanc and Rao, 1975). Among such species are *Lecanora, Buellia* and *Candelariella* (Fenton, 1964 as cited by Le Blanc and Rao, 1975). There are indications that *Lecanora* has some nutritional requirements which are easily met with polluted environments (Gilbert, 1970).

Difference in sensitivity were exhibited within the fruticose growth forms. *Usnea*, recorded 31 Km from the pollution source appear the most sensitive, followed by *Teloschistes*, recorded at 10 Km, from pollution source, and lastly *Ramalina* which was recorded 2.5 Km from pollution source. This is because the intake of pollutants by lichen thalli increases with

wettability (Hawkswoth and Rose, 1976). For *Usnea* uptake of pollutants by wet thalli was found to be six times the uptake by dry thalli. This could explain why *Usnea* is the most sensitive.

Effects of substrate availability on lichen distribution.

There is no doubt that lichens disappear from polluted environments (Treshow and Anderson, 1989) and are more sensitive indicators higher plants in the same area which show no such effects. It is a mistake, however to attribute all effects of poor lichen species diversity to pollution. Growth of certain lichen species is determined by plants species which grow in an area. In this study, for example, *Xanthoria* was recorded in every site where *Lycium* occurred, and its percentage cover was greatly reduced in the absence of *Lycium*. This was also observed in sites further from the pollution source, suggesting that *Lycium* is a good substrate for *Xanthoria*. Other field experiments indicate that pollution sensitivity of a species is related to the buffering capacity of its substrate (Le Blanc and Rao, 1975) or of both the substrate and the lichen species (Hawksworth and Hill, 1974). The former case was found to be true for Xanthorion community which includes Physcia, Candelariella and Xanthoria. When growing on eutrophicated barks, lichens resist pollution better than those growing on uneutrophicated barks (Hawksworth and Rose, 1970). This is attributed to the particulate contaminants, especially alkaline earth metals trapped in bark crevices, which increase the intrinsic buffering capacity thereby reducing the rate of conversion of sulphur dioxide to sulphate ions (So_2 to So_4^{2-}) (Le Blanc and Rao, 1975). The same thing could be happening with *Xanthoria* which when growing on Lycium had high percentage cover even when

occuring close to the pollution source.

Lichens and fire prone vegetation.

Fire is one of the most important ecological forces that can either facilitate change or help maintain the structure of vegetation (Bond pers. comm.). Both wild and controlled fires contribute large quantities of certain pollutants to the atmosphere (Miller and McBride, 1975). Even though the levels of sulphur dioxide may be negligible, lichens may be affected. Furthermore, it is suggested that lichens disappear in unpolluted areas if the area is ecologically altered (Le Blanc and Rao, 1975). This could explain the poor lichen species diversity along the N7 road transect, which is dominated by *Acacia* which burn readily. The fynbos survey also showed poor lichen species diversity. This difficulty in establishment of lichens in fire prone vegetation, is possibly due to their slow growth rate. If lichens are to be used as pollution monitors, fynbos should therefore be avoided.

Laboratory analyses.

Colour changes were not observed for most experimental specimens, possibly because the time of exposure to pollutants was short. Failure to detect any noticable growth cannot only be attributed to pollution injury, but also to the fact that lichens are amongst the slowest growers known to botanists (Hale, 1978).

Chlorophyll content analyses for *Parmelia* revealed that chlorophyll a and b were degraded most near the pollution source (Figure 8). However, specimens put in close proximity to the pollution source showed slight chlorophyll a and b injury compared to those put at radii 4

and 5 km respectively. This might be due to the chimneys which are projected at the height which would favour pollution dispersal by wind to areas not in the immediate proximity to the oil refinery. There is ample evidence concerning the effects of sulphur dioxide on chlorophyll (Le Blanc and Rao, 1975). It has been reported that exposure of lichen to sulphur dioxide causes the conversion of chlorophyll to phaeophytin (Hawksworth and Rose, 1976). In their study, Le Blanc and Rao (1975) found that exposure of *Xanthoria* to sulphur dioxide, lead to total chlorophyll degradation. This is due to the lowering of pH which leads to a loss of mg^{2+} from chlorophyll (Mudd, 1975), followed by plasmolyses and other cellular abnormalities (Le Blanc and Rao, 1975). It is not easy however, to explain the mechanism of carotenoid injury for *Xanthoria*, since literature on carotenoid injury by environmental stress is lacking.

There was a weak relationship between fluorescence and photosynthetic pigment analyses. Since fluorescence is a measure of photosynthetic efficiency it was expected that there be some kind of relationship. However, the condition under which fluorescence values were taken were too artificial because of the behaviour of lichens as resurrection plants. Due to different absorption rates, it is unlikely that 15 minutes for each thalli to absorb water was appropriate to elicit a positive response. Furthermore, different response of specimens collected from the same sites can be expected due to the eneven surfaces of lichens.

Comparison with situation around 1940s.

It is difficult to predict the abundance and percentage cover of lichens around the 1940s. However, by comparing lichen growth forms in the area with herbarium specimens, the

effect of contemporary pollution can be measured. Sensitive species such as *Teloschistes* were collected around 1940 in Melkbosstrand and Blaawberg. In both collections *Teloschistes* was described as being plentiful. Presently, Teloschistes is very rare in these areas. This cannot be attributed to substrate availability because it was reported that collections were made from the same species occurring in the area at present.

CONCLUSION.

Regardless of the inconclusive physiological data, this study proved lichens to be good indicator of pollution. Effects of pollution according to this study are minimal 31 km away from the refinery whereas the residential surburbs are within a radius of 20 km. Species like *Teloschistes* appear to be good air pollution biomonitors because they are sensitive, whereas *Xanthoria* can be misleading because it does not seem to be affected most by pollutants but by substrate availability.

Lastly, a quote from 20 year history of the Evolution of Air pollution Control Legislation in USA- Atmospheric Environment Vol. 27B No1 pp.15, 1993 is appropriate. "Finally, clean air cannot be achieved through study and research. Clean air can only be achieved through appropriate amount of study followed by a major commitment to a plan of action" (adopted from Annual report of medical officer of health vol. 1 1992/1993, SA).

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References.

Bolhar-Nordenkampf, H. R., Long, S. P., Baker, N. R., Oquist, G., Schreibers, U., and Lechner, E. G. (1989). Chlorophyll fluorescence as a probe for photosynthetic competence of leaves in the field. Functional Ecology 3: 497-514.

Botha, A. J., Visser, J. H., and Moore L. D. (1989). Evaluation of possible fluoride injury to vegetation in the vicinity of an industrial site near Cape Town. SA. J. Sci. 85: 741-745.

Davis, S. A., (1991). Biomonitoring as a means to determine pollution level in Stellenbosch. M.sc thesis. University of the Western Cape.

De Wit, T. (1976). Epiphytic lichens and air pollution in the Netherlands. J. Crammer. Germany.

Gilbert, O. C. (1970). Further studies on the effects of sulphur dioxide on lichens and bryophytes. New Phytol. 69: 605-627.

Goliath, J. (1988). Plants as pollution monitors (Kuilsrivier).
Honours thesis. University of the Western Cape.

Hale, J. R., and Mason, E. (1967). Lichen handbook. A guide to lichens of eastern north America. Smithsonian institution Press, Washington, D. C.

Hawksworth, D. L and Rose, F. (1976). Lichens as pollution monitors. Edward Annold . London.

Hawksworth, D. L., and Hill, D. J. (1984). The lichen-forming fungi. Blackie USA: Chapman & Hall, New York.

Kozlowski, T. T., and Mudd, J. B. (1975). Introduction. *In* Response of plants to air pollution. pp. 2-8. Eds. Mudd, J. B., and Kozlowski, T. T. Academic Press, Inc. London.

Le Balnc, F., and Rao, D. N. (1975). Effects of air pollution on lichens and bryophytes. *In* Response of plants to environmental pollution. pp.337-272. Eds. Mudd, J. B. ,and Kozloski, T. T. Academic Press, Inc. London.

Lichtenhaler, (1987). Chlorophylls and carotenoids: Pigments of photosynthetic Biomembranes. Methods in enzymology.

Miller, P. R., and McBride, J. R. (1975). Effects of air pollution on forest. pp. 196-236. *In* Response of plants to air pollution. Eds. Mudd, J. B, and Kozlowski, T. T. Academic Press, Inc. London.

Mudd, J., B., (1975). Sulphur dioxide. pp. 9-23. *In* Response of plants to air pollution. Eds. Mudd, J. B., and Kozlowski, T. T.

Academic Press, Inc. London.

Oxley, B. D. Air pollution. In Annual report of the medical officer of health 1992/1993. vol. 1. pp. 41.

Rutherford, M. C, Midgley, G. F., and Davis, G. W. (1993). Covert symptoms of pollution stress in introduced vegetation near Cape Town. SA. J. Sci. 89: 50-51.

Saunders, P J. W. (1985). Regulations and research on sulphurdioxide and its effects on plants in european communities. *In* Sulphurdioxide and vegetation: Physiology, ecology, and policy issues. Eds. Winner, W. E., Mooney, H. A., and Goldstein, R. A. Stanford University Press, California.

Treshow, M., (1970). Environment and plant response. McGraw-Hill Publishers. New York.

Treshow, M. and Anderson, F. (1989). Plant stress from air pollution. John Willey & Sons. New York.

Appendix 1 Species number, growth forms and percentage cover along the coastal road transect.

SITE	DISTANCE	SPECIES	GROWTHF	COVER	SPECIES NUM
20	1	Lepraria	Leprose	2	
20	1	Lecanora	Crustose	2	
20	1	Xanthoria	Foliose	1	3
21	2	Lepraria	Leprose	2	
21	2	Xanthoria	Foliose	1	2
24	5.5	Lepraria	Leprose	2	
24	5.5	Lecanora	Crustose	1	
24	5.5	Xanthoria	Foliose	1	3
25	6.5	Lepraria	Leprose	2	
25	6.5	Lecanora	Crustose	1	
25	6.5	Xanthoria	Foliose	1	3
26	7.5	Lepraria	Leprose	3	
26	7.5	Lecanora	Crustose	3	
26	7.5	Xanthoria	Foliose	2	3
27	8.5	Lepraria	Leprose	3	
27	8.5	Lecanora	Crustose	4	
27	8.5	Xanthoria	Foliose	3	3
28	9.5	Lepraria	Leprose	3	
28	9.5	Lecanora	Crustose	3	
28	9.5	Xanthoria	Foliose	3	3
29	10.5	Lepraria	Leprose	4	
29	10.5	Lecanora	Crustose	4	
29	10.5	Pertusaria	Crustose	4	
29	10.5	Parmelia	Foliose	1	
29	10.5	Xanthoria	Foliose	3	5
30	11.5	Lepraria	Leprose	3	
30	11.5	Lecanora	Crustose	2	
30	11.5	Pertusaria	Crustose	2	
30	11.5	Parmelia	Foliose	2	
30	11.5	Telosch	Fruticose	1	
30	11.5	Xanthoria	Foliose	2	6
31	12.5	Lepraria	Leprose	3	
31	12.5	Lecanora	Crustose	3	
31	12.5	Pertusaria	Crustose	2	
31	12.5	Parmelia	Foliose	2	
31	12.5	Ramalina	Fruticose	1	
31	12.5	Telosch	Fruticose	1	
31	12.5	Xanthoria	Foliose	2	7
32	13.5	Lepraria	Leprose	3	
32	13.5	Lecanora	Crustose	3	
32	13.5	Pertusar	Crustose	3	
32	13.5	Parmelia	Foliose	2	
32	13.5	Ramalina	Fruticose	2	
32	13.5	Teloschiste	Fruticose	1	
32	13.5	Usnea	Fruticose	1	
32	13.5	Xanthoria	Foliose	2	8

Appedix 2. Species number, growth forms and percentage cover along the R27 road transect.

SITE	DISTANCE	SPECIES	GROWTHF	COVER	SPECIESNUM
54	4	Lepraria	Leprose	1	
54	4	Lecanora	Crustose	1	
54	4	Pertusaria	Crustose	1	
54	4	Parmelia	Foliose	1	
54	4	Xanthorea	Foliose	3	4
55	5.5	Lepraria	Leprose	1	
55	5.5	Xanthorea	Foliose	1	2
56	6.75	Lepraria	Leprose	2	
56	6.75	Lecanora	Crustose	1	
56	6.75	Parmelia	Foliose	1	
56	6.75	Xanthorea	Foliose	3	4
57	8	Lepraria	Leprose	2	
57	8	Parmelia	Foliose	1	
57	8	Xanthorea	Foliose	1	3
56	9.45	Lepraria	Leprose	3	
56	9.45	Lecanora	Crustose	1	
58	9.45	Xanthorea	Foliose	3	3
59	10.5	Lepraria	Leprose	3	1
60	11.5	Lepraria	Leprose	2	
60	11.5	Xanthorea	Foliose	3	2
61	12.5	Lepraria	Leprose	4	
61	12.5	Lecanora	Crustose	4	
61	12.5	Pertusaria	Crustose	3	
61	12.5	Parmelia1	Foliose	4	
61	12.5	Parmelia2	Foliose	4	
61	12.5	Teloschist	Fruticose	1	
61	12.5	Xanthorea	Foliose	5	7
62	14	Lepraria	Leprose	2	
62	14	Lecanora	Crustose	2	
62	14	Pertusaria	Crustose	2	
62	14	Parmelia	Foliose	1	
62	14	Xanthorea	Foliose	3	5
63	15.5	Lepraria	Leprose	2	
63	15.5	Lecanora	Crustose	2	
63	15.5	Xanthorea	Foliose	3	3
64	17.5	Lepraria	Leprose	1	
64	17.5	Xanthorea	Foliose	1	2
65	19.5	Lepraria	Leprose	3	
65	19.5	Lecanora	Crustose	3	
65	19.5	Parmelia1	Foliose	2	
65	19.5	Parmelia2	Foliose	2	
65	19.5	Parmelia3	Foliose	1	
65	19.5	Ramalina	Fruticose	2	
65	19.5	Xanthorea	Foliose	3	7
66	22	Lepraria	Leprose	4	
66	22	Lecanora	Crusrose	4	
66	22	Parmelia1	Foliose	1	
66	22	Ramalina	Fruticose	2	
66	22	Xanthorea	Foliose	2	5
67	24	Lepraria	Leprose	4	
67	24	Lecanora	Crustose	4	
67	24	Ramalina	Fruticose	2	
67	24	Xanthorea	Foliose	3	4
68	27	Lepraria	Leprose	5	
68	27	Lecanora	Crustose	4	
68	27	Pertusaria	Crustose	3	
68	27	Parmelia1	Foliose	2	
68	27	Parmelia2	Foliose	2	
68	27	Ramalina	Fruticose	3	
68	27	Xanthorea	Foliose	3	7
69	29	Lepraria	Leprose	5	
69	29	Lecanora	Crustose	5	
69	29	Parmelia1	Foliose	3	
69	29	Parmelia2	Foliose	3	
69	29	Parmelia3	Foliose	3	
69	29	Parmelia4	Foliose	3	
69	29	Ramalina	Fruticose	2	
69	29	Teloschist	Fruticose	3	
69	29	Xanthorea	Foliose	3	9
70	31	Lepraria	Leprose	5	
70	31	Lecanora	Crustose	5	
70	31	Parmelia1	Foliose	3	
70	31	Parmelia2	Foliose	3	
70	31	Parmelia3	Foliose	2	
70	31	Parmelia4	Foliose	3	
70	31	Ramalina	Fruticose	3	
70	31	Teloschist	Fruticose	4	
70	31	Usnea	Fruticose	3	
70	31	Xanthorea	Foliose	3	10

Appendix 3. Species number, growth forms and percentage cover along the N7 road transect.

SITE	DISTANC	SPECIES	GROWTH	COVER	SPECIES NUM
40	0.75	Lepraria	leprose	1	
40	0.75	Lecanora	Crustose	1	
40	0.75	Ramalina	fruticose	1	3
41	1.35	Parmelia	Foliose	1	1
42	2.75	Leprraria	Leprose	2	
42	2.75	Lecanora	Crustose	1	
42	2.75	Parmelia	Foliose	1	
42	2.75	Xanthorea	Foliose	3	4
43	4.5	Lepraria	Leprose	2	
43	4.5	Lecanora	Crustose	2	
43	4.5	Pertusaria	Crustose	2	
43	4.5	Parmelia	Foliose	2	
43	4.5	Ramalina	Fruticose	2	5
44	6	Lepraria	Leprose	1	1
44	6	Parmelia	Foliose	1	
44	6	Ramalina	Fruticose	1	
44	6	Xanthorea	Foliose	1	3
45	7.25	Parmelia	Foliose	1	1
46	8.5	Lepraria	Leprose	2	
46	8.5	Lecanora	Crustose	1	
46	8.5	Pertusaria	Crustose	1	
46	8.5	Lecidea	Crustose	1	
46	8.5	Parmelia	Foliose	2	
46	8.5	Ramalina	Fruticose	1	6
47	11.5	Lepraria	Leprose	2	
47	11.5	Parmelia	Foliose	2	2
48	12.5	Lepraria	Leprose	3	
48	12.5	Lecanora	Crustose	3	
48	12.5	Parmelia	Foliose	2	
48	12.5	Parmelia	Foliose	2	
48	12.5	Ramalina	Fruticose	1	
48	12.5	Teloschist	Fruticose	1	
48	12.5	Xanthorea	Foliose	2	7
49	15.5	Lepraria	Leprose	1	
49	15.5	Lecanora	Crustose	2	
49	15.5	Pertusaria	Crustose	2	
49	15.5	Parmelia	Foliose	2	
49	15.5	Parmelia	Foliose	2	
49	15.5	Ramalina	Fruticose	3	
49	15.5	Xanthorea	Foliose	2	7
50	16.5	Lepraria	Leprose	2	
50	16.5	Lecanora	Crustose	2	
50	16.5	Pertusaria	Crustose	1	
50	16.5	Ramalina	Fruticose	1	4
52	17.5	Lepraria	Leprose	2	
52	17.5	Lecanora	Crustose	2	
52	17.5	Parmelia	Foliose	1	
52	17.5	Ramalina	Fruticose	1	
52	17.5	Teloschist	Fruticose	1	5

Appendix 4.

Site	Distance	species	Fo	Fm	Fv/Fm
8	5.5	Xanthoria	104	263	0.604
8	5.5	Xanthoria	100	285	0.649
8	5.5	Xanthoria	53	137	0.613
9	6.5	Xanthoria	79	160	0.506
9	6.5	Xanthoria	64	138	0.536
9	6.5	Xanthoria	83	194	0.572
10	7.5	Xanthoria	85	231	0.632
10	7.5	Xanthoria	96	260	0.63
10	7.5	Xanthoria	88	255	0.654
11	8.5	Xanthoria	93	233	0.6
11	8.5	Xanthoria	81	197	0.588
11	8.5	Xanthoria	79	185	0.572
12	9.5	Xanthoria	101	262	0.614
12	9.5	Xanthoria	79	182	0.565
12	9.5	Xanthoria	98	238	0.588

APPENDIX 5: SAMPLING SITES