ASSESSMENT OF AIR POLLUTION IMPACTS ON VEGETATION IN SOUTH AFRICA

by

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(ABSTRACT)

Field surveys and biomonitoring network experiments were conducted in selected areas in South Africa to assess possible air pollution damage to vegetation. During field surveys, atmospheric fluoride was identified as an important pollutant that damaged vegetation in residential areas north of Cape Town. Gaseous air pollutants, including acid deposition and acidic mist, probably play a major role in the development of characteristic air pollution injury symptoms observed on pine trees in the Eastern Transvaal area.

The impact of urban air pollution in the Cape Town area was evaluated by exposing bio-indicator plants in a network of eight biomonitoring network stations from June 1985 to May 1988. Sensitive *Freesia* and *Gladiolus* cultivars were used to biomonitor atmospheric fluoride, while a green bean cultivar was used as a biomonitor of atmospheric sulphur dioxide and ozone. At one location, bio-indicator plants were simultaneously exposed in a biomonitoring network station (plant cages), open-top chambers (filtered and

unfiltered), as well as in open plots. The responses of plants grown under these different conditions were compared.

During both the winter and summer seasons, ambient fluoride concentrations were estimated to be particularly high at the Loumar biomonitoring station (eastern side of Cape Town), as compared to that at the other biomonitoring stations. Elevated levels of atmospheric fluoride as well as sulphur dioxide appeared to prevail in the vicinity of industries located in the northern suburbs of Cape Town (Bothasig, Table View and Edgemead). Interveinal bleaching, which is characteristic of sulphur dioxide injury, was regularly observed on bean plants exposed at the Bothasig biomonitoring station and was usually determined to be significantly worse at this location than at the other biomonitoring stations. These results were confirmed by the evaluation of foliar sulphur content.

Ambient pollutant concentrations appeared to be effectively reduced inside filtered open-top chambers, as exemplified by higher biomass production and lower foliar fluoride and sulphur levels in the relevant bio-indicator species, compared to that of plants grown in the open plots.

The methodology used during this research provided baseline data of the impact of air pollution on vegetation in South Africa which, in the absence of networks of sophisticated state of the art equipment, can be applied to aid in air pollution control strategies.

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THE ASSESSMENT OF AIR POLLUTION IMPACTS

ON VEGETATION IN SOUTH AFRICA

CHAPTER 1

ASSESSMENT OF AIR POLLUTION IMPACTS ON VEGETATION IN SOUTH AFRICA

ASSESSMENT OF AIR POLLUTION IMPACTS ON VEGETATION IN SOUTH AFRICA

1. INTRODUCTION

Air pollution is generated primarily from the activities of man, adversely affecting his own health and welfare as well as that of the whole biosphere and all its organisms. In recent years the extent of air pollution has reached global proportions, transcending natural and political boundaries and extending from industrialized areas into remote and sparsely populated areas. Terms such as "acid rain" and "Waldsterben" have been popularized.

It was estimated that in West Germany, 75% of the famous Black Forest has been killed or damaged due to acid rain (including dry deposition), while in East Germany, an estimated 86% of the country's 3 million hectares of woodland have been visibly affected (Tifft, 1985). Extensive damage has also been reported in Austria, Czechoslovakia, Poland, Yugoslavia, Hungary, Romania, the Netherlands, Belgium, France, Switzerland, Sweden and the United States. "Waldsterben" symptoms have also been reported in Great Britain, the Soviet Union, Spain, Italy, and Canada (Hinrichsen, 1987).

Whereas "Waldsterben" in Europe affected 11 species, of which the four most important are conifers and the other seven are broadleaved tree species, forest decline in North America has affected only conifers (Hinrichsen, 1987). However, there are similarities between the forest declines in Europe and North America in that the most severely damaged trees in both cases are found on high slopes facing the prevailing air masses, particularly on slopes often covered in clouds or fog (Hinrichsen, 1987).

Air pollution is generally worse in countries with higher *per capita* incomes and higher rates of energy consumption. These countries usually also have stricter air pollution control laws than the poorer countries where inhabitants are more concerned with the basic needs of food, shelter and clothing and are less concerned about the disamenities and effects of dirty air.

In the Republic of South Africa (hereafter referred to as South Africa), industry is rapidly growing because of the availability of native raw materials and the necessity for economic development in order to meet basic needs and fulfill the aspirations of its people. In the metropolitan areas of Cape Town in the south and Johannesburg and Pretoria in the north (Fig. 1.1), air pollution is emerging as a regularly observed phenomenon that people in South Africa have to accept as part of their environment. The tendency to export less raw material and process and fabricate more within South Africa has increased the pollution consequences for the country. Due to the nature of its major industries,

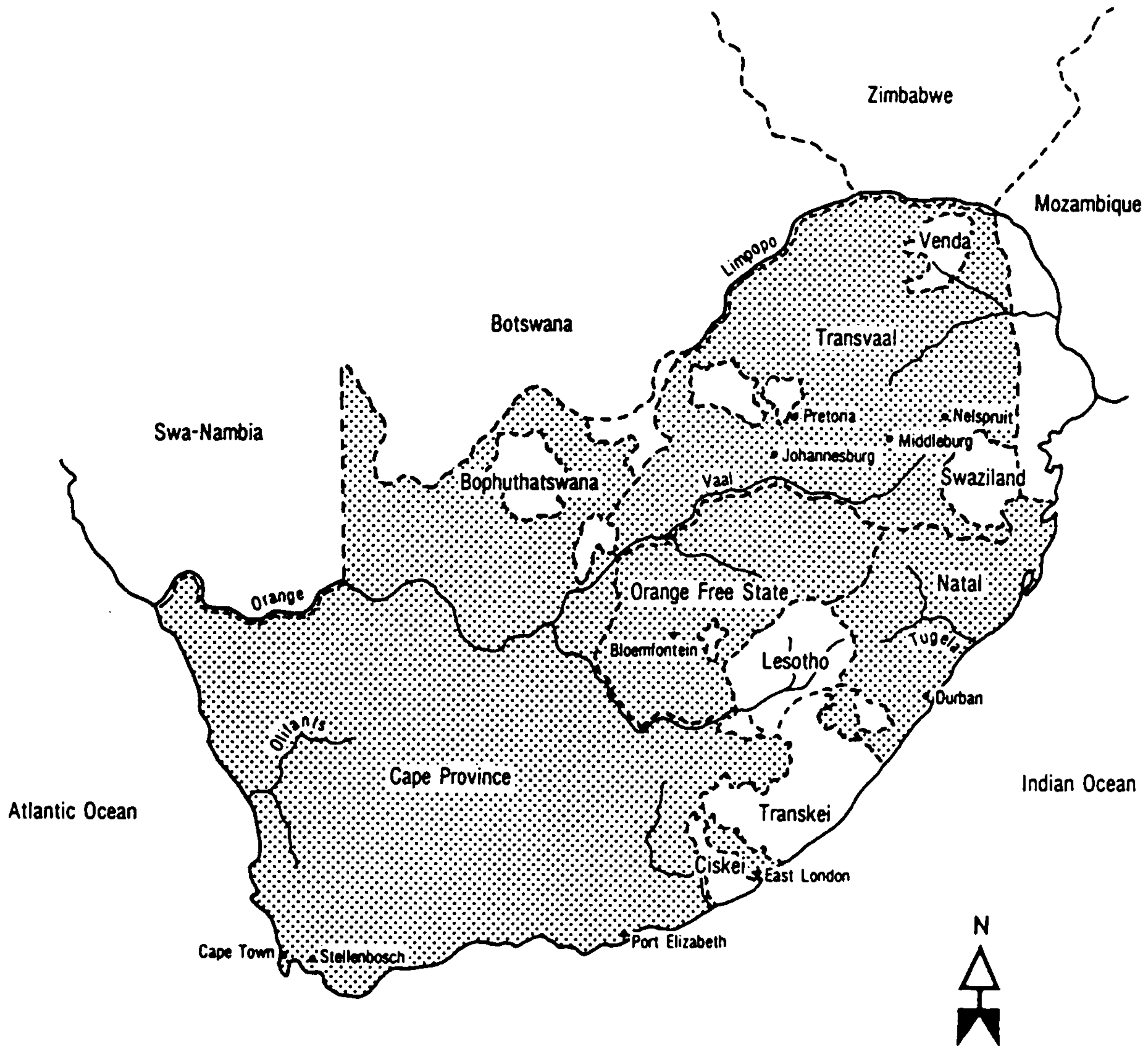

Fig. 1.1 Republic of South Africa: general orientation map.

South Africa has a relatively high electricity demand in relation to its overall industrial size. A network of pulverized coal-fired power stations in the Transvaal provide about 90% of all electrical power consumed in South Africa and, in fact, 60% of all electricity used on the continent of Africa. Most of these power stations are located in an area only 100 by 200 km in extent (Lloyd, 1987). Consequently, the release of noxious gases and fly-ash from these power stations, has the potential to seriously affect the air quality of this region.

In the Western Cape Province, the meteorology and air pollution of the greater Cape Town area has been compared to that of Los Angeles and Sydney, Australia (Dutkewicz, 1979). According to Fuggle (1986), total oxidants in Cape Town are at times as bad as those in Los Angeles and Tokyo. However, in a study conducted in 1987 the occurrence of photochemical smog in Cape Town was considered to be of a lesser magnitude than in those foreign cities (Loewenheim, 1988).

1.1 Topography and Meteorology:

The topography of South Africa resembles a huge narrow-rimmed, inverted saucer. The rim is a coastal belt varying in width from 60 km in the west to more than 200 km in the east. The low-lying coastal areas abuts on an escarpment which is more pronounced in the east and south where the country's highest mountain ranges are located. The interior plateau is a vast plain with an average elevation of 1200 m, interrupted occasionally by isolated hills or low ranges. The warm Mozambique-Agulhas Current flows southwards along the east coast and westwards along the south coast as far as Cape Point, and the cold Benguela Current flows north along the west coast as far as Angola. The climate in South Africa is mild, with mean annual temperatures around 17 °C (Bureau for Information, 1987).

Surface temperature inversions are ubiquitous over South Africa, especially at night during the winter months when the frequency of occurrence exceeds 80% over most of the country. Meteorological studies indicated that the Transvaal Highveld (i.e. the interior northern, northwestern and western regions of South Africa) experience the highest pollution potentials (Venter and Tyson, 1978). The climate of the Transvaal Highveld region is characterized by high atmospheric stability, associated with low wind speeds and subsidence of air in the slow moving high pressure cells that frequently occur over southern Africa (Closs and Venter, 1982). Dispersion is poor, thus the climate strongly favours the accumulation of air pollutants (Tyson et al., 1988).

Maximum winter mixing depths vary from just under 1000 m along the coast to over 1500 m over inland plateaux areas (Diab, 1977). Over coastal areas average winter transport wind speeds are high (e.g. 5.6 m/s at Cape Town, 7.2 m/s at Port Elizabeth in July) and thus pollution is lower than inland where, although mixing depths are greater, transport wind speeds are lower, e.g. 3.6 m/s at Pretoria in July (Diab, 1977; Venter and Tyson, 1978).

The potential for atmospheric pollution in the South Western Cape Province is nevertheless a reason for concern. The air pollution research group of the Council for Scientific and Industrial Research (CSIR) in South Africa recommended in 1984 that pollution sources on the western side of the Hottentots-Holland mountain range, which extends in a north-eastern direction approximately 45 miles (72 km) east of Cape Town, should be minimized and that no sources with high pollution potential should be allowed to become established within 5 km of the coast (Die Burger, 1984). Low lying temperature inversions, entrapping significant amounts of pollutants, are regularly observed over the coastal regions of the greater Cape Town metropolitan area (Fig. 1.2).

1.2 Pollution levels:

Legislation of air pollution control in South Africa is based upon the policy to use "the best practical means" to combat air pollution. In the last four to five years the Dept. of Health and other government institutions have been

<u>Fig. 1.2</u>: Temperature inversion over Cape Town and vicinity.

1.2

using state of the art instruments and standard quality assurance and quality control measures to monitor the concentrations of specific pollutants continuously at a number of locations in South Africa. Since the 1950's moreover, total acids have been monitored at various locations in the Johannesburg and Cape Town metropolitan areas, using an acidimetric titration method during which air is bubbled through a hydrogen peroxide solution. A filter paper at the inlet of the bubbler apparatus is analyzed for lead and particulates at regular intervals. This is an ongoing monitoring program, coordinated by the CSIR in Pretoria.

According to Worswick (1985), particulate matter (dust) is the greatest single air pollution problem generally encountered in most areas of South Africa. He attributed this state of affairs to the following: (i) the industries are fossil fuel based (coal), (ii) the "law of the best practicable means" to control air pollution does not function adequately in the South African environment and (iii) the South African climatic conditions are prone to inversions and therefore cannot tolerate heavy particulate emissions.

Much of the data available on the levels of atmospheric pollutants for the Cape Town and Transvaal regions are either roughly approximate or very limited. Data available from the monitoring network operated since the 1950's (Kemeny and Halliday, 1974; Kemeny, 1977; Kemeny and

Vleggaar, 1983) utilizing the acidimetric titration method, may be useful in evaluating long term trends of sulphur dioxide (SO_2) pollution, but it is not regarded as very accurate and also does not identify the occurrence of concentration peaks, since sampling periods were either 48 or 72 hours. In the Cape Town area continuous monitors have been periodically used in mobile units at various locations since the late 1970's (Dutkewicz et al. 1980) and more permanently since 1985 (records of the Western Cape Regional Services[1], Cape Town). The levels of atmospheric pollution and rates of deposition in the Transvaal have been assessed with continuous monitors since 1979, but in most instances for relatively brief periods (Tyson et al., 1988). The Electricity Supply Commission (ESCOM), established a network of continuous monitors that recorded SO_2 since 1979 at nine sites in the Eastern Transvaal Highveld. Since its inception this network has gradually been expanded as new power stations came into operation. Ozone (O_3) has been measured at only one station (Phoenix) in the eastern Transvaal rural area, which is a major agricultural area, during 1985/1986. Aerosols and wet deposition are monitored at several sites in the Eastern Transvaal Highveld (Tyson et al., 1988).

According to data presented by Tyson et al. (1988), ambient SO_2 concentrations in the eastern Transvaal often exceeded the 0.05 ppm level, a concentration above which injury to vegetation may be expected (Manning and Feder,

1. Previously known as the Divisional Council of the Cape.

1976). In the greater Cape Town area SO_2 concentrations of 0.28 ppm are regularly recorded at certain sites, while levels of nitrogen oxides (NO_x) reach 0.3 to 0.4 ppm and O_3 levels of 0.10 to 0.15 ppm have been recorded at the city center (Ravenscroft, 1987; Dutkewicz, 1979). Depending on the duration of each episode, these levels most probably exceed the general threshold values for injury to plants.

The CSIR and ESCOM have both been leading parties involved in the study of air pollution levels in South Africa and its effects on the environment. Special credit is due to Dr. C.W. Louw, coordinator of the National Programme for Weather, Climate and atmosphere Research of the CSIR, for being a torch-bearer in this field. CSIR and ESCOM directed studies were mostly conducted in the Transvaal (Louw and Richards, 1977; Walker and Briggs, 1984; Zwi et al., 1987; Kelly, 1986; Engelbrecht, 1987). In the Cape Province, studies on air pollution levels occurring in Cape Town as well as studies on the effects of air pollution on human health and the environment have been conducted at the University of Cape Town since 1974 (Ashton, 1977; Dutkewicz et al. 1980; Von Schirnding, 1984; Loewenheim 1988).

1.3 Potential impact on vegetation:

Although pollution levels are monitored in some areas and various aspects concerning the nature and meteorology of air pollution in South Africa are being studied, much remains to be known about the extent of pollution and its impact on man and the environment. The need for basic research to assess the extent of ambient air pollution damage to indigenous and cultivated vegetation in South Africa had been emphasized during a workshop held in 1987 under the auspices of the CSIR (Tyson et al. 1988). Both the Transvaal and Western Cape metropolitan areas are surrounded by vast agricultural areas. The major agricultural crops produced in the Transvaal region are maize, sunflower (relatively sensitive to SO_2 and NO_x) and dry beans which are sensitive to SO_2, NO_x and O_3 (Tyson et al., 1988). Agriculture in the Western Cape comprises a variety of crops including deciduous fruit, grapes, wheat, tobacco and vegetables, all of which may be adversely affected by the pollutants in the area. South Africa is one of only six net food exporting countries in the world and South African food exports have become a lifeline for many sub-Saharan African countries (Bureau for information, 1987).

In addition to its major agricultural activities, southern Africa is endowed with a richness of indigenous species. There are high species/area ratios, many vegetation types and high levels of endemism, unequalled anywhere else in the world (Gibbs Russel, 1985). This richness is especially notable in the South Western Cape, where the Cape Floral Kingdom, one of the world's six Floristic Kingdoms, exists in less than 500 square kilometers (Good, 1964). Table Mountain, on which slopes the city of Cape Town nestles, supports over 1400 species of indigenous flowering plants. Agriculture, forestry and urban development has taken over about 60% of the Cape Floral Kingdom (Hall and Rycroft, 1979) and only isolated patches and narrow mountain corridors of natural vegetation remain. According to Morsbach (1983) only one per cent of the surface area of the Cape Province is being conserved in official nature reserves or national parks. Ninety percent of the plant species that became extinct in Southern Africa recently, were from the South Western Cape, while over a thousand species are in danger of extinction in this area (Hall, 1981). Unfortunately, the remnant natural areas are not excluded from air pollution, which can contribute to the further decline of vulnerable plant communities.

In addition to visible injury and reduced yield, air pollution can induce subtle changes in plants that may affect their reproductive and/or genetic systems, resulting in changes in plant populations and communities (Heck and Brandt, 1977). In this way air pollution, together with the manual destruction of plant populations, can lead to the impoverishment of significant evolution. The geneticist engaged in propagating higher-yielding cultivars may unknowingly assist nature in selecting the most pollution resistant species, not realising that air pollution resistance per se may be the major factor accounting for the higher yields (Gillette, 1984).

Certain plant species are very sensitive to specific pollutants and can be used to estimate the risk imposed by air pollution on agricultural and natural ecosystems. Indicator plants can provide information concerning the kinds of pollutants present, the concentrations of pollutants present and the biological effects of these pollutants. Although it is advisable to correlate data obtained with plants with instrument measurements, the latter are not always available. In addition to being very expensive, modern continuous measuring instruments are highly sensitive and delicate and not well suited for functioning in adverse weather conditions, unless environmental factors are controlled at great expense (Manning and Feder, 1980). The costs to import and maintain state of the art continuous monitoring instruments are prohibitive in South Africa. For example, it was estimated in 1987 that a single SO_2 continuous monitor will cost about R40 000 (Ravenscroft, 1987). In addition to the purchasing costs, funds would be needed to train and employ a technician responsible for the regular calibration and maintenance of these instruments. Advantages of using plants as bio-indicators to monitor pollutants are that they are less expensive than instruments, they require less maintenance and attendance and they can be used almost anywhere.

Research was initiated in 1985 to study the effects of air pollution on plants growing in the greater Cape Town area and the use of plants as bio-indicators and biomonitors of pollutants in this area. The research was conducted by the author under the auspices of the CSIR, at the University of the Western Cape (Bellville, South Africa) and the University of Stellenbosch (Stellenbosch, South Africa), under the leadership of Prof. J.H. Visser (University of Stellenbosch) and Dr. L.D. Moore (Virginia Polytechnic Institute and State University). The research project was funded by the CSIR, while some financial contributions were made by the University of the Western Cape, where the author was employed.

This study was the first major investigation into the use of plants as bio-indicators and biomonitors for air pollutants in South Africa. The study concentrated on the assessment of air pollution damage to plants in the Cape Town area, although surveys were also conducted in the eastern Transvaal to evaluate possible pollutant damage to pine plantations in that area. The research was based on experience gained during fumigation studies conducted previously at the Virginia Polytechnic Institute and State University. Visible injury symptoms and growth responses of well-known bio-indicator as well as various South African species, indigenous to the South Western Cape, were determined.

The specific objectives of this study were to:

1. Evaluate the occurrence of air pollution related visible injury symptoms on vegetation, in selected areas in South Africa, by means of field surveys.

2. Establish a network of biomonitoring stations at selected sites in the greater Cape Town area, as well as two additional stations in rural areas, in order to identify the occurrence of pollution as well as pollutant gradients.

3. Establish an Air Pollution Research Site at the University of the Western Cape, containing a biomonitoring station as well as filtered and unfiltered open-top chambers, in order to compare the response of plants grown in the biomonitoring stations with that of plants grown in filtered air at the same site.

4. Expose various bio-indicator species in the biomonitoring stations and open-top chambers over a 3 year period in order to identify phytotoxic air pollutants that might be present and to obtain some estimation of the air quality in the greater Cape Town

area. Summer growing and winter growing species were used, each sensitive to a specific pollutant or pollutants.

The effects of the major phytotoxic gaseous air pollutants were considered, including SO_2, O_3, and hydrogen fluoride (HF). However, it is realized that the vegetation in urban areas is subjected to complex mixtures of the mentioned gases, together with NO_x, hydrocarbons and minor pollutants such as chlorine, ammonia, ethylene and heavy metals.

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CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

Prior to 1940 the major recognized pollutants were particulate matter and sulphur dioxide (SO_2) in smoke (Kozlowski and Mudd, 1975). Since then man-made pollution has increased to such an extent that, in many regions, natural as well as man-made ecosystems can hardly tolerate the levels of environmental pollutants that are being released, including gases, particulates, agricultural chemicals, radioactive substances, industrial water pollutants, sewage and solid wastes. The polluting substances reduce the productivity of plants and animals, enter food chains of higher animals, corrode metals and building materials, and have marked effects on man's health and well-being (Kozlowski and Mudd, 1975).

In the last decade pollution related problems have increased and new problems have emerged. These include acidic deposition (acid rain), asbestos, carbon dioxide, nonionizing radiation and stratospheric ozone depletion (Urone, 1986).

2.1 Acidification and Air Pollution

Acidic deposition is considered as one of the most serious environmental problems facing industrialized countries today (Rhode and Herrera, 1988) and has received widespread attention among scientists (Toribara et al. 1980; Park, 1987) as well as industrialists and economists (Anonymous, 1983). To answer the question whether acidification is also a serious problem in other parts of the world, including the developing countries, SCOPE[1] launched a research programme in 1984, which resulted in the publication of the current understanding of the potential for acidification in Venezuela, Brazil, Nigeria, China and Australia (Rhode and Herrera, 1988). However, much work remains to be done to adequately assess the situation in these and other developing countries, including South Africa.

The term "acid rain" has been coined in our vocabulary and strongly appeals to the imagination, but is often used incorrectly to include all forms of precipitation (Heck et al. 1986). The term acidic deposition describes inputs of substances from the atmosphere to the earth which cause, or have potential to cause, increased acidity or associated effects (Whelpdale, 1983). Acidic deposition includes dry (including SO_2 and nitrogen dioxide (NO_2)), wet (acid rain) or bulk (combined) deposition (Whelpdale, 1983). Heck et al. (1986) preferred the term acidic precipitation which includes the transformed products $SO_4^{=}$ and NO_3^{-}, but not the gaseous forms SO_2 and NO_2.

Acid deposition results from SO_2 and oxides of nitrogen (NO_x) that are released when fuels such as oil or coal or many metal ores are burnt or heated. The primary pollutants

1. SCOPE is the 'Scientific Committee on Problems of the Environment' of the 'International Council of Scientific Unions (ICSU)' and of the 'United Nations Environment Programme (UNEP)'.

SO_2 and NO_x may be deposited as dry deposition or be further oxidized by various chemical routes to sulphuric and nitric acid. Nitrogen oxides, together with hydrocarbons that are released by vehicles and various industrial processes, under the influence of sunlight, lead to the formation of secondary pollutants such as ozone (O_3) and peroxyacyl nitrates (PAN). SO_2, O_3 and PAN are considered to be highly phytotoxic to plants, whereas combinations of these pollutants with NO_x may result in synergistic effects (Tingey et al. 1971; Dunning et al., 1970). Another major phytotoxic pollutant, hydrogen fluoride (HF), is commonly released by ceramic works, fertilizer factories, metal smelting processes and the burning of fossil fuels.

Particulates are released by many industrial processes including cement manufacturing, aluminium-reduction and the burning of fossil fuel. In themselves, particulates are regarded to be rather inert and have little consequences on plant health (Manning and Feder, 1980). Indirectly however, particulates may be detrimental to plant growth since dust particles can form nuclei onto which strong acids derived from emissions of HF, SO_2 and NO_2 may adhere. This acidic dust may either be washed out to form acidic rain or be dispersed and slowly fall to the earth and be deposited on plants, on the ground or in bodies of water as acid deposition. Dissolution of SO_2 can result in acidic particles which burn plant leaves (Lacasse and Treshow, 1976; Lerman and Darley, 1975). Particulate matter has been considered as the greatest air pollution problem in South Africa (Worswick, 1985). In addition to its potential effects on plant health, high incidences of particulate emissions can result in severe medical problems associated with respiratory disorders (Worswick, 1985; Goldsmith and Friberg, 1977).

The effects of wet deposition (acid rain) on vegetation appears to be largely indirect, although there are indications of increased erosion of cuticular waxes (Saunders, 1985). The reported death of trees in several countries appear to involve other factors such as the coincidence of flushes of acid rain (following periods of drought) with high concentrations of O_3 and other gaseous pollutants (Saunders, 1985). Although the full significance of acid precipitation to forest ecosystems remains to be defined, plant growth may be reduced by factors such as an imbalance in the availability of calcium, magnesium and potassium. These factors may have special significance in shallow soils that may already be acidic due to a conifer forest cover (Miller and McBride, 1975). In addition to the leaching of essential nutrients from the soil, aluminum may be mobilized, which has been shown to damage root systems (Hinrichsen, 1987).

On the other hand, some plant species are extremely sensitive to gaseous air pollutants (dry deposition) and exhibit typical symptoms of visible injury upon exposure. Except for carbon monoxide and some heavy metals, it is much easier to demonstrate the effects of gaseous air pollutants on plants than on animals and humans (Heggestad and Heck, 1971). The major gaseous air pollutants and their phytotoxic effects will be briefly discussed in this section.

2.2 Phytotoxic effects of the major gaseous air pollutants:

2.2.1 Ozone:

Background concentrations of O_3 range from 0.02 to 0.04 parts per million (ppm), whereas plants can be damaged by concentrations of 0.06 ppm. Concentrations of 0.15 to 0.25 ppm have been measured in many areas (Stephens, 1969). Peak concentrations of 0.5 to 0.7 ppm have been measured for one hour in California (Manning and Feder, 1980).

Presently, O_3 is believed to be the most important pollutant affecting vegetation in the United States, while it is also gaining credibility as a pollutant of primary concern in Europe (Heck et al., 1986). Ozone primarily injures the palisade parenchyma or the spongy parenchyma in leaves that lack palisade cells. The affected cells collapse and pigmentation of the cell walls may follow (Stern et al. 1973). Small, whitish to reddish-brown lesions (stipples) appear on the upper leaf surface. In cases of more acute injury these stipples may broaden to flecks and become bifacial, extending right through the leaf. Chlorotic mottling and increased pigmentation may also be observed, as well as premature senescence (Heggestad and Heck, 1971).

2.2.2 Sulphur dioxide:

Sulphur dioxide injury can occur at dosages ranging from 0.05 to 0.50 ppm for 8 hours of more (Manning and Feder, 1976). Sulphur dioxide is absorbed by the leaves and metabolized in the cells to HSO_3^- and $SO_4^=$. Low SO_2 concentrations can apparently be metabolized by the leaves without injury being observed. In the case of plants grown in a sulphur deficient soil, SO_2 even has a `fertilizing' effect. When a certain threshold concentration is exceeded, the sulphate ion ($SO_3^=$) which is a highly toxic intermediate of sulphate metabolism, accumulates and causes acute injury. Acute SO_2 injury is usually bifacial and interveinal with relatively large collapsed areas surrounding the larger veins which remain green. The mesophyll cells collapse, resulting initially in areas with dull green color or water-soaked appearance. On drying, the affected areas bleach to an ivory color. When sublethal SO_2 concentrations are absorbed, the toxic $SO_3^=$ is slowly metabolized to the less toxic sulphate ion ($SO_4^=$) and neutralized in the plant cells. The $SO_4^=$ ion may then accumulate in the cells in concentrations that are several times higher than that occurring in unexposed plants of the same species. With time these increased levels of sulphate may lead to chronic $SO_4^{=}$ injury which is usually observed as chlorosis of the leaves and early senescence (Heggestad and Heck, 1971; Stern et al., 1973; Lacasse and Treshow, 1976).

2.2.3 Nitrogen dioxide (NO_2) and nitric oxide (NO):

Nitrogen dioxide and NO have been studied as separate air pollutants, as well as combined pollutants referred to as NO_x, to include oxides of nitrogen in general. Higher concentrations of NO_x are usually needed to cause injury than for other pollutants such as O_3 and SO_2. On leaves of sensitive plants 1.0 ppm of NO_2 for 24 hours caused injury, whereas plants like peas, bushbean and alfalfa were found to be susceptible only to 6 ppm for 4 to 8 hours (Lacasse and Moroz, 1969). Oxides of nitrogen caused growth inhibition in tomato at levels between 0.4 and 0.8 ppm, whereas 0.4 ppm actually stimulated growth (Andersen and Mansfield, 1979). Manning and Feder (1980) also observed that low concentrations stimulated growth and that the plants appeared darker green in color.

2.2.4 Fluorides:

Atmospheric fluoride can occur either as a gas, particulates, or as gaseous fluoride adsorbed to other particulate matter. Gaseous HF is more toxic than particulate fluoride and has been studied most (Lacasse and Treshow, 1976).

Chronic HF injury may result in general chlorosis or chlorosis along leaf veins. Hydrogen fluoride accumulates along leaf margins and leaf tips and may lead to marginal necrosis that begins at leaf tips and progresses to leaf bases (Chang, 1975; Treshow, 1971). A list of higher plants and lichens which are known to be sensitive or resistant to atmospheric fluoride and which can effectively be used as biomonitors, is provided by Manning and Feder (1980).

Moisture stress, cold temperatures and the facultative parasite *Botrytis* may cause injury that resembles fluoride injury. The expression of visible fluoride injury symptoms should therefore be combined with fluoride analysis of leaf tissue. Under normal conditions, leaves of many plant species accumulate 0.05 to 0.10 ppm fluoride (Treshow and Pack, 1970).

2.2.5 Pollutant combinations:

Many air pollutant symptoms observed in the field are really due to a mixture of gases rather than just one pollutant. Mixtures of gases may affect the threshold level where plants become sensitive to one or both pollutants, causing more or less injury than either alone. Possible interactions can be additive, antagonistic or synergistic. With mixtures of O_3 and SO_2, greater than additive (synergistic) effects have been observed on alfalfa, broccoli, cabbage, onion, Pinto bean, radish, spinach, soybean, tobacco, tomato and White Pine (Reinert et al., 1975). Mixtures of SO_2 and NO_2 at concentrations below the injury thresholds for each, caused upper leaf surface flecking or pigmentation on oat, Pinto bean, radish, soybean, tobacco and tomato. On the lower leaf surfaces, silvering or reddish pigmentation occurred (Tingey et al., 1971; Dunning et al., 1970).

Concern for the effects of pollutant mixtures on vegetation has increased during the past decade (Lefohn and Ormrod, 1984; Reinert, 1984). While most studies still only involved combinations of SO_2 with O_3 (Heck et al. 1986), a few addressed the combined effects of SO_2, O_3 and NO_2 (Elkiey and Ormrod, 1980; Reinert and Sanders, 1982; Reinert et al., 1982; Kress et al., 1982). In a review of these studies, Heck et al. (1986) concluded that, in general, mixtures at concentrations below a level that would cause visible effects from single pollutants, tended to give a greater-than-additive (synergistic) response; concentrations at or slightly above levels that cause a threshold effect tended to produce an additive response; concentrations well above threshold levels tended to cause a less-than-additive (antagonistic) response.

2.3 Plants as bio-indicators and biomonitors

Because of the characteristic markings caused by some pollutants on the leaves of sensitive species, such species can be used as bio-indicators and biomonitors of air pollutants. Specific biomonitor species most generally used for the various pollutants, will be discussed in Chapter 3. The value of using plants as bio-indicators and bio-monitors of air pollution has been well documented (Manning and Feder, 1980; Posthumus, 1984). In most cases the use of plants as bio-indicators is based upon the development of characteristic foliar markings as a result of air pollution. In general these visible injury symptoms can be categorized as follows (Treshow, 1970):

1. Necrosis and bleaching of interveinal areas or leaf margins.
2. Glazing or silvering of leaf surface, particularly the undersurface.
3. Chlorosis.
4. Flecking or stippling on upper leaf surface.

It is recognized that poor water relations, mineral deficiencies, high winds, insects or other plant diseases could cause mimicking symptoms which resemble the typical visible injury symptoms caused by certain air pollutants.

These factors need to be taken into account when diagnosing pollutant injury from visible injury symptoms.

The effects of ambient air pollutants on plants can be studied by observing plants in the field or by distributing indicator plants in polluted and relatively unpolluted areas to form a biomonitoring network. Open-top chambers can be used, in addition to these methods, to provide a means whereby plants can be grown in unpolluted (charcoal filtered) air as well as ambient (unfiltered) air at the same location. Data obtained with open-top chamber experiments can thus be used to verify data obtained from biomonitoring networks and field surveys.

Guidelines for the successful conduction of field surveys were given by Heck and Brandt (1977) and Weinstein and McCune (1970). Plants may not only be used to indicate or detect the presence of a pollutant, but certain bio-indicators are also good biomonitors in the sense that information from them can be used to estimate the relative amounts of pollutants present. Many different plant species proved to be sensitive bio-indicators of air pollutants and have been used to monitor the biological effects of air pollutants on local (Van Raay, 1969), as well as regional and national scales (Floor and Posthumus, 1977). Practical guidelines for the use of certain species as bio-indicators and biomonitors were given by Manning and Feder (1980). The methodology to use filtered and unfiltered open-top chambers to study the effects of pollutants on plants growing in the field under as natural conditions as possible, was developed by Heagle et al. (1973) and Mandl et al. (1973) in parallel developments. Since then open-top chambers have been used widely in the United States and other countries (Kats et al., 1976; Olszyk et al., 1980; Buckenham et al., 1981; Weinstock et al., 1982; Roberts et al., 1983). The construction and maintenance of open-top chambers are more expensive than that of the biomonitoring network stations (transport costs excluded), but it is much less expensive than what state of the art continuous monitoring equipment would cost in South Africa. Open-top chambers can be used concurrently with a biomonitoring station to verify that symptoms observed in the biomonitoring station are due to air pollution per se.

The use of plants as bio-indicators and biomonitors not only provides information on the kinds and levels of air pollutants encountered in a given environment, but the aquisition of suitable data can eventually lead to predictions of agricultural losses (Heck et al., 1986). Agricultural losses are difficult to assess. O'Gara (1922) provided an equation to estimate loss due to SO_2, which was revised by Guderian, Haut and Stratman (1960). Annual losses for the United States have earlier been estimated at $200 million (Lacasse and Treshow, 1976), to $500 million (Hindawi, 1970). According to Heck et al. (1986), economic estimates made prior to 1980 provided some guidance for early policy decisions, but the calculations can not be regarded as economic studies. Linzon et al. (1984), using data form the National Crop Loss Assessment Network (NCLAN) (Heck et al., 1983), predicted an increase of $15 million per year in crop production in Ontario if the O_3 standard were set at 0.08 ppm for 1 hour. Whereas data are available to initiate preliminary estimates of crop losses from O_3, we have to rely on subjective estimates by trained investigators as far as losses due to other pollutants, or losses associated with forest productivity are concerned.

2.4 Research on Environmental Effects of Air Pollution in South Africa

A number of cases where air pollution has affected community health have been reported in South Africa. Differences in lead levels in blood (Grobler et al. 1984; Von Schirnding 1984) as well as lead levels in the deciduous teeth of children (Van Wyk and Grobler, 1983) were reported for different locations in the Cape Town area. In the Transvaal Coetzee et al. (1984) found that the lung functions of children in Sasolburg were inferior to that of children in surrounding country towns, while Zwi et al. (1987), found increased frequency of asthma in boys and chest colds in girls living in polluted areas in the Eastern

Transvaal Highveld.

Limited studies have been conducted in South Africa concerning the effects of air pollution on vegetation. Louw and Richards (1972) determined fluoride concentrations in sugar cane using an ion selective electrode. Engelbrecht and Louw (1973) investigated ultrastructural changes in sugar cane fumigated with HF. Their results indicated that the color changes that occurred during the development of injury symptoms (green through chlorotic and reddish-brown to dark brown), were due to a decrease in the internal chloroplast membranes and the destruction of chlorophyll followed by the formation and accumulation of yellow and red carotenoid pigments.

Bester (1976) determined the effects of NO_2 on the ultra structure of bean (Pinto 114) and corn (strain 432) plants. Fumigations were carried out in 2.5 liter perspex containers which were inverted over each test plant. The soil was covered with plastic to prevent absorption of the administered gas by the soil. Microsyringes were used to introduce 50 ppm to 100 ppm NO_2 at one hour intervals. Visible symptoms developed after 3 to 14 applications. Concomitant ultrastructural changes included a decrease in the size of chloroplasts and an increase of osmiophilic globuli (Bester, 1976).

Ashton (1977) determined the sensitivity of various South African plants to acute dosages of SO_2. Dosages ranging from 1 to 4 ppm were administered for 3 to 4 hours at a time. Young trees, shrubs and herbaceous species were fumigated in an exposure chamber at ambient conditions of temperature, light intensity and relative humidity. Among the families well represented in the South African flora, she found the Ericaceae to be resistant while the Proteaceae were sensitive to acute dosages of SO_2.

Walker and Briggs (1984) used vegetation in a study of the spatial distribution of trace elements in Pretoria, South Africa, while Wessels (1982) conducted a study in the city of Pretoria on the distribution of lichens occurring on tree bark. Phillips et al. (1985) studied the effects of simulated acid rain and sulphur nutrition on the growth, sulphate and cation content of Bromus diandrus Roth. As part of the Environmental Investigations programme of Electricity Supply Commission (ESCOM), Kelly (1986) conducted SO_2 fumigation experiments with Eucalyptus and Pinus species and Engelbrecht (1987) with a dry bean cultivar. The fumigation experiments by Kelly (1986) and Engelbrecht (1987) were conducted in two rectangular perspex chambers (1m x 1m x 2m), using 50 to 1000 ppb SO_2 and 50 to 3000 ppb SO_2 respectively.

Injury symptoms that might be ascribed to air pollution were recently observed at various locations in the Eastern Transvaal (Botha, 1988). According to Tyson et al. (1988) a substantial proportion of pine plantations in the Eastern

Transvaal Highveld are probably already at risk of toxicity because of acidity of the soil or imbalance in the calcium:aluminium ratio. Moreover, given the current and projected levels of atmospheric pollution from sources in the Eastern Transvaal Highveld, there is reason for concern about the long-term productivity of South African forests (Tyson et al., 1988).

Thompson (1984) commented on the possible effects of acid rain on soils in South Africa and concluded that acidification due to natural leaching by rainfall, and the application of nitrogenous fertilizers is much more serious than the possible contribution of mineral acid fall-out. The application of 100 kg/ha of elemental nitrogen per year is common practice in the crop producing areas of South Africa and causes soil acidification to the extent that regular applications of considerable amounts of agricultural lime are needed to counteract this effect (Thompson, 1984). Thompson (1984) further commented that atmospheric sources of sulphur are probably beneficial to plants in many agricultural areas in South Africa, since sulphur deficiencies may be expected on many of the soils derived from sandstones, granite and dolomite.

Reviews of numerous studies towards an understanding of the effects of air pollution on vegetation are available, especially concerning research in the northern hemisphere (Mudd and Kozlowski 1975; Unsworth and Ormrod 1982; Ulrich and Pankrath 1983; Treshow 1984; Nurnberg 1985; Winner et al. 1985). However, there are considerable gaps in our knowledge regarding the injury (or potential injury) to vegetation by air pollution levels encountered in southern hemisphere countries, including South Africa. Basic research programmes are needed to assess the situation in these countries. Moreover, special research is needed worldwide to determine the loss of ecosystem resilience, increased susceptibility to insects, pathogens and climatic stresses, as well as negative aesthetic values, factors that remain hard to quantify.

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CHAPTER 3

BIOMONITORING THE MAJOR GASEOUS AIR POLLUTANTS: THEIR EFFECTS ON BIO-INDICATOR AND INDIGENOUS PLANT SPECIES - A BRIEF REVIEW

3 BIOMONITORING THE MAJOR GASEOUS AIR POLLUTANTS: THEIR EFFECTS ON BIO-INDICATOR AND INDIGENOUS PLANT SPECIES - A BRIEF REVIEW

3.1 LITERATURE REVIEW

Many plant species have specific responses to certain air pollutants and can be used as indicators of those pollutants. In some cases these responses can be related to the actual concentration level of a pollutant that prevailed at the time of exposure and thus the plant can be used to monitor concentrations of pollutants. Some plant species have become classic biomonitors for certain air pollutants, for example the *Gladiolus* cv. 'Snow Princess' as biomonitor for fluoride. The use of plants as biomonitors for the major gaseous air pollutants will be reviewed briefly, followed by a discussion of experiments conducted to become familiar with the responses of some well known bio-indicators, as well as some native South African species.

3.1.1 Biomonitoring Ozone(O_3)

The following plant species are often used as bio-indicators and biomonitors of O_3:

3.1.1.1 Tobacco

Weather fleck disease of tobacco (Nicotiana tabacum) is a specific response to ambient O_3. The cultivars Bel-W3 (sensitive) and Bel-B (tolerant) can be comparatively used to estimate air quality. Feder (1978), Feder and Manning (1979) and Feder et al. Perkins (1975) demonstrated from field studies that a linear relationship exists between the degree of leaf injury and ambient O_3 concentrations. The degree of leaf injury on Bel-W3 can also be correlated directly with ambient O_3 concentrations (Menser et al. 1963; MacDowall, 1965).

A detailed discussion on the cultivar of tobacco plants in a charcoal filtered growth chamber (to remove oxidants and sulphur dioxide), care of the plants, their transfer to pots followed by their transfer to the test sites where they should be arranged in a grid system and properly watered, is given by Manning and Feder (1980). The test sites should be open to all wind directions. For pest control, it is recommended that the plants be sprayed with `Malathion' once a week, as it was shown that this chemical did not alter the sensitivity of the plants (Manning and Feder, 1980). Injury rating is done once a week.

3.1.1.2 Bean:

A number of cultivars of Phaseolus vulgaris L. are known to be very sensitive to O_3. Examples of injury rating systems for beans are given by Manning and Feder (1980). Cumulative readings are taken at three to five day intervals until the leaf falls. The plants are useful until the third trifoliate stage, after which it becomes difficult to keep track of the individual leaves. The cultivars 'Tempo' and 'Pinto III' have been used as O_3 biomonitors (Manning and Feder, 1980).

3.1.1.3 Grapes:

Being woody, perennial plants, grapes (*Vitis vinifera*) can be used at specific sites for many years. They also do not require shading as tobacco does. The quantity and sugar content of the harvest are both affected by O_3 and can yield additional data. The cultivars `Ives' (sensitive) and `Delaware' (tolerant) have the same sensitivity range as Bel-W3 and Bel-B tobacco (Manning and Feder, 1980).

3.1.1.4 Pine trees:

The use of trees as biomonitors can be helpful in areas where herbaceous and more delicate plants will be impractical. White Pine has been used as bio-indicator in several studies in the Eastern U.S.A. (Manning and Feder, 1980).

3.1.2 Biomonitoring Sulphur dioxide (SO_2)

Sulphur dioxide injury may be observed on plants near a point source, while chronic injury might occur further away. Data from such observations may be used to construct a map that reflects the extent of SO_2 present as well as the influence of prevailing winds and the topography (LeBlanc and De Sloover, 1970).

3.1.2.1 Spermatophytes:

Various indigenous and cultivated plant species have been used as bio-indicators for SO_2. Manning and Feder (1980) list several species which could be used during each particular season, e.g. Zinnia (*Zinnia elegans* Jacq.), blackberry (*Rubus* sp.) and apple (*Malus* sp.) in spring and early summer, pumpkin (*Cucurbita* sp.) and alfalfa (*Medicago sativa* L.) in summer and Eastern White Pine (*Pinus strobus* L.) in late summer.

3.1.2.2 Lichens:

Lichens are excellent bio-indicators for SO_2 and a simple and reliable system can be developed where pieces of lichens of known dimensions are set out at the test site. Growth rate data, color changes and sulphur content of the thallus are indicative of ambient SO_2 concentrations. Gilbert (1965) found the sulphur content in the thallus to be about three times higher with ambient SO_2 concentrations of 0.02 ppm than with 0.014 ppm. The only problem with the use of lichens as bio-indicators in this way is to obtain a regular and large enough supply of the same species of lichen, since they are very slow growing organisms.

Sulphur dioxide also has an indirect effect on lichens since it lowers the pH of tree bark on which the lichens grow. As tree bark acidity increases the acid sensitive lichens are eliminated first. Zones can be established which relate to the predominance of certain species or growth forms along transects. These zones can be correlated with ambient SO_2 concentrations measured in the same area and isopleth maps may be constructed from the data (Gilbert, 1970).

The advantages and disadvantages encountered when lichens are used as biomonitors are listed by Manning and Feder (1980). The most important advantage is that lichens are much more sensitive to low SO_2 concentrations than higher plants. The threshold level for SO_2 injury on lichens is 0.002 ppm (LeBlanc and Rao, 1973). Disadvantages are that lichens also accumulate fluoride and heavy metals which can contribute to symptom expression, that they do not respond quickly, and that specialized knowledge of lichens species is often needed. However, the advantages seem to outweigh the disadvantages and they have been used extensively as biomonitors for ambient SO_2.

Ideally data on symptom expression, chemical analyses and air monitoring data should be combined to determine the effect of SO_2 on vegetation. Standard chemical analyses can be used to determine total sulphur or sulphate in plant tissues (Lihnell, 1969; Van Raay, 1969). Limitations to the use of sulphur concentration in plant leaves as an indication of SO_2 injury were listed by Linzon et al. (1979):

1. Background levels within the plant tissues change with the season.
2. The normal sulphur concentration of the soil must be known.
3. The location of the SO_2 source must be known.
4. Instrument monitoring should be available.

Tree bark acidity can also be measured as an indirect indication of ambient SO_2 levels. High pH-values are indicative of low SO_2 concentrations and vice versa (Grodzinska, 1977; Johnson and Sochting, 1973). Rosenberg et al. (1979) studied species richness and diversity near a coal-burning plant and concluded that these were better indicators of the effects of SO_2 than were studies on individual trees.

3.1.3 Biomonitoring Nitrogen dioxide (NO_2) and Nitrogen oxides (NO_x):

Ambient concentrations of NO_x are usually too low to cause visible injury. There are no reliable or typical diagnostic symptoms or common bio-indicator plants for NO_x.

Acute NO_x injury may resemble acute SO_2 injury. A non-specific chlorosis may occur which is followed by premature leaf fall. Plant growth and dry weight may be reduced (Manning and Feder, 1980).

3.1.4 Biomonitoring Fluoride

Hydrogen fluoride accumulates along leaf margins and leaf tips and may lead to marginal necrosis that begins at leaf tips and progresses to leaf bases (Chang, 1975; Treshow, 1971). A list of higher plants and lichens which are known to be sensitive or resistant to atmospheric fluoride and which can effectively be used as biomonitors, is provided by Manning and Feder (1980). Moisture stress, cold temperatures and the facultative parasite *Botrytis* may cause injury that resembles fluoride injury. The expression of visible symptoms therefore should be combined with fluoride analysis of leaf tissue. A number of methods are available for the chemical analysis of fluoride in leaves (Adams, 1963; Cooke et al., 1976). The use of a fluoride ion-selective electrode, facilitates rapid, accurate determinations. Manning and Feder (1980) stress the importance of careful sample preparation and outline the correct procedure.

3.1.4.1 Gladiolus and Freesia:

Gladiolus (*Gladiolus hortulanus* Bailey) is the most widely used bio-indicator for fluoride. The bulbs as well as the leaves accumulate fluoride and Gladiolus plants are suitable to use as biomonitors for one season only. A fluoride sensitive variety e.g. `Snow Princess' should be used together with a fluoride resistant variety such as `Mansoer'. This comparison is of special importance when no other means of control is available. Manning and Feder (1980) discuss the procedures involved to grow and use Gladiolus plants as bio-indicators. Other important bio-indicators are Freesias (*Freesia hybrida* Hort.) (Van Raay, 1969) and lichens (Gilbert, 1973).

3.1.5 Biomonitoring Pollutant combinations

The influence of pollutant mixtures on vegetation started to receive attention from scientists during the past decade (Lefohn and Ormrod, 1984; Reinert, 1984). Most studies involved combinations of SO_2 with O_3 (Heck et al. 1986), while only a few studied the combined effects of SO_2, O_3 and NO_2 (Elkiey and Ormrod, 1980; Reinert and Sanders, 1982; Reinert et al., 1982; Kress et al., 1982). Plant species used during these studies included radish, marigold, turfgrass, sunflower and sycamore. However, there are no specific biomonitor species for pollutant combinations.

During research referred to in this chapter, plants were exposed to SO_2 and O_3 singly, as well as in combination with NO_2. At the start of the fumigation period, plants were exposed to SO_2 for two hours, followed by a mixture of SO_2, O_3 and NO_2 for another two hours, to simulate the daily build up of pollutants over urban atmospheres. Moderate concentration ranges, expected to be encountered under local conditions in Cape Town, were used.

The use of plants as bio-indicators and biomonitors not only provides information on the kinds and levels of air pollutants encountered in a given environment, but the aquisition of suitable data can eventually lead to predictions of agricultural losses (Heck et al., 1986).

3.2 FUMIGATION EXPERIMENTS

A number of South African cultivated and indigenous plant species were fumigated with known concentrations of gaseous pollutants in order to become familiar with symptom expression due to air pollution damage and to determine the sensitivity of certain South African plants towards SO_2 and O_3, as well as combinations of SO_2, O_3 and NO_2. Well-known indicator plants such as the petunia cultivar 'White Cascade' and sensitive soybean varieties were also fumigated.

Fumigation experiments were conducted at the Laboratory for Air Pollution Impact to Agriculture and Forestry, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, U.S.A. Prior to fumigation, seeds or cuttings of the appropriate species were propagated in a greenhouse in "clean" charcoal filtered air. Young plants were fumigated in the adjacent fumigation laboratory which contained 12 continuously stirred tank reactors (CSTRs) which are each 1 m in diameter x 1.5 m in height. Ambient air was drawn from outside the building, purified by a charcoal filter, forced through the CSTRs, and purified by filtration before release outside the building. The air stream leading to each CSTR was supplemented with a specific concentration of a pollutant or combination of pollutants. Inside the chambers relative humidity was maintained at 75-80%. The irradiance measured at plant height within the chambers was in the range of 400±20 $\mu E\ m^{-2}\ sec^{-1}$, obtained from sodium vapour lamps providing 400-700 nm photosynthetically active radiation. Chamber air temperature during periods of fumigation was 80-88 F (27-31 °C). Air was continuously sampled from each CSTR and a system of solenoid switches enabled the automatic switching of sample lines to O_3, NO_x and SO_2 continuous monitors, at 5 minute intervals. Pollutant concentrations measured within each CSTR chamber were recorded on chart dataloggers.

Seven CSTR chambers were used and the following concentrations were maintained within each chamber:

1. 0.05 ppm SO_2
2. 0.07 ppm O_3
3. 0.5 ppm SO_2
4. 0.16 ppm O_3
5. 0.05 ppm SO_2 + 0.07 ppm O_3 +0.4 ppm NO_2
6. 0.5 ppm SO_2 + 0.16 ppm O_3 + 1.0 ppm NO_2
7. Carbon filtered air (Control)

Plants were fumigated with the above pollutant concentrations for four hours per day for five consecutive days. In the case of the pollutant combinations (treatments 5 and 6), plants were fumigated with SO_2 for two hours, upon which O_3 and NO_2 were added for another two hours. Gases were administered in this sequence in order to simulate ambient conditions during which SO_2 concentrations would build up in the night and be high in the early morning, followed by O_3 and NO_2 that reach peak concentrations only later during the day. With the relatively low concentrations of SO_2, O_3 and combined pollutants (treatments 1, 2 and 5), little or no visible injury would be expected on plants. With the relatively high concentrations of pollutants (treatments 3, 4 and 6), typical visible injury symptoms were expected on sensitive plants.

The following cultivated and indigenous South African species were fumigated:

Cultivated species:

Phaseolus vulgaris (Green bean), cultivars: 'Provider', 'Seminole', 'Wintergreen' and 'Topcrop'.

Vigna unguiculata (a forage crop), cultivar: 'Saunders'.

Pelargonium hortorum (Geranium), cultivar: 'Red Express'.

Petunia hybrida cultivar: 'White Cascade'.

Nemesia sp. cultivar: 'Mosaic of Jewels'.

Indigenous species:

Arctotis hirsuta (Family: Compositae (Asteraceae)), orange and white varieties.

Arctotis fastuosa (Compositae)

Arctotis acaulis (Compositae)

Senecio elegans (Compositae)

Senecio glastifolius (Compositae)

Dimorphotheca pluvialis (Compositae)

Felicia echinata (Compositae)

Ursinia anthemoides (Compositae)

Sutherlandia frutescens (Leguminosae)

Lobelia valida (Lobeliaceae)

Leucadendron salignum (Proteaceae)

Dorotheantus bellidiformis (Aizoaceae)

Seeds of the indigenous species were obtained from the Kirstenbosch National Botanical Garden in Cape Town, and the species are mostly typical of the South Western Cape region. Many Pelargonium and Nemesia species, of which cultivated forms have been fumigated, are also indigenous to this area. Seeds of the Pelargonium, Petunia and Nemesia cultivars were obtained in the U.S.A., but these cultivars are also regularly planted in South Africa.

The growth media for the plants were either a 1:1:1 mixture of soil, peat and perlite to which 3 oz. (58 g) of osmocote (14-14-14) and 3 oz. of 4-9-3 fertilizer were added per cubic foot of soil or, in the case of soybeans and beans, a "Weblite" mixture consisting of a 2:2:1 mixture of Weblite[1], vermiculite and peat to which 1.5 oz. (29 g) lime, 1.5 oz. 4-9-3 fertilizer and 1.5 oz. osmocote (14-14-14) were added per cubic foot of Weblite.

3.2.1 Observations

3.2.1.1 The expression of macroscopically visible symptoms

Plants were rated according to the visible symptoms they expressed on the tenth day after the last fumigation. The

1. Weblite is the registered trade mark of an expanded shale product of Weblite Corp., Roanoke, VA.

manner in which visible injury was rated depended upon the species and how much leaf area per plant was affected. Whether to rate percentage injury on specific leaves or percentage injury per plant, was decided upon only after the symptoms developed and it became clear what rating system would be most descriptive. In the case of soybeans and beans an injury index of 1 to 5 was used. Symptoms varied from stippling on the upper leaf surface in the case of O_3 injury, to interveinal and marginal bleaching and chlorosis in the case of SO_2 injury, to glazing and bronzing of the lower leaf surface in the case of the pollutant combinations used. On species which they occurred, the latter symptoms resembled those typically described for PAN injury.

3.2.1.2 Growth Measurements

Before fumigation and on the tenth day after the last fumigation appropriate growth measurements, such as the width and length of specific leaves, stem length and stem diameter, were taken. Parameters such as total leaf area and dry weight of the shoot were also determined on the tenth day after the last fumigation.

3.2.1.3 Chlorophyll Content

For comparative purposes, and to evaluate injury quantitatively, chlorophyll analyses were performed on two basal injured leaves of each plant of *Senecio elegans* and

S. glastifolius, according to the method of Knudson et al. (1977).

3.2.2 Summary of Results

In this section the major results of a number of the fumigation experiments will be briefly reviewed to give an idea of the sensitivity of these plants towards air pollutants and the kinds of results obtained during the fumigation experiments. More attention will be paid to results obtained with S. elegans since, due to its abundance in the South Western Cape Province and the ease of cultivation, the most detailed investigations were conducted with this species. This species was also subsequently used in open-top chamber experiments conducted in South Africa.

S. elegans (vernacular name "wild cineraria" or "American groundsel"), is an erect herb and was one of the earliest South African plants to be cultivated overseas in 1700 (Smith, 1966).

S. elegans exhibited severe injury when fumigated with the high concentration of combined pollutants: the upper leaf surfaces were chlorotic with stippling and flecking, and the lower leaf surface chlorotic with heavily glazed areas (Figs. 3.1 & 3.2). Undersurface glazing and bronzing is typical of smog or peroxy acetyl nitrate (PAN) injury (Manning and Feder, 1980). Glazing was also observed on other species that received this treatment, for example on Lobelia valida (Figs. 3.5 & 3.6). S. elegans plants fumigated with 0.16 ppm O_3 exhibited typical white stippling on the upper leaf surface (Fig. 3.3). Leaves of plants that received the control treatment (charcoal filtered air), had no injury symptoms (Fig. 3.4).

In addition to the development of visible injury symptoms, the pollutant treatments affected the growth of S. elegans plants: The mean leaf areas of plants subjected to the high concentrations of SO_2 and O_3 as well as both pollutant combinations, were significantly smaller than that of control plants. It is of interest that the high SO_2 concentration treatment (0.5 ppm) had a marked effect on leaf area development, since the plants that received this treatment did not exhibit characteristic SO_2 injury symptoms, only slight chlorosis. Such physiological effects caused by air pollutants without the concomitant development of visible injury symptoms (foliar markings) are generally referred to as "hidden" injury (Kozlowski and Mudd, 1975).

Measurements on three leaves of each plant indicated that the high concentration of combined pollutants caused leaf elongation to be significantly less than in the case of control plants. The low concentrations of SO_2 and O_3 had a stimulating effect and caused the leaves of treated plants to elongate significantly more than that of control plants, while the high concentrations of SO_2 and O_3 had no

Figs. 3.1-3.6 Visible injury symptoms on *Senecio elegans* and *Lobelia valida* treated with various pollutant concentrations:

3.1 Stippling and purple pigmentation on the upper leaf surface of *S. elegans* treated with a mixture of 0.16 ppm O_3, 0.5 ppm SO_2 and 1 ppm NO_2.

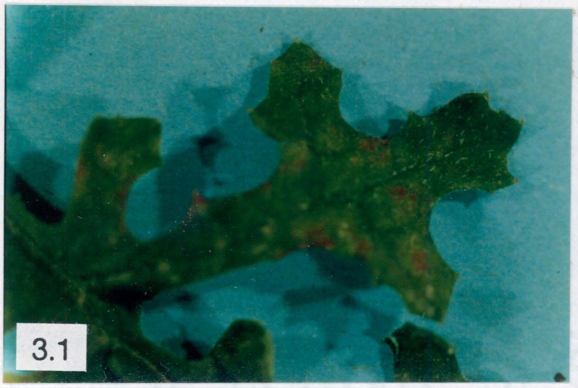
3.2 Glazing observed on the lower surface of the same leaf as in 3.1.

3.3 *S. elegans* plants fumigated with 0.16 ppm O_3 exhibited typical white to brown stippling on the upper leaf surface.

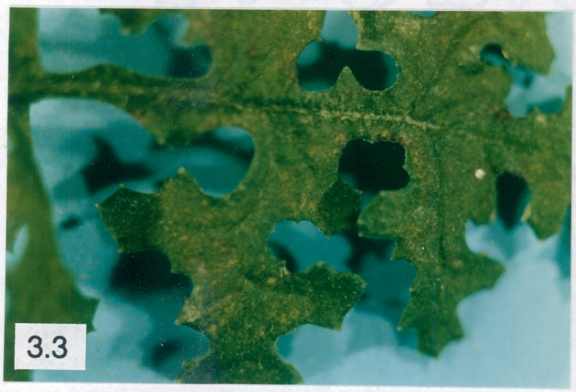
3.4 Control leaves of *S. elegans* exhibited no symptoms. Upper surface (close-up).

3.5 Upper leaf surfaces of *L. valida* treated with a mixture of 0.16 ppm O_3, 0.5 ppm SO_2 and 1 ppm NO_2, exhibiting bleaching and chlorosis of the leaf surfaces.

3.6 Lower surface glazing and bronzing that eventually resulted in bifacial necrosis on *L. valida* treated with a mixture of 0.16 ppm O_3, 0.5 ppm SO_2 and 1 ppm NO_2.


3.1


3.2


3.3


3.4

3.5

3.6

significant effect.

Results from chlorophyll analyses indicated that the chlorophyll content of plants subjected to the high concentration of SO_2 as well as the high concentration of combined pollutants, was significantly less than that of control plants. Although S. elegans is probably not among the species most sensitive to air pollutants, it is suggested that, because of the typical visible symptoms that developed, this species may be useful as a bio-indicator and provide information on the air quality if pollution levels of 0.16 ppm O_3 and pollutant combinations of 0.5 ppm SO_2, 0.16 ppm O_3 and 1 ppm NO_2 are approached.

Arctotis hirsuta, also a member of the Compositae, proved to be very sensitive to SO_2 (Fig. 3.7) and leaves exhibited severe interveinal bleaching when treated with 0.5 ppm SO_2 (Fig. 3.8). A. hirsuta was also sensitive to O_3 and developed characteristic white stipples on the upper leaf surface when exposed to O_3 (Figs. 3.9 & 3.10). The Nemesia cv. 'Mosaic of Jewels' was also highly sensitive to SO_2, as well as O_3 and pollutant combinations (Figs. 3.11 to 3.14). A well-known bio-indicator for SO_2, the Petunia cv. 'White Cascade', exhibited a range of symptoms which varied from chlorosis and slight marginal bleaching when fumigated with 0.05 ppm SO_2, to chlorosis, bleaching and early senescence when fumigated with 0.5 ppm SO_2 (Fig. 3.15 & 3.16). However, symptoms were not as severe as in the case of

Figs. 3.7-3.10 Visible injury symptoms on *Arctotis hirsuta* treated with SO_2 and O_3:

3.7 Chlorosis observed on the older leaves of *A. hirsuta* treated with 0.05 ppm SO_2 (chronic injury).

3.8 Typical interveinal bleaching of acute SO_2 injury *A. hirsuta*, caused by 0.5 ppm SO_2.

3.9 *A. hirsuta* was also sensitive to O_3 and developed characteristic white to brown stipples and flecking on the upper leaf surface when exposed to 0.16 ppm O_3.

3.10 Chlorotic stippling on a middle-aged leaf of *A. hirsuta* treated with 0.07 ppm O_3. Left = older, right = younger middle-aged leaves.

3.7

3.8

3.9

3.10

<u>Figs. 3.11-3.14</u> Visible injury symptoms on the *Nemesia* cultivar 'Mosaic of Jewels', treated with various pollutant concentrations:

3.11 The relatively low concentration treatment of 0.05 ppm SO^2 did not cause injury symptoms on *Nemesia* plants.

3.12 The relatively high concentration treatment of 0.5 ppm SO_2 caused severe interveinal bleaching.

3.13 *Nemesia* was also very sensitive to 0.16 ppm O_3, which caused characteristic white to brown stippling on the upper leaf surface.

3.14 The high concentration of combined pollutants (0.16 ppm O_3, 0.5 ppm SO_2 and 1 ppm NO_2) caused severe bleaching and chlorosis (plant on the right), while control plants exhibited no symptoms (e.g. plant on the left).


3.11


3.12


3.13


3.14

A. hirsuta and the Nemesia cultivar, in the sense that a smaller percentage of leaves on a plant was affected. Indications are that A. hirsuta and Nemesia should be further investigated for possible use as bio-indicators for SO_2. Fumigation experiments should also be performed in open-top chambers, to evaluate the susceptibility of these species to SO_2, under conditions closer to the ambient environment.

The green bean cultivars fumigated, exhibited typical O_3 injury. The cultivar 'Kentucky Wonder' was very sensitive and leaves developed substantial upper surface stippling when treated with the low concentration of 0.07 ppm O_3 (Figs. 3.17 & 3.18). The high concentration of combined pollutants caused chlorosis, flecking and stippling on the upper leaf surfaces of some cultivars (Fig. 3.19), but no undersurface glazing was observed. Control leaves exhibited no symptoms (Fig. 3.20). Only a few symptoms of SO_2 injury (small bleached areas) were observed on the cultivars 'Topcrop' and 'Kentucky Wonder'.

Experience obtained during the above mentioned experiments and during courses attended at Virginia Polytechnic Institute and State University, was used to evaluate air pollution injury symptoms on vegetation during field surveys and biomonitoring experiments conducted in South Africa. Detailed discussions of results obtained during the fumigation experiments are beyond the scope of this dissertation and will appear in publication.

<u>Figs. 3.15-3.20</u> Visible injury symptoms on *Petunia hybrida* cv. 'White Cascade' and several green bean (*Phaseolus vulgaris*) cultivars, treated with various pollutant concentrations:

3.15 *Petunia* exhibited chlorosis and slight marginal bleaching when fumigated with 0.05 ppm SO_2.

3.16 *Petunia* leaves developed chlorosis, bleaching and early senescence when fumigated with the higher concentration of 0.5 ppm SO_2. Leaves are arranged from old (left) to younger (right). The younger leaves appeared not to be affected by the SO_2 treatment.

3.17 The green bean cultivar 'Kentucky Wonder' was very sensitive to O_3 and leaves developed substantial upper surface stippling when treated with the low concentration of 0.07 ppm O_3.

3.18 The treatment of 0.16 ppm O_3 resulted in more severe symptoms of upper surface stippling and chlorosis on 'Kentucky Wonder' leaves.

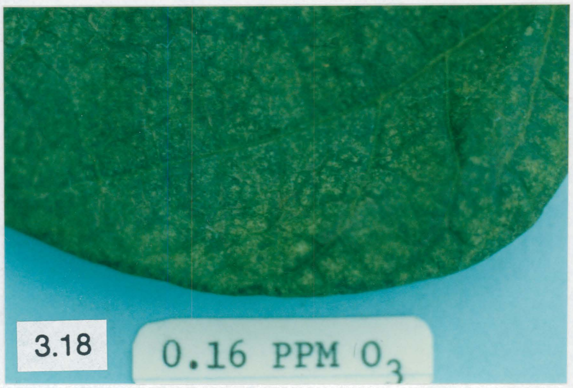
3.19 The high concentration of combined pollutants (0.16 ppm O_3, 0.5 ppm SO_2 and 1 ppm NO_2), caused severe chlorosis and mottled bleaching on the cultivar 'Wintergreen'.

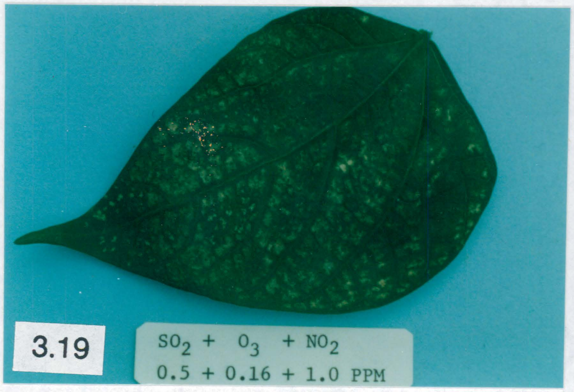
3.20 The control treatment (purified air), resulted in no symptoms, as indicated in this example of 'Kentucky Wonder'.


3.15


3.16
0.5 PPM SO_2


3.17
0.07 PPM O_3


3.18
0.16 PPM O_3


3.19
SO_2 + O_3 + NO_2
0.5 + 0.16 + 1.0 PPM


3.20

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CHAPTER 4

INJURY TO PLANTS UNDER AMBIENT CONDITIONS IN SOUTH AFRICA I: FIELD SURVEYS

4. INJURY TO PLANTS UNDER AMBIENT CONDITIONS IN SOUTH AFRICA I: FIELD SURVEYS

Field surveys of vegetation growing in possibly polluted areas provide a relatively simple and inexpensive means to assess air pollution damage to vegetation and to identify areas with relatively high pollution concentrations. Foliar symptoms (visible injury) caused by pollutants that accumulate in foliar tissue, such as sulphur oxides, fluorides and some salts, can often be correlated with results of chemical analyses of the vegetation (Heck and Brandt, 1977). When conducting a field survey the relative sensitivity of the vegetation should be taken into account, the foliar symptoms must correlate with wind direction and topography and a pollutant source must be in the area (Stern et al. 1973). Considerable caution must be exercised in defining an air pollution problem, since disease, insects, cultural conditions and other factors, singly or in combination, may produce foliar patterns similar to air pollution injury symptoms (Heck and Brandt, 1977). The sensitivity of a large number of plant species to 13 pollutants was listed by Stern et al. (1973), including plants native to many parts of the world. This list, together with photographic records such as the pictorial atlas of Jacobson and Hill (1970) may be valuable aids in the recognition of foliar injury symptoms caused by air pollutants. Weinstein and McCune (1970) provided detailed guidelines for the conduction of field surveys.

In areas where vegetation is not disturbed, field surveys can be used to develop data-bases over a number of years. In the Tamar valley of Tasmania, surveys of fluoride levels in vegetation have been conducted since 1957 (Lee, 1982). A program to monitor fluoride in the environment by collecting vegetation samples has also been conducted successfully for a number of years near an aluminium smelter in Frederick, Maryland, U.S.A. (Laurence, 1982). Field surveys involving sulphur dioxide (SO_2) date back to the nineteenth century (Thomas, 1951).

4.1 EVALUATION OF POSSIBLE FLUORIDE INJURY TO VEGETATION IN THE VICINITY OF AN INDUSTRIAL SITE NEAR CAPE TOWN

4.1.1 ABSTRACT

A field survey was conducted in the Table View and Bothasig residential areas north of Cape Town to assess damage to vegetation due to fluoride possibly emitted by two industries in the area. Visible symptoms were described for _Eucalyptus gomphocephala_ DC, _E. cladocalyx_ F. Muell., _Acacia saligna_ Wendl., and _A. cyclops_ A. Cunn ex G.Don. occurring at 12 different locations. Fluoride levels

measured in _Eucalyptus_ leaf samples corresponded well with visible injury symptoms. The highest fluoride concentration and injury symptom values were obtained in the proximity of the pollution sources and at sites in line with the sources and the predominant wind directions. However, in the case of the two _Acacia_ species, no clear relationship appeared to exist between the visible injury symptoms observed and the foliar fluoride concentrations determined. The _Acacia_ species also accumulated fluoride to a lesser extent than the _Eucalyptus_ species. General deterioration of vegetation around the two pollution sources was evident. Results suggest that airborne fluoride is a major pollutant emitted in the area.

OPSOMMING

'n Veldopname is in die Table View en Bothasig-omgewing noord van Kaapstad uitgevoer ten einde die beskadiging van plantegroei as gevolg van fluoried-emissies afkomstig van twee moontlike industriële besoedelingsbronne in die gebied te ondersoek. Die sigbare simptome van skade op die blare van *Eucalyptus gomphocephala* DC, *E. cladocalyx* F. Muell., *Acacia saligna* Wendl., en *A. cyclops* A. Cunn ex G.Don. is beskryf soos wat dit by 12 verskillende lokaliteite gevind is. Die hoeveelheid fluoried in die *Eucalyptus* blaarmonsters was in ooreenstemming met die hoeveelheid sigbare blaarskade en die ligging van die lokaliteite. Die hoogste waardes vir beide fluoried konsentrasie en sigbare skade is in die nabyheid van die besoedelingsbronne en in lyn met die besoedelingsbronne en die heersende windrigtings gevind. In die geval van die twee *Acacia* species het sigbare skade nie met die fluoried-inhoud van die fillodes ooreengestem nie. Fluoried het ook nie in dieselfde mate opgehoop in die geval van die *Acacia* species as in die *Eucalyptus* species nie. Die plantegroei in die omgewing van die twee besoedelingsbronne het merkbare tekens van agteruitgang getoon. Huidige resultate dui op fluoried as 'n belangrike atmosferiese besoedelstof in die gebied.

4.1.2 INTRODUCTION

Field surveys have a significant place in the assessment of air pollution problems and provide the most valuable means of periodically assessing the status of vegetation in areas of concern (Weinstein and McCune, 1970). If both the pollutant and its effect on vegetation are known, a field area can be examined for relatively few characteristic symptoms. Through a series of inferences involving factors such as tissue age, the site, the weather conditions and the history of the monitoring plant, the competent observer can reach conclusions regarding the nature of pollutants emitted in the area (Heck and Brandt, 1977). Fluoride accumulation in plant tissues has special significance since, depending on the species, even small increases in foliar fluoride content, can indicate fluoride air pollution problems (Heck and Brandt, 1977).

Gaseous hydrogen fluoride (HF) is probably the most phytotoxic air pollutant and affects plants at concentrations of 0.0001 ppm/h (Manning & Feder, 1980). When leaves absorb fluoride from the atmosphere, it dissolves in the aqueous phase and is transported acropetally and accumulates where the vascular system terminates. The initial visible injury symptoms usually consists of chlorosis or necrosis at the tips and margins of leaves. The degree and pattern of injury depend on the relative sensitivity of the plant species (MacLean, 1982). Long-term, low concentration exposures to HF result in chronic injury characterized by general chlorosis or chlorosis along leaf veins. Short term, high concentration exposures result in acute injury, characterized by tip and marginal necrosis that progress toward leaf bases (Manning & Feder, 1980). Even extremely low concentrations of fluoride can cause injury to plants (Hill, 1969), since it accumulates against any gradient in leaves. Fluoride can also be passed along food chains (Murray, 1981). The damage done to animals grazing vegetation high in fluoride content, is described by Suttie (1977). Most of the current knowledge of the effects of airborne fluoride on vegetation comes from studies of the more common cultivated varieties and some indigenous species of Europe and North America (Treshow, 1971; NAS, 1971; Chang, 1975). Considerable amounts of work have also been conducted in Australia (Murray, 1982), where vegetation types are similar to those in South Africa. However, very little work has been done on the effects of fluoride on vegetation in South Africa. Louw and Richards (1972) determined fluoride concentrations in sugar cane growing in Natal, while Matthee (1984) reported on fluoride damage to deciduous fruit species in an agricultural area south-east of Cape Town. Based on previous fumigation experiments involving various South African plant species (Chapter 3), it was planned to conduct a field survey in the vicinity of an industrial area north of Cape Town. The chosen area included two residential suburbs, Bothasig and Table View, which border on opposite sides of an industrial area containing a petroleum refinery and a fertilizer plant which are both potential sources of fluorides and nitrogen oxides (NO_x). Ground phosphate rock is treated with sulfuric acid in the manufacture of normal superphosphate fertilizer, a process in which both hydrofluoric acid and silicon tetrafluoride are formed (NAS, 1971). During petroleum refining HF is widely used as an alkylation catalyst for the production of high-octane gasolines. Volatile fluorides may be released during loading operations (eg. from hydrogen fluoride tank cars) and during waste disposal. Tar residues that liberate fluoride fumes on exposure to air are frequently produced (NAS, 1971). Sulphur dioxide and hydrogen sulfide (H_2S) are also characteristically emitted by petroleum refineries (Fox, 1986).

During a survey of vegetative species in the area, no symptoms of SO_2, ozone (O_3) or peroxy acetyl nitrate (PAN) induced injury were observed on plant leaves. However, symptoms typical of fluoride induced injury were observed on leaves of several species.

Topographically the area under investigation consists of low-lying flat land with the Durbanville hills, a ridge of low altitude, towards the east and north-east of Bothasig and Table View (Fig. 4.1). Table Mountain is situated

Fig. 4.1 Topography of the study area indicating low lying mountainous ridge towards the north-west and east. Photograph was taken from a point near site 11 (indicated on Fig. 4.2).


4.1

across Table Bay south of Table View. The area is approximately 1 km from the Atlantic Ocean on the western side (Fig. 4.2).

The predominant wind directions, recorded at D.F. Malan airport (approximately 25 km from the survey area), are south and south-south-east (SSE) in summer (December - February) and north-north-west (NNW) in winter (June - August). A wind rose for January (D.F. Malan airport data) is included in Fig. 4.2. Maximum wind speeds of 7.4 to 8.5 m/s (monthly mean) are obtained from the SSE in December and January and from the ESE in February. Similarly, maximum wind speeds in winter are 6.3 to 6.6 m/s in July and August and are obtained from the NNW (Weather Bureau, 1985). The wind speed and direction over the Cape Town and vicinity can vary considerably within as little as a five kilometer radius (Dutkewicz et al., 1980), which might influence the expected dispersion of plumes from pollutant sources.

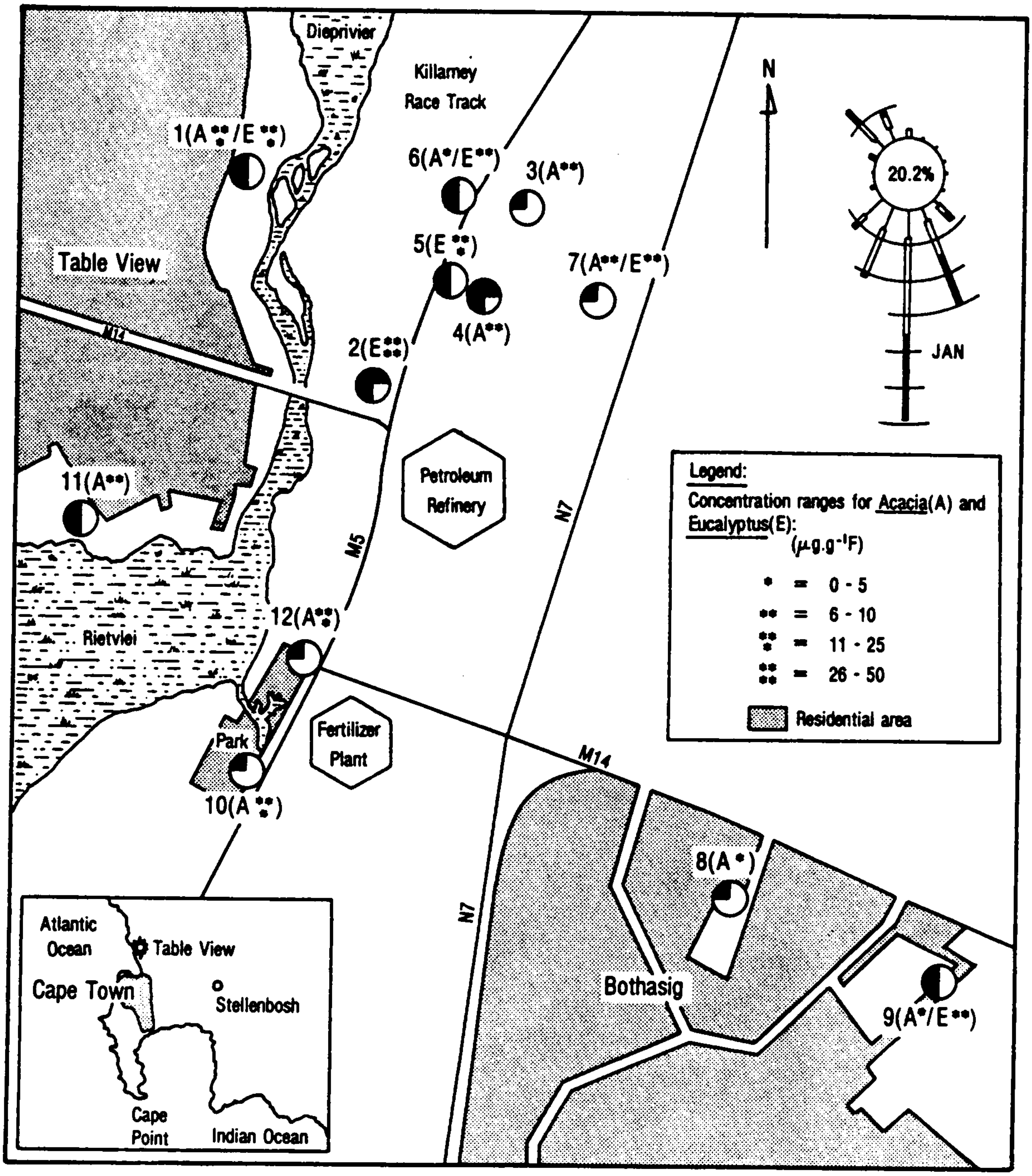
This paper reports a detailed survey to evaluate fluoride type injury in the vicinity of an industrial site near Cape Town. It provides an initial data base on vegetation growing under local concentrations of fluoride pollution.

4.1.3 PROCEDURE AND METHODS

4.1.3.1. Vegetation Monitoring:

A survey to determine the frequency of occurrence of

Fig. 4.2 Bothasig, Killarney and Table View sites at which leaf samples were collected. ◔ = little visible injury; ◐ = moderate visible injury; ◕ = severe visible injury. Site number and genus sampled are indicated e.g.: $9(A^{*}/E^{**})$ = site 9, *Acacia* and *Eucalyptus*; * refers to the concentration range, as depicted in the legend.



Dieprivier
Killarney
Race Track
N
20.2%
JAN
1(A/E)
6(A*/E**)
3(A**)
5(E)
7(A**/E**)
Table View
4(A**)
2(E)
M14
11(A**)
Petroleum
Refinery
N7
M5
Legend:
Concentration ranges for Acacia(A) and Eucalyptus(E):
(µg.g⁻¹F)
* = 0 - 5
** = 6 - 10
11 - 25
26 - 50
Residential area
12(A)
Rietvlei
Fertilizer
Plant
Park
10(A)
M14
8(A*)
N7
Atlantic
Ocean
Table View
Cape Town
Stellenbosh
Bothasig
9(A*/E**)
Cape
Point
Indian Ocean

plant species suitable for vegetation monitoring and sampling was conducted in the Bothasig, Killarney and Table View areas. Four evergreen tree species were identified on the basis of their accessibility, location with respect to the potential sources and suitability for the collection of leaf samples: Eucalyptus gomphocephala DC, E. cladocalyx F. Muell., Acacia cyclops A. Cunn ex G. Don and A. saligna Wendl.

These species were all introduced from Australia: the fast growing Eucalyptus trees for their wood and the Acacia species as a sand binder on the Cape Flats from where it spread. In addition to its cultivation in forestry plantations, Eucalyptus trees were often planted along roadsides or on farms for their shade and ornamental value. A. saligna proved to be an aggressive antagonist of the native flora and large sums of money have to be spent annually for its control and for clearance of building sites or for agricultural practices (Smith, 1966). Under normal conditions Eucalyptus and Acacia species thrive in South Africa.

Twelve different sites, indicated in Fig. 4.2, were selected where there were five or more individuals of one or more of the four species present. At each site the general condition of the trees and their foliage were evaluated (Table 4.1). A symptom severity rating (little = <25% ; moderate = 25-50% ; severe = >50%), was allocated to the vegetation at each site, considering the degree of leaf tip necrosis as well as the general condition of the trees. In addition the presence or absence of lichens or algae on tree trunks was recorded since they are very sensitive to HF.

4.1.3.2 <u>Chemical analysis of fluoride in leaf samples:</u>

Mature, middle-aged leaves were collected from five individuals of a selected species at each site. As far as possible leaves were collected from three or more points around each tree, to form one aggregated sample per tree. As detailed below, soluble unbound fluoride was measured in these samples by the Official First Action Potentiometric Method of the Association of Analytical Chemists (AOAC, 1980), which involves extraction with nitric acid and potassium hydroxide, followed by fluoride determination with a specific ion electrode.

<u>Preparation of vegetation samples:</u> Foliage was oven dried at 60 °C to constant weight and stored in plastic containers with silica gel until the samples could be milled. They were ground to pass a 40-mesh sieve (0.5 mm diameter) and stored in clean, dry, tightly closed plastic bottles over silica gel in larger plastic containers.

<u>Moisture determination:</u> Moisture determinations were carried out in duplicate on 0.3 g aliquots of plant tissue by drying them at 110 °C until constant weight (±0.003 g) was

obtained (Louw & Richards, 1972). Since the material available for some samples was relatively limited, composite reference samples, which consisted of a mixture of portions of samples from the same group, were used for the moisture determinations and also as a sample standard.

Fluoride determination: Aliquots of about 0.25-3.00 g were weighed to the nearest 0.005 and agitated on a rotating flask shaker, with the appropriate solvents as indicated by the AOAC method (1980). Prior to agitation, one drop of wetting agent (`Tween') was added to each sample (Jacobson & Heller, 1973). Together with each set of seven samples, one aliquot of the reference sample was analyzed to provide a sample standard. A `blank' sample was prepared in the same way, but without the leaf sample. The blank provided a check on the background reading which, upon completion of the procedure, should be 0.1 ppm fluoride.

Since some plant samples had relatively low levels of fluoride, the amounts of solvent used were correspondingly reduced so that a final volume 25 cm^3 was obtained. All solute reagents were stored in tightly closed, plastic bottles in the refrigerator. Solutions were allowed to reach room temperature before use.

A combined fluoride ion selective electrode (Orion, Model 96-09-00), together with an ionanalyzer (Radiometer ION85 or Crison Ionanalyzer) was used in the final step to determine fluoride concentrations in the leaf samples. Prior to each day's measurements, a drop of silicon oil was placed on the bottom of the electrode to decrease response time at low fluoride concentrations (Jacobson & Heller, 1973). Excess oil was carefully removed and it was ensured that no air bubbles were trapped on the electrode membrane when immersed in the sample. The calibration of the ionanalyzer was checked with standard solutions before and after each series of samples. Standard solutions of 0.1 and 0.2 ppm were freshly prepared as needed.

The electrode slope was checked daily and complied with the electrode specification of 57±2 mv per tenfold change in fluoride concentration. Temperatures at which analysis were performed varied between 16 and 26°C depending on ambient temperature, but did not vary by more than 1°C during the analysis of a series of samples.

The fluoride content of each sample was calculated as follows:

$$\text{ppm F } (\mu g.g^{-1}) = (C - 0.10) \times vol/w$$

where C = ppm fluoride reading from ionanalyzer;

0.10 = ppm background fluoride in final solution;

vol = volume of final solution (cm^3); and

w = sample mass (g).

4.1.4 RESULTS AND DISCUSSION

4.1.4.1 Visible Symptoms

Table 4.1 presents a summary of general conditions of the selected tree species at the twelve sites. The symptom severity rating as depicted in Fig. 4.2 and Table 4.1, is an indication of the general condition of the plants in the vicinity of the petroleum refinery and fertilizer plant. Plants in the vicinity of these two industries appeared not to be in a healthy state, especially those towards the north and north-west of the industries. Apart from the presence of spidermite on stressed individuals of _A. saligna_ at site 4 and gray dust at site 12, no other visible indication of stress, disease, insect infestations or symptoms typical of acute SO_2 or O_3 injury were noted. Symptoms were typical of that caused by fluoride (Figs. 4.3-4.9).

The presence of lichens on the trunks of monitored trees did not weigh heavily in determining the symptom severity index, since it is known that the occurrence and growth of lichens are very dependent on the microclimate of an area. Although trees monitored at sites 10, 11 and 12 had no lichens on their stems, numerous lichens occurred on a stand of trees in the moist area on the western side of the park (Fig. 4.2) as well as on stands of trees along the edge of the water toward the west of Rietvlei. Out of the 12 sites

Table 4.1. Symptoms which may be attributed to air pollution damage observed at 12 different sites in the Bothasig - Table View area.

Site no.	Species observed	Remarks	Symptom severity
1	*E. gomphocephala*:	Most leaf tips necrotic on 4 out of 5 trees.	Moderate
	A. cyclops:	Phyllode tip necrosis; Phyllode relatively small (2.5-3.0 cm long); Sampled trees had <1% lichens and 5-30% green algae on stems.	Moderate
2	*E. gomphocephala* and *E. cladocalyx*	Most leaf tips necrotic on all trees. 50% of trees in this area are dead or have dead branches.	Severe
3	*A. saligna*	Phyllodes slightly chlorotic; 2 spp. of lichens: 1-5% coverage on 4 out of 5 trees; 2 out of 5 trees have green algae on stems.	Little
4	*A. saligna*	Phyllodes very chlorotic with necrotic areas. Spidermite present. No lichens; Traces of green algae on stems. Tree trunks black on S.E. side, evidence of veld fire on this side some months before.	Severe
5	*E. gomphocephala*	Tip necrosis range from 20-60% of the leaf area.	Moderate
6	*A. cyclops*	Branches on S.E. side bare. Phyllode tips necrotic. Lichens: 1-5% coverage on 3 out of 5 trees. No algae.	Moderate
	E. gomphocephala	Leaf tips necrotic. Lichens: <1% coverage on 1 out 5 trees. Traces of green algae.	Moderate

Table 4.1 continued.........

7	E. gomphocephala	No lichens; algae range 1-50%	Little
	A. saligna	Lichens <1%; algae 20-40%	Little
8	A. saligna	No lichens; algae range from 10-80%; 1 out of 5 trees with intercostal necrotic areas on phyllodes.	Little
9	E. cladocalyx	No lichens; 50-80% algae. Necrotic leaf tips.	Moderate
	A. saligna	Phyllodes sparse, relatively small. Marginal chlorosis (younger phyllodes), tip necrosis (older phyllodes) on 2 out of 5 trees. No lichens; Algae 20-80%.	Moderate
10	A. saligna	Stand of 30 trees: 5 dead, 1 with numerous chlorotic phyllodes. Phyllode tip necrosis typical of fluoride injury absent. No lichens; Algae 20-80% on 2 out of 5 trees.	Little
11	A. saligna	Phyllodes sparse. No lichens; algae 5-30% on 3 out of 5 trees.	Moderate
12	A. saligna	No lichens; 1-30% algae on 4 out of 5 trees. Phyllodes covered with grey dust.	Little

<u>Figs. 4.3-4.4</u> <u>Eucalyptus</u> <u>gomphocephala</u> at site 1:

4.3 Branches are defoliated on the side most exposed to the pollutant sources.

4.4 Tip necrosis typical of fluoride injury were observed on leaves.

4.3

4.4

<u>Figs. 4.5-4.6</u> <u>Eucalyptus</u> <u>gomphocephala</u> at site 5:

4.5 General condition of trees: many branches defoliated.

4.6 Close up of trees to show extent of defoliation.

4.5

4.6

<u>Fig. 4.7-4.8</u> Injured and healthy leaves of <u>Eucalyptus gomphocephala</u>:

4.7 Injured leaves of <u>E</u>. <u>gomphocephala</u> at site 5. Tip necrosis ranged from 20-60 % of the leaf area.

4.8 A "healthy" leaf of a <u>E.</u> <u>gomphocephala</u> tree beyond site 6. The leaf was taken from the side of a tree distant to the sources of pollution.

4.7

4.8

Fig. 4.9 Acacia saligna at site 10. Some trees were dead, others had numerous chlorotic phyllodes, as in this example. Typical tip necrosis due to fluoride injury was absent.


4.9

surveyed, lichens were reported to be present at 4 sites only, with a maximum tree trunk coverage of 1-5 %. Perkins et al. (1980) found that exposures which cause accumulation of fluoride below 100 ppm in the lichen tissues, caused the community structure of the lichens to change with the demise of the more sensitive species.

In this study, no apparent relationship was found between the occurrence of algae on the trees monitored and the bearing of the sites, the fluoride content or the visible symptoms of vegetation.

4.1.4.2 Fluoride Content of Vegetation.

The mean fluoride content for the *Eucalyptus* and *Acacia* species sampled is given in Tables 4.2 and 4.3, respectively. Approximate distance and direction from the two potential sources as well as the visible symptom rating for each site is indicated.

In a review by Horning & Mitchell (1982) in which the relative sensitivity of Australian native plants were compared, *E. cladocalyx* was categorized as sensitive, whereas *E. gomphocephala* was categorized as relative tolerant to fluoride. If the response of both species at site 2 are considered, (Table 4.2), it is evident that the more sensitive species, *E. cladocalyx*, accumulated considerably more fluoride although both species exhibited severe fluoride type injury at the site.

Table 4.2 The leaf fluoride content of *Eucalyptus gomphocephala* and *E. cladocalyx* sampled at the various sites in relation to distance from potential fluoride sources and the occurrence of visible injury.

		Approx. distance and direction from site (km)				F content ($\mu g.g^{-1}$ DW)	
Species	Site no.	Re-finery	Ferti-lizer plant	Visible symptom rating	No. of trees sampled (n)	Mean ($\bar{x}$)	Standard error ($s/\sqrt{n}$)
E. cladocalyx	2	0.8SE	1.75S	Severe	4	50.11	±12.64
E. gomphocephala	2	0.8SE	1.75S	Severe	5	31.35	±6.81
E. gomphocephala	5	1.5S	2.4SSW	Moderate	5	16.11	±1.17
E. gomphocephala	7	1.5SW	2.5SSW	Little	5	10.09	±2.11
E. gomphocephala	6	1.9S	2.8SSW	Moderate	5	10.02	±1.47
E. gomphocephala	1	2.25SE	2.9SSE	Moderate	5	22.30	±1.87
E. cladocalyx	9	3.5NW	3.4WNW	Moderate	5	10.23	±3.48

Table 4.3 The fluoride content of phyllodes of *Acacia saligna* and *A. cyclops* sampled at the various sites in relation to distance from potential fluoride sources and the occurrence of visible injury.

Species	Site no.	Approx. distance and direction from site (km): Re-finery	Approx. distance and direction from site (km): Ferti-lizer plant	Visible symptom rating	No. of trees sampled (n)	F content ($\mu g.g^{-1}$ DW): Mean ($\bar{x}$)	F content ($\mu g.g^{-1}$ DW): Standard error ($s/\surd n$)
A. saligna	12	0.9NE	0.4SE	Little	4	23.34	±2.80
A. saligna	10	1.5NE	0.7ENE	Little	5	17.62	±2.39
*A. saligna**	4	1.5S	2.35SSW	Severe	6	6.77	±0.56
A. saligna	7	1.5SW	2.5SSW	Little	5	6.65	±0.87
A. saligna	11	1.8E	1.7SE	Moderate	4	10.18	±1.76
A. saligna	3	1.8SSW	2.8SSW	Little	5	10.18	±1.07
A. cyclops	6	1.9S	2.8SSW	Moderate	6	4.79	±0.51
A. cyclops	1	2.25SE	2.9SSE	Moderate	5	18.85	±3.55
A. saligna	8	2.35NW	2.25WNW	Little	5	3.67	±0.22
A. saligna	9	3.5NW	3.4WNW	Moderate	5	4.79	±0.58

* Severe injury symptoms probably related to previous veld fire.

For the Eucalyptus species observed, high levels of fluoride in the leaves corresponded to high visible injury ratings. In addition, this data corresponded well with the predominant wind directions and distance from the possible sources. The fluoride contents of samples collected at sites 1 and 9, which are furthest from the sources, were relatively high. However, these sites are located NW - NNW and SE - ESE, respectively, from the two sources, which are the directions in which maximum wind speeds are obtained during summer and winter respectively. The fluoride content of A. saligna and A. cyclops phyllode samples (Table 4.3) appear to be comparable, provided that the site locations and predominant wind directions are taken into account. Visible symptom expression appeared to be worse in the case of A. cyclops.

The visible symptoms observed for the two Acacia species did not correlate with the fluoride concentrations in their phyllodes. This suggests that these species may be relatively tolerant to fluoride, i.e. have a relative high threshold level for fluoride injury. This possibility is supported by the observation that although a number of dead trees as well as trees with chlorotic leaves were observed at sites 10 and 12 (close to the potential sources), the majority of trees exhibited little visible injury. In addition, the response of the phyllodes of Acacia species which have organs other than leaves adapted for photosynthesis, are probably not typical of the general response of broad-leaf species to air pollutants. In an assessment of the relative resistance of Australian native plants to fluoride, Horning & Mitchell (1982) categorized seven out of 15 Acacia species studied as tolerant, including Acacia saligna.

In spite of the high fluoride content of the phyllodes sampled at site 12, little visible injury was observed. The phyllodes were covered with a relatively thick layer of grey dust which could have been generated by activities at the fertilizer plant. Particulate fluoride contained in this dust probably contributed to the elevated fluoride concentrations measured for these samples. In general the Acacia species accumulated fluoride to a lesser extent than the Eucalyptus species studied.

Other phytotoxic pollutants that may be emitted by the petroleum refinery and the fertilizer plant include SO_2 hydrogen sulphide (H_2S) and lead. These pollutants possibly contributed, in part, to the visible injury observed on the Eucalyptus and Acacia species, although the typical symptoms of acute SO_2 injury (interveinal bleaching followed by necrosis), were not observed. General chlorosis was more readily observed on the Acacia species. With low doses of SO_2, sulphate ions accumulate in leaf tissue and cause chlorosis, growth inhibition and early senescence. Bennett et al. (1980) found that relatively low concentrations of H_2S caused growth inhibition in snap beans. Strong odors of

H_2S are often experienced towards the north-west (site 1) or the south-east (site 9) of the petroleum refinery.

O'Connor & Horsman (1982) conducted a field survey around a superphosphate works near Portland, Australia and found that foliar fluoride concentrations ranged from 13.9 to 57.6 $\mu g.g^{-1}$ in E. nitida and E. baxteri, and from 16.8 to 105.0 $\mu g.g^{-1}$ in various Acacia species, excluding the two species used in this study. (O'Connor & Horsman, 1982). These levels could constitute a hazard to grazing livestock. In order to protect animals the yearly average (monthly samples) fluoride content should not exceed 40 ppm dry mass (Suttie, 1977). Similar hazardous levels may possibly be found in forage in the Bothasig and Table View areas where fluoride levels up to 50.1 $\mu g.g^{-1}$ were measured in Eucalyptus samples. This may be important in view of the fact that the area north of Bothasig is used for agricultural practices, amongst others dairy farming.

O'Connor & Horsman (1982) considered a background fluoride concentration of 10 $\mu g.g^{-1}$ dry weight as appropriate for the species they sampled. Background concentrations for the species sampled during this study appear to be considerably lower, especially in the case of the Acacia species. More work is required to determine appropriate background concentrations applicable to the local situation. In contrast with the findings of O'Connor & Horsman (1982), that accumulation above background was confined to a 0.5 km radius from the source, this study indicated considerable accumulation for both Eucalyptus and Acacia at distances greater than 2 km from the sources.

As far as could be established ambient atmospheric fluoride has not been measured in the Bothasig - Table View area. Ambient SO_2 concentrations were monitored in the area by the petroleum refinery, utilizing `Casella' type monitors that measure 24 hour averages. Values recorded were reported to the Divisional Council of the Cape[1] and were found to be below the guidelines for acceptable air pollution levels of the Department of National Health and Population Control (Rossouw, 1988). A network of bubbler type monitors which measure total acidity of the air over 48 hour periods, is operated in the greater Cape Town area, coordinated by the Council for Scientific and Industrial Research (CSIR). An average yearly concentration of 18.5 $\mu g.m^{-3}$ SO_2 was reported for Edgemead (a suburb on the south-western side of Bothasig) in 1984. This value is well below the yearly average SO_2 guide line of 79 $\mu g.m^{-3}$ (Anonymous, 1987). Mobile units of the Cape Divisional Council and the Dept. of State Health containing continuous monitors for the measurement of SO_2, O_3 and (NO_x) in operation for several months in the suburbs of Edgemead and Table View since June 1985 and February 1986, respectively. During this time average values recorded at Edgemead by the continuous SO_2 monitor differed considerably from similar values recorded by the bubbler monitor. Unfortunately, problems were often experienced with some of the continuous monitors during these periods, resulting in incomplete records of pollution levels. Moreover, 24 or 48 hour averages, as obtained with the bubbler type monitors, fail to account for instantaneous pollutant peaks that might occur.

4.1.5 CONCLUSIONS

1. Field surveys and studies with bio-indicator plants can effectively be used in the greater Cape Town area to supplement information provided by the limited number of continuous monitors currently available in this area. Since ambient fluoride is not monitored, field surveys can be especially valuable to evaluate the impact of airborne fluoride levels on vegetation and the environment.

2. The *Eucalyptus* species used in this study proved to be good indicators of fluoride pollution and can be recommended for this purpose in areas where they occur.

3. *A. saligna* can not be recommended as an indicator species for fluoride. *A. cyclops* may prove to be a better indicator than *A. saligna*.

4. Leaf symptoms typical of fluoride injury, as well as a comparison of leaf fluoride content with the bearing of the monitoring sites and the predominant wind directions, pointed to airborne fluoride as a major pollutant emitted in this area.

Other species that are sensitive to airborne fluoride and which are commonly used as bio-indicators of fluoride pollution are members of the Iridaceae. Members of this family are indigenous to the South Western Cape and may occur abundantly in undisturbed areas. However, in urbanized and disturbed areas such as the one considered in this study, Iridaceous species are best placed out and maintained at chosen monitoring sites. Two members of this family, *Freesia* and *Gladiolus*, were subsequently used in biomonitoring network experiments (Chapter 6).

4.2 VISIBLE INJURY TO MANAGED PINE PLANTATIONS

4.2.1 DECLINE OF PINUS RADIATA AT TOKAI FORESTRY STATION, CAPE TOWN

The Tokai Forestry station is located on the eastern slopes of the Muizenberg, which is part of the Table Mountain range which extends in a north-south direction along the Cape Peninsula (Fig. 4.10). The area forms part of the southern suburbs of Cape Town and is exposed to potential urban and industrial pollution. A general survey of the Tokai Forestry station, to evaluate the possible involvement of air pollution as an abiotic pathogen, was conducted upon the request of the Director of Forest Research (Kruger, 1987), to investigate the unexplained dieback of stands of *Pinus radiata* trees that had been observed in the Tokai plantations. The results of this investigation, conducted by Dr. L.D. Moore (Virginia Polytechnic Institute and State University) and the author, on October 16, 1987, will be discussed in this section. These results were also presented as a concept report on the "Decline of *Pinus radiata* at Tokai Forestry Station, Cape Town" to the Director of Forest Research, Pretoria, South Africa.

During our investigation, we were accompanied and guided by Mr. R. Basson (Assistant Forester, Tokai Forestry

Fig. 4.10 A view of the Muizenberg (right), False Bay and the Hottentots-Holland mountain range (in the distance), as seen from the Tokai Forestry Station. Tokai is located on the eastern slopes of the Muizenberg, which is part of the Table Mountain range, which extends in a north-south direction along the Cape Peninsula.


4.10

Station), who is commended for his helpfulness and enthusiasm.

4.2.1.1. Visible Symptoms

A dieback of the tree tops of a significant number of trees amongst other healthy trees was observed in various stands ranging from low lying areas up to the higher slopes (Figs. 4.11 to 4.13). The greatest number of trees affected were between the ages of 8 and 25 years, although some older trees (30-40 years old) were also affected. Apparently the decline has developed gradually over the last four years (van Zyl, 1987) The dieback now appears to be widespread and except for the very young trees, most areas and most age groups of trees are affected.

Closer inspection of affected tree tops that were not yet dead, revealed what appeared as abnormal growth of the growing regions, with dwarfed needles and a thickening of the young shoots.

On a substantial number of trees, of which the tops were not defoliated, extensive dieback of the second year needles were observed all over the tree. These needles were either completely chlorotic or necrotic (Fig. 4.14).

4.2.1.2 Typical Air Pollution Injury Symptoms

No needle tip necrosis or chlorotic mottling, which are typical of injury due to gaseous air pollutants, were

Figs. 4.11-4.12 Decline of *Pinus radiata* observed at the Tokai Forest Station in October, 1987:

4.11 The bare terminal branches of affected trees are visible amongst other healthy trees within a stand (Photo: L.D. Moore).

4.12 Mature tree exhibiting sparse foliage and a less vigorant appearance.

4.11

4.12

Fig. 4.13 Decline of *Pinus radiata* observed at the Tokai Forest Station in October, 1987: Individual trees exhibiting decline, within a stand on the edge of the plantation, bordering a vineyard.


4.13

<u>Fig. 4.14</u> Extensive chlorosis and necrosis observed on needles of the second whorl from the growth tip (*Pinus radiata*).


4.14

observed on _Pinus radiata_ needles.

A member of the Iridaceae family (probably the genus _Aristea_), exhibited tip and marginal necrosis of the leaves (Fig. 4.15). Approximately 7 cm of the leaf tips were necrotic. These plants were growing close to a stand of older _Pinus radiata_ (approximately 40 years old) that exhibited decline. The symptoms observed on this _Aristea sp_. could be indicative of injury due to gaseous HF. However, if HF was the dominant air pollutant and phytotoxic concentrations were experienced, typical needle tip necrosis or necrotic bands across needles of _Pinus sp_. would have been expected to occur. No visible symptoms typical of fluoride injury was observed.

The nature of the forest decline observed, i.e. the die-back of certain trees amongst other healthy specimens, is typical of decline ascribed to acid rain and air pollution in the United States of America and Europe. The possible involvement of air pollution and acid rain in the present decline, can therefore not be totally excluded.

4.2.1.3. Air Quality

Two years prior to the present investigation, during the period June to October 1985, the State Health mobile air monitoring unit was stationed at Lakeside, approximately 5 km south-east of the Tokai Forestry Station. Levels of SO_2, O_3, nitrogen oxides (NO_x) and non-methane hydrocarbons

Fig. 4.15 A member of the Iridaceae (probably the genus *Aristea*) exhibiting tip and marginal necrosis of the leaves.


4.15

(NMHC), were continuously measured. The levels of pollutants measured during this period were fairly low and only exceeded the State Health Department acceptable levels in the case of O_3 and NMHC. The following values were obtained from a 1985 State Health Laboratory Report, Cape Town (Ravenscroft, 1987): the one hour peak value measured for NO_x was 676 $\mu g.m^{-3}$ (0.36 ppm). The Dept. of Health acceptable level for NO_x is 1504 $\mu g.m^{-3}$ (0.8 ppm) for one hour, according to the Department's 1988 air pollution guidelines. The one hour peak value measured for NMHC was 324 $\mu g.m^{-3}$ (0.5 ppm), compared to the Dept. of Health acceptable level of 260 $\mu g.m^{-3}$ (0.4 ppm) for one hour. The highest daily mean measured for O_3 was 72 $\mu g.m^{-3}$ (0.037 ppm), compared to the Dept. of Health acceptable level (1987 guidelines) of 60 $\mu g.m^{-3}$ (0.030 ppm). The Dept. of Health 24 hour acceptable level for O_3 was changed to 98 $\mu g.m_{-3}$ (0.05 ppm) in 1988 (Dept. of Health, 1988). These values were below levels that would generally be considered as phytotoxic. However, meteorological conditions as well as the topography at Lakeside are probably very different from that at the Tokai Forestry Station. In addition, it must be considered that the monitoring at Lakeside was carried out during the late winter to early spring, seasons that are generally regarded as the least polluted. The highest pollutant concentrations in the Cape Town area are usually recorded during March to July (Ravenscroft, 1987).

A recent study on the occurrence of photochemical smog in the greater Cape Town area was conducted at the University of Cape Town. The study concluded that levels of photochemical smog in Greater Cape Town are not high enough to constitute a significant air pollution problem and that the areas with higher photochemical smog potential, are predicted to be in the region of the northern suburbs (Loewenheim, 1988). However, continuous monitoring for an adequate period of time would be needed at a carefully selected site at the Tokai Forestry Station in order to address the question of whether phytotoxic pollutant levels do occur in the area.

4.2.1.4. Soil Factors

The dieback of young shoots of *Pinus radiata* was observed on soils that have been described by the foresters as "poor" as well as on soils that have been described as "rich". The symptoms observed are not typical of obvious nutrient deficiencies. A more homogeneous occurrence of symptoms such as general chlorosis would be expected on most trees in a stand if nutrient deficiency was suspected.

In a seriously affected stand, the remaining stumps of a previous planting were large in diameter, indicating that the trees were most likely healthy and grew to a considerable age. Since the present stand was only the second planting, it is doubtful that the soil would already be naturally depleted.

4.2.1.5. Biotic Pathogens

Biotic pathogens were dismissed as a cause of the observed decline by Wingfield (1987). According to Wingfield (1987), the organisms observed on affected trees were species that typically infect stressed trees or tissue that is already dead. No biotic pathogens were isolated that could have caused the tree decline.

Basson (1987) reported needle loss due to feeding by the insect *Pachyonix affaber*. This injury was of a mechanical nature and could easily be distinguished from any typical symptoms that would be due to air pollution. *Pachyonix affaber* only affected very young trees.

We do not know of any investigations into mycorrhizal root associations of *Pinus sp.* in the area, neither of investigations into possible root pathogens that may be associated with the tree decline observed. These factors should be investigated in order to help clarify the problem.

4.2.1.6. Possible involvement of growth regulators

A *Eucalyptus* tree, which was previously assumed to be dead, unexpectedly produced leaves on a few terminal branches. The leaves were small and clustered along the branches and were reminiscent of abnormal growth that could be due to the application of growth regulators. The typical decline symptoms as described in par. 4.2.1.1 were also observed in a *Pinus radiata* stand, close to the border between the forest station and a vineyard. It was suggested that the use of growth regulators in the neighboring vineyards be investigated and their possible effects on *Pinus radiata* be determined.

During a subsequent visit to the Tokai Forestry Station in November 1987, growth abnormalities on the young shoots of *Pinus* and young *Eucalyptus* trees, were observed to be even more pronounced than before. Typically the tips of *Pinus* shoots or young branches were thickened, with short, stout needles developing abnormally in these regions. The terminal parts of young *Eucalyptus* shoots appeared flattened and exhibited a fasciation type growth. Examples of affected *Pinus* and *Eucalyptus* shoots were presented to Mr. J. Loubscher of the Elsenburg Agricultural College near Stellenbosch. Mr. Loubscher did not ascribe the atypical growth observed to the application of growth regulators. In his opinion the leaves would be affected first if the symptoms were due to growth regulators. In the case of *Eucalyptus*, for example, fasciated fan shaped leaves would be typical. The question was raised whether the decline and / or growth abnormalities could have been caused by a virus infection.

4.2.1.7 Conclusions

1. Dieback of the young shoots of *Pinus radiata* appears to be widespread in the Tokai Forest Station and of a serious nature. The occurrence of second year needle fall should be further investigated to determine its extent and whether it is connected to the dieback of young shoots on mature trees.

2. No visible injury symptoms typical of gaseous air pollutant injury were observed. This does not exclude the possible involvement of acid rain or photochemical smog in causing or contributing to the decline. The typical visible injury symptoms on *Pinus sp*. of one of the major components of photochemical smog, peroxy acetyl nitrate (PAN) and of the peroxacyl nitrates in general, are not known (Manning and Feder, 1980). The effects of acid rain (acidic precipitation) on forest ecosystems are largely indirect (Ulrich and Pankrath, 1983) and further studies will be required to determine whether acid rain could potentially contribute to the decline of *Pinus radiata* at Tokai.

3. Further investigations are needed to evaluate the occurrence of similar symptoms in neighboring and/or other areas. Van Zyl (1987) reported that similar symptoms

were observed at the La Motte Forestry Station near Franschhoek, which is approximately 80 km from Cape Town.

During a third visit to the Tokai Forestry Station in 1988, attention was paid to tip burn (leaf scorch) of young *Pinus radiata* trees that grew on an exposed mountainous ridge. As this tip burn could typically be caused by either atmospheric fluoride pollution, heat stress or drought stress, the author recommended that needle samples be chemically analyzed for fluoride. Strong, desiccating southeastern winds were experienced in the area earlier in the year, accompanied by high temperatures (February-March, 1988). These weather conditions could either be solely responsible for the tip burn observed, or the winds could have transported pollutants from a fertilizer factory and explosives plants located on the False Bay coast, southeast of Tokai. During this visit, the general decline of *Pinus radiata* at the Tokai Forestry Station appeared to have continued as before, and the matter still needs to be resolved.

4.2.2 FOREST DECLINE IN MANAGED PINE PLANTATIONS IN THE EASTERN TRANSVAAL

4.2.2.1 Introduction

The eastern part of the Transvaal Province of South Africa contains over 50 % of the country's 3.1 million hectares of high-potential agricultural land and half of its forest resources (Tyson et al., 1988). The area also contains a network of coal fired power stations which provides about 60 % of all the electricity used on the continent of Africa (Fig. 4.16). Most of these power stations are located on the Eastern Transvaal Highveld (plateaux region) in an area only 100 by 200 km in extent (Lloyd, 1987). There is sufficient evidence to believe that the release of noxious gases and fly-ash from these power stations, as well as emissions from various smaller industries, smouldering discard coal dumps, domestic combustion and motor vehicles in the region, probably have a very negative impact on the environment. The rates of atmospheric pollutant deposition, as well as rainfall acidity, were determined to be higher than normal through much of the region (Tyson et al., 1988).

The potential for adverse air pollution impacts on agricultural crops in the Eastern Transvaal Highveld was investigated by researchers of the Electricity Supply Commission

<u>Fig. 4.16</u> Typical topography of the Eastern Transvaal Highveld. One of the many power stations located in this area, can be seen in the distance.

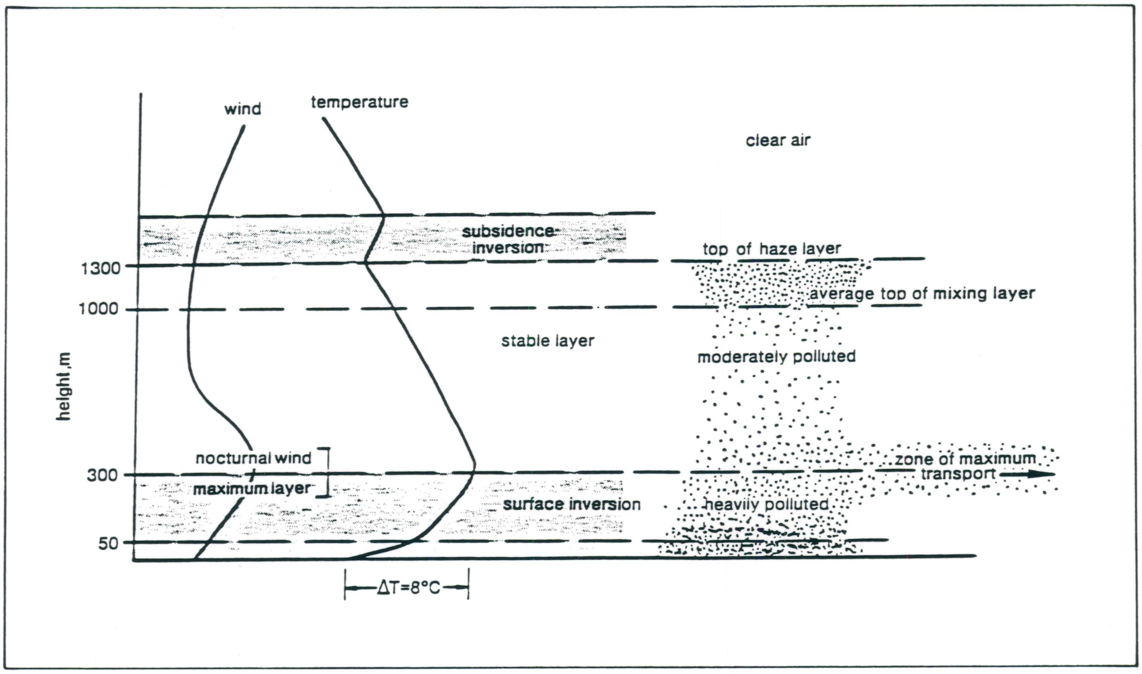
4.16

(ESCOM) (Engelbrecht, 1987b). The major crop produced in the area, maize, was expected to be tolerant to ambient SO_2 and NO_x levels. The second most important crop, sunflower, was regarded as sensitive to SO_2 and NO_x and tolerant to O_3. The dry bean crop was regarded as relatively sensitive to SO_2, NO_x and O_3 (Engelbrecht, 1987b).

4.2.2.2 <u>Meteorology:</u>

Meteorological conditions in the Eastern Transvaal Highveld region strongly favour the accumulation of air pollutants. Pollution is often trapped in a low level surface inversion above which a relatively non-turbulent low level wind maximum is observed. Pollution reaching this level may be transported horizontally over great distances. Above this zone of maximum transport pollutants mix to some extent, but is not able to rise further than the subsidence inversion (Fig. 4.17). No plumes have been reported to penetrate the subsidence inversion, nor is it likely to happen in the future. The conditions for plume dispersion over the Eastern Transvaal Highveld region are thus highly adverse (Tyson et al., 1988). Episodes of heavy fog, especially in the early morning, are regularly observed over the highveld and escarpment regions.

<u>Fig. 4.17</u> Mean winter temperature and wind profiles for the ETH and the major pollution accumulation layers. (From Tyson et al., 1988 Fig. 30, p. 33)


wind
temperature
clear air
subsidence inversion
top of haze layer
1300
1000
average top of mixing layer
stable layer
moderately polluted
height, m
nocturnal wind maximum layer
300
zone of maximum transport
surface inversion
heavily polluted
50
ΔT=8°C

4.2.2.3 Pollution Levels

The acidity of rainfall sampled in the Eastern Transvaal Highveld region resembles that of regions in North America and Europe where problems of fish population decrease and forest decline have been experienced. Average pH levels of 3.9 to 4.8 were recorded in the Eastern Transvaal Highveld region. In the Vaaldam catchment area (Topfontein) and the forestry plantations at Sabie, the critical limit of 20 kg of sulphate $ha^{-1}.yr^{-1}$ in wet deposition, as suggested in Canada for the protection for sensitive aquatic ecosystems, had been exceeded. Sulphur dioxide emission densities observed in the Eastern Transvaal Highveld are comparable with those of some of the large industrial areas of the world. Ozone concentrations appear to be within acceptable limits (Tyson et al., 1988).

4.2.2.4 Field Surveys

Visible injury symptoms, that may be associated with air pollution injury, were first observed on needles of *Pinus sp*. growing in plantations in the Eastern Transvaal Highveld and escarpment region in October, 1987 (Wessels, 1988). Subsequent field surveys, in which the author participated, were initiated by Dr. C.W. Louw of the CSIR, Pretoria, to investigate the occurrence and distribution of the injury symptoms. The surveys were conducted in November 1987 and February 1988, followed by a workshop to address the problem in February 1988. Results of these surveys were respectively reported to the CSIR in January 1988 (Botha, 1988) and to the South African Forestry Research Institute, Pretoria, in April 1988 (Baines, 1988). The results of these investigations and field surveys will be briefly discussed in this section.

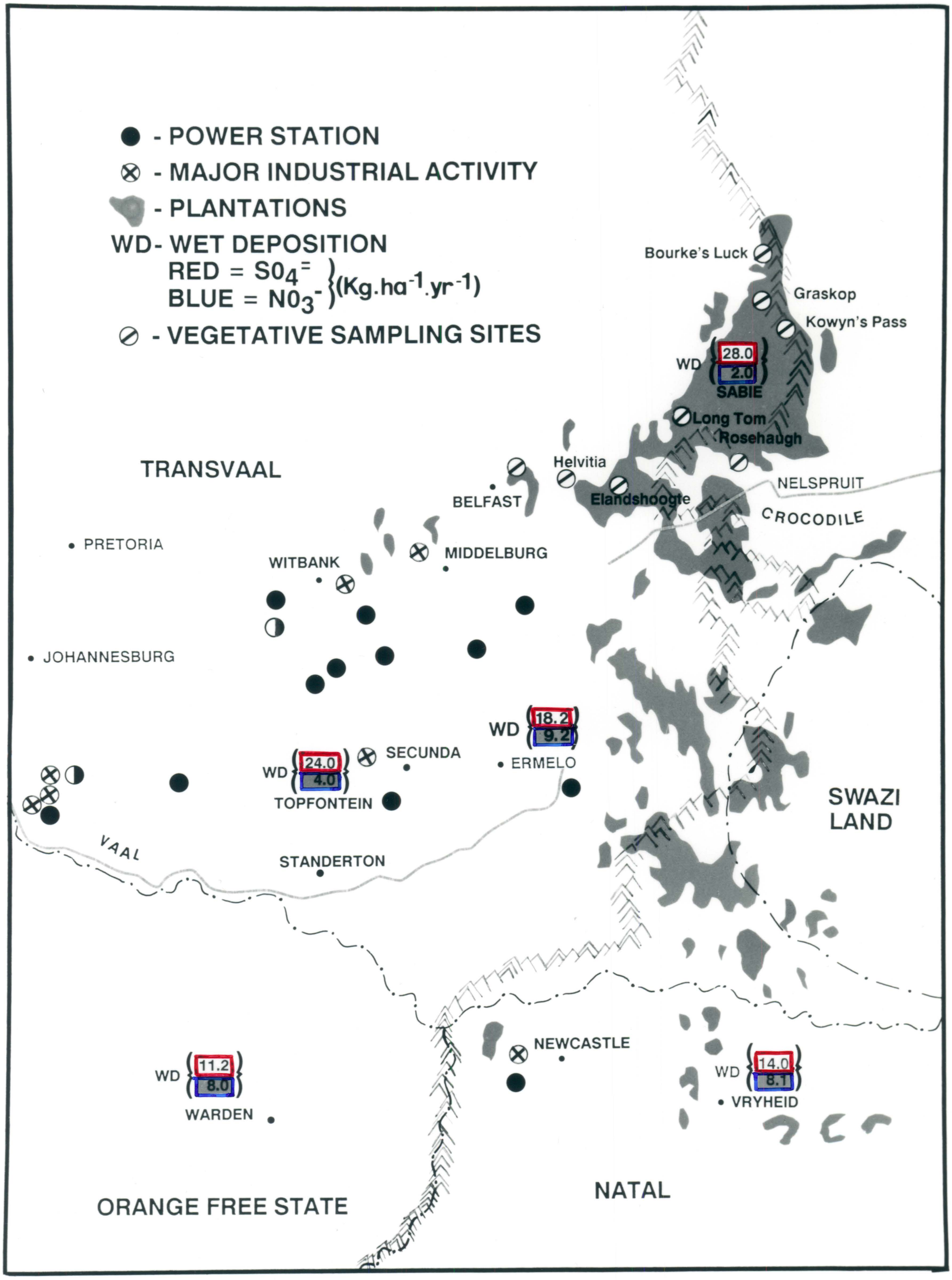
A map of the Eastern Transvaal Highveld and escarpment regions, showing the escarpment, afforested areas, potential sources of pollution and sites visited to evaluate possible air pollution injury on pine trees, is presented in Fig. 4.18. Mean levels of $SO_4^{=}$ and NO_3^{-} measured during 1985/86 are indicated at selected wet deposition sampling stations (Tyson et al., 1988). An example of the typical topography of the Eastern Transvaal Lowveld region (i.e. the area below the escarpment), is presented in Fig. 4.19.

4.2.2.4.1 Visible Injury symptoms:

Both the field surveys conducted in November 1987 and February 1988, revealed that substantial damage occurred consistently on the foliage of *Pinus sp*. over a large area. Similar symptoms were observed in plantations on the escarpment (Eastern Transvaal Highveld), as in the Lowveld near Sabie.

The predominant symptoms observed during the survey

<u>Fig. 4.18</u> A map of the Eastern Transvaal Highveld and escarpment regions, showing the afforested areas, sources of pollution and sites visited (⊘) to evaluate possible air pollution injury on pine trees. Mean levels of $SO_4^=$ and NO_3^- measured during 1985/86 are indicated at selected wet deposition sampling stations.



- POWER STATION
- MAJOR INDUSTRIAL ACTIVITY
- PLANTATIONS
WD- WET DEPOSITION
RED = $SO_4^{=}$
BLUE = NO_3^{-}
($Kg.ha^{-1}.yr^{-1}$)
- VEGETATIVE SAMPLING SITES
Bourke's Luck
Graskop
Kowyn's Pass
WD 28.0 2.0
SABIE
Long Tom
Rosehaugh
Helvitia
Elandshoogte
NELSPRUIT
CROCODILE
TRANSVAAL
BELFAST
PRETORIA
WITBANK
MIDDELBURG
JOHANNESBURG
WD 18.2 9.2
ERMELO
WD 24.0 4.0
SECUNDA
TOPFONTEIN
VAAL
STANDERTON
SWAZI LAND
NEWCASTLE
WD 11.2 8.0
WARDEN
WD 14.0 8.1
VRYHEID
NATAL
ORANGE FREE STATE

Fig. 4.19 Typical topography of the Eastern Transvaal Lowveld region in the vicinity of the Elandshoogte Forest Station. A kraft mill is visible in the valley, November, 1987.

4.19

conducted in November 1987, were chlorotic and necrotic mottling, often associated with uniform tip chlorosis or tip necrosis (tipburn). Chlorotic individuals of pine trees could be distinguished among healthy individuals in plantation stands (Fig. 4.20). The degree of injury ranged from little injury on P. taeda and P. eliottii, to medium and severe injury on P. patula. Necrotic tip burn on needles of Pinus patula ranged from one to six centimeters (6 cm equalled approximately 40 % of the needle length). In some cases a chlorotic band of about 2-10 cm wide was observed on the distal parts of the needles. Chlorotic bands of this nature in time usually become necrotic and result in the typical symptom of tip burn. Chlorotic and necrotic mottling of the needles, which were associated with the tip burn, were common. On some individuals numerous chlorotic bands ranging in width from about 1-4 mm could be distinguished across needles, leading to an excessively mottled appearance. This type of severe injury, which affected 50% or more of the leaf area, was observed on a substantial number of individuals over a widespread area. On Pinus taeda and P. eliottii small chlorotic bands (1-2 mm wide) were also distinguished on the needles, but these were sparse. On some P. taeda trees general chlorosis which affected 50% or more of the distal parts of the needle area was observed. Visible injury symptoms were observed at all the vegetation sampling sites indicated in Fig. 4.18, distributed over an

<u>Fig. 4.20</u> Pine plantations with interspersed chlorotic individuals in the Sabie area, Eastern Transvaal escarpment region, November, 1987 (Photo: D. Wessels).


4.20

area of approximately 6300 km^2. The most severe injury symptoms were observed on Pinus patula at Rosehaugh, Graskop, Goedgeloof Plantation (Bourke's Luck), Long Tom Pass and a private plantation near Bambi. Little visible injury was observed on the needles of P. taeda at Rosehaugh and at the bottom of Kowyn's pass as well as on the needles of P. eliottii at Rosehaugh. Examples of the symptoms observed, are presented in Figs. 4.21 to 4.29.

During the investigation conducted in February 1988, similar symptoms were observed as during November 1987, but it was determined that the severity of symptom expression was closely related to the seasonal growth cycle of the species concerned. At a particular site (Helvetia), injury on P. eliottii were found to be much more severe than on P. patula which, since November 1987, had produced a second flush of new growth. Examples of injury observed during February 1988, are presented in Figs. 4.30 to 4.33.

4.2.2.4.2 Biotic pathogens

Plant samples were examined extensively by several plant pathologists in South Africa and abroad (S.A. Alexander at the Virginia Polytechnic Institute and State University), but no biotic agents isolated proved responsible for the symptoms observed (Wessels, 1988).

Fig. 4.21-4.22 Visible injury symptoms observed on pine needles at Rosehaugh Forest Station, Eastern Transvaal, November 1987:

4.21 Sparse chlorotic mottling on needles of *Pinus taeda*.

4.22 Necrotic banding and chlorotic mottling on needles of *Pinus patula*.


4.21

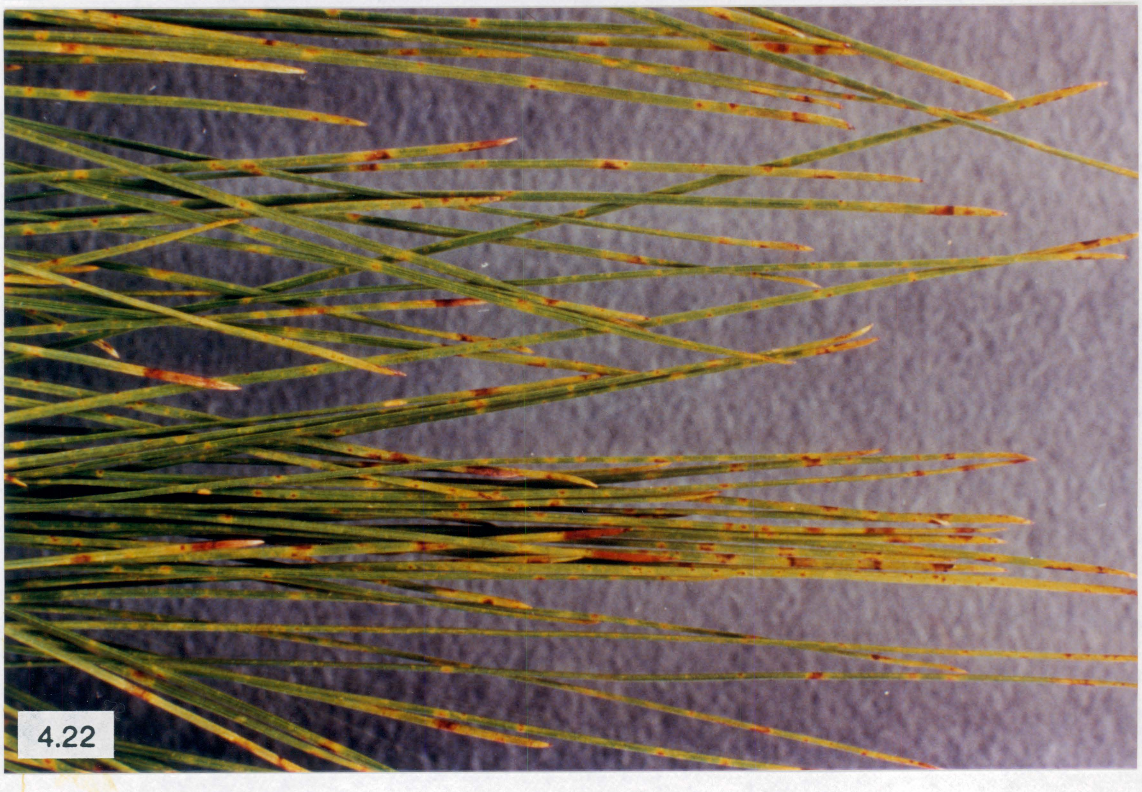

4.22

Fig. 4.23-4.24 Visible injury symptoms observed on pine needles at Rosehaugh Forest Station, Eastern Transvaal, November 1987:

4.23 Excessive chlorotic and necrotic mottling observed on needles from the exposed canopy of a mature *Pinus patula* tree.

4.24 Chlorotic banding observed on needles of *Pinus Patula* (Photo: D. Wessels).

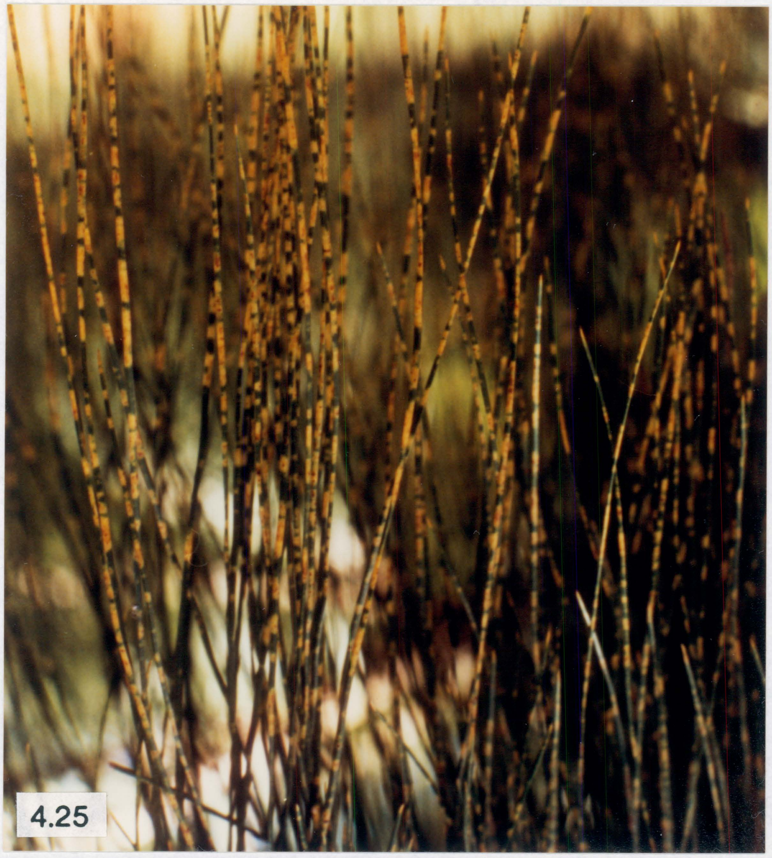

4.23


4.24

Fig. 4.25-4.26 Visible injury symptoms observed on pine needles at Rosehaugh Forest Station, Eastern Transvaal, November 1987:

4.25 Severe chlorotic mottling on needles of *Pinus patula*.

4.26 Necrotic banding on needles of *Pinus patula*.



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4.26

<u>Fig. 4.27</u> Visible injury symptoms observed on needles of <u>Pinus patula</u> at Goedgeloof Forest Station, Bourke's Luck, Eastern Transvaal, November 1987: Exposed tree with necrotic banding (Photo: D. Wessels).


4.27

<u>Fig. 4.28-4.29</u> Visible injury symptoms observed on needles of <u>Pinus patula</u> at Goedgeloof Forest Station, Bourke's Luck, Eastern Transvaal, November 1987:

4.28 Twig with young shoot from a severely injured tree: The present season's growth appears healthy and green, the previous season's growth exhibits yellow to brown mottle over the total needle area.

4.29 Close-up of needles from the same twig as in Fig. 4.28.

4.28

4.29

<u>Fig. 4.30-4.31</u> Visible injury symptoms observed on needles of <u>Pinus patula</u> at Belfast Forest Station, Belfast, Eastern Transvaal, February 1988:

4.30 Needles with extended necrosis and tip burn.

4.31 Young shoot with severe tip burn.

4.30

4.31

<u>Fig. 4.32-4.33</u> Visible injury symptoms observed on needles of <u>Pinus patula</u> at Elandshoogte Forest Station, Eastern Transvaal, February 1988:

4.32 Needles exhibiting tip burn (necrosis of needle tips), as well as chlorotic and necrotic mottling.

4.33 Needles exhibiting chlorotic banding at similar positions across adjacent needles.

4.32

4.33

4.2.2.4.3 Anatomical investigations

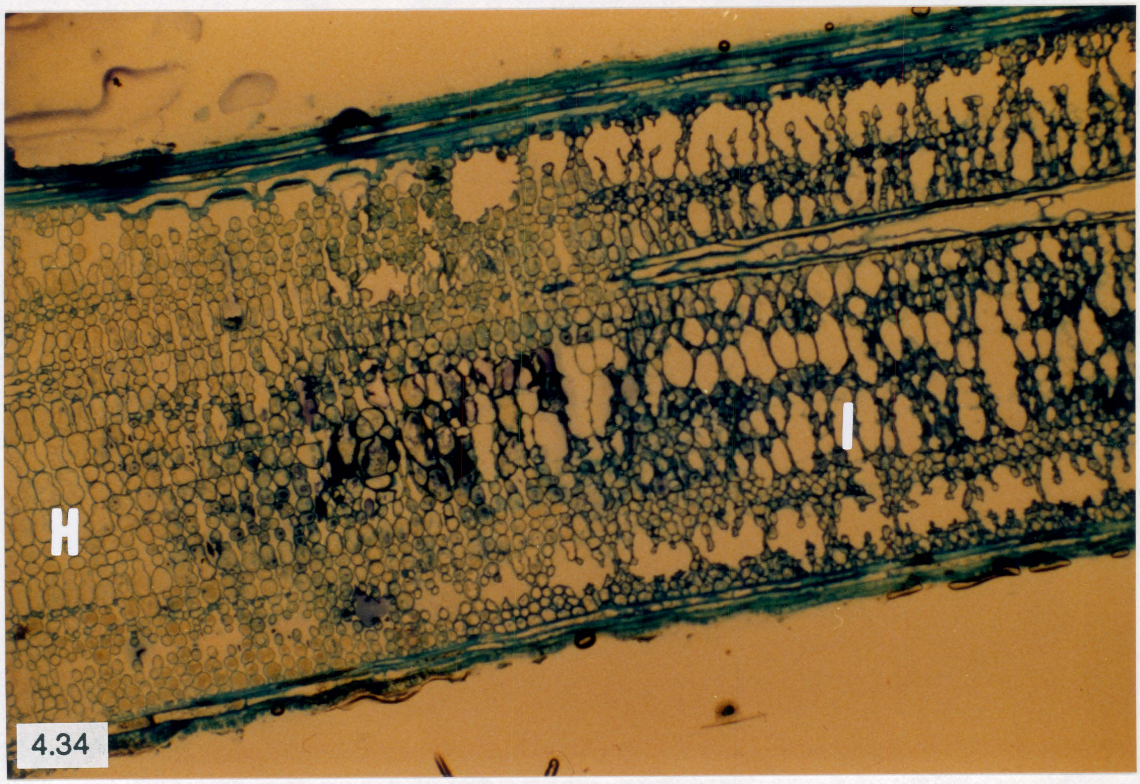
Anatomical investigations (Wessels, 1988), exhibited injured mesophyll cells, similar in appearance to mesophyll injury symptoms reported to be associated with air pollution (Chevone et al., 1986; Rice et al., 1986). A photomicrograph of a cross section through a damaged needle indicating healthy as well as injured cells, is presented in Fig. 4.34.

4.2.2.4.4 Possible involvement of air pollution, acid rain and acid mist

Chlorotic mottling is a well known symptom of chronic injury caused by low levels of air pollutants on conifer needles. Chlorotic banding and tip burn (necrosis) of needles are usually associated with definite pollutant episodes of higher concentrations that might lead to acute injury. Hayes and Skelly, (1977), Blanchard et al., (1979), and Usher and Williams (1982) described the occurrence of visible injury symptoms, associated with atmospheric oxidant pollutants, on pine trees in the northern and eastern U.S.A. Direct injury symptoms due to acid rain are difficult to demonstrate on vegetation but it is generally accepted that tree decline may be caused in part, by indirect effects of acid rain on the soil and changes in the availability of nutrients (Ulrich and Pankrath, 1983).

In view of the numerous small chlorotic bands that were observed on needles of especially _P. patula_, the possible

Fig. 4.34 Cross section through a damaged needle of Pinus patula, showing healthy cells left (H), and injured cells right (I), November, 1987 (Photo: D. Wessels).


H
I
4.34

involvement of acidic mist, which could cause or contribute to these symptoms should be considered. Moisture, which accumulates on the needles by deposition from mist, might form droplets that could have a fairly long contact time with the needles. Since the pH of rain measured in this area (Tyson et al., 1988), is appreciably below normal, it is possible that condensating moisture or mist might be of similar low pH. These droplets might also contain sulphates and/or other injurious ionic species. Wessels (1987) reported that a pilot study of the cation content of lichens revealed ten times as much Mn^{++} in lichens growing in the Eastern Transvaal than in the Soutpansberg area. Regular mist episodes, especially in the early morning, apparently occur over the whole area in which these symptoms have been observed.

4.2.2.5 Conclusions

1. The numerous chlorotic bands observed to occur at the same position across adjacent needles, suggest the involvement of an air pollution episode, affecting sensitive leaf tissue of similar age.

2. The available evidence strongly suggests that air pollution and acid rain or acid mist are major factors in the development of typical air pollution

injury symptoms on pine needles and the general decline of pine trees observed in the Eastern Transvaal Highveld and escarpment regions.

4.2.2.6. Recommendations

To ascertain whether air pollution and acid rain or acid mist are causing the observed injury symptoms on pine needles, the following recommendations were proposed:

1. A thorough investigation (field surveys) of the occurrence of the reported symptoms should be conducted and compared to rain pH data, meteorological conditions, and the topography of the area. Air quality should be measured, possible pollutant sources identified and control strategies identified.

2. The occurrence, pH and composition of mist should be studied, as well as its interaction with conifer needles of various species.

3. Further investigation is needed to determine whether the severity and distribution of symptoms on needles of Pinus patula at the lower elevations of the Lowveld (e.g. the bottom of Kowyn's pass and vicinity), are similar to that of the Sabie, Graskop and

escarpment regions, and whether the severity of symptoms can be related to the mist belt that mainly occurs at the higher elevations in the mountainous regions.

4. A data bank of soil pH measurements taken over the whole area should be created as a matter of urgency. These measurements must be repeated on a regular basis so that trends in soil pH fluctuations can be identified. This data will be useful to either substantiate the reasons for tree decline in certain areas and/or to prognosticate areas in which species might be at risk.

Additional recommendations for the study of various meteorological, leaf anatomical and plant physiological parameters, in order to gain an understanding of the problem at hand, was made by Wessels (1988).

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CHAPTER 5

INJURY TO PLANTS UNDER AMBIENT CONDITIONS IN SOUTH AFRICA II: BIOMONITORING WITH INDICATOR PLANTS IN THE GREATER CAPE TOWN AREA

5. INJURY TO PLANTS UNDER AMBIENT CONDITIONS IN SOUTH AFRICA II: BIOMONITORING WITH INDICATOR PLANTS IN THE GREATER CAPE TOWN AREA

5.1 INTRODUCTION

Certain plant species are used to indicate or detect the presence of a particular pollutant and can in some situations be used to estimate the relative amounts of pollutants present. Many different plant species have been identified as sensitive bio-indicators of air pollutants (Manning and Feder 1980) and some have been used to monitor the biological effects of air pollutants at local (Van Raay, 1969), as well as regional and national scales (Floor and Posthumus, 1977; Ashmore et al., 1978; Posthumus, 1984). A choice can be made among various shortlived (herbaceous) species that would have to be replaced every season (or several times a season) and woody plants species, which can be used to indicate relative pollutant levels for many seasons.

Plant injury symptoms, altered growth and reproductive patterns, changes in yield and or productivity and changes in species distribution, can be used singly or in combination as monitoring parameters.

5.1.1 Biomonitoring network studies:

In biomonitoring network studies plants should be distributed to get maximum exposure to the pollutant bearing winds (Manning and Feder, 1980). In addition, the seasons and developmental stage of the plant species should be considered. According to Heggestad and Heck (1971) most injury is caused when plants are in the seedling or in the young stage, or as they approach maturity.

Tolerant and sensitive cultivars of the same bio-indicator species, as well as different bio-indicator species should ideally be used, each sensitive to different pollutants or pollutant combinations (Manning and Feder, 1980). Plants can be set out in pots or planted directly into the soil. In the latter case the plant holes should be filled with a known soil mix (Manning and Feder, 1980). With the aid of an automatic watering device such as that deviced by Oshima (1974), plants can be left unattended in the field for a week to ten days. Because of the variability within species and populations, large numbers of plants should be used if possible.

5.1.2 Open-top chambers:

In order to fumigate plants with air pollutants under "field" conditions or to exclude air pollutants from plants growing in the field, portable and fixed chambers of various designs have been used since 1903 (Mandl et al., 1973). All of these chambers have been of a closed design whereby air was passed into the chamber and vented under positive pressure through one or more openings. Problems associated with this type of design include the entrapment of radiant heat and changes in the spectrum and intensity of light reaching the plants, caused by the use of various transparent or translucent plastics. In addition, natural precipitation, insect activity and fungal and bacterial parasites are excluded. The temperature can be reduced somewhat by increasing the rate of air exchange through the chamber, but this causes air movement around the foliar surfaces to be abnormal and leads to changes in the water economy and growth of the plant (Mandl et al. 1973).

In order to provide more natural conditions and to alleviate the problems mentioned above, chambers with open tops were designed and tested by Heagle et al. (1973) in Raleigh, North Carolina and Mandl et al. (1973) at the Boyce Thompson Institute, New York, in parallel developments.

The open-top chamber designed by Heagle et al. (1973) consisted of a cylindrical aluminium frame 2.4 m (8 feet) high and 3 m (10 feet) in diameter), covered by polyvinyl chloride plastic film panels. The upper 1.2 m of the frame is covered by a single layer of plastic film, while the lower 1.2 m is covered by a double layer of plastic of which the inner layer is perforated to serve as an air distributing duct. Air is pumped through the chamber to maintain a positive pressure inside the chamber so that the upward movement of air prevents pollutants from entering from the top.

The open-top chamber developed by Mandl et al. (1973) consisted of modules 1.2 m (4 feet) high and 2.74 m (9 feet) in diameter. The modules are constructed of clear corrugated fibreglass and designed to be stacked vertically in combinations of one, two or three modules. The air flow system consisted of a 20.3 cm (8 inches) diameter perforated duct at ground level around the inside perimeter of the chamber.

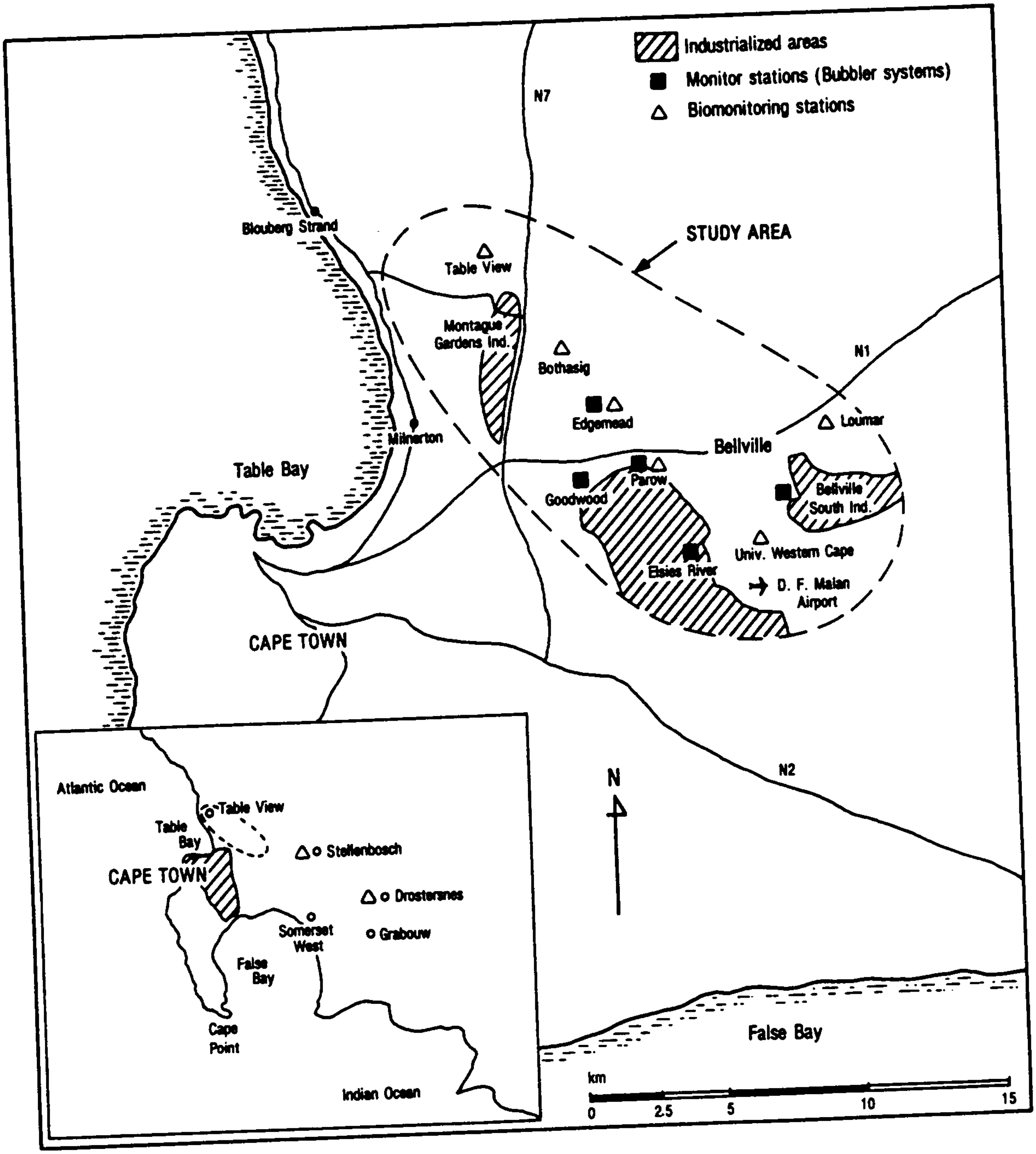
In the case of both of these designs, pollutant concentrations inside chambers fitted with charcoal filters were reduced to approximately 30% of the ambient concentrations. In experiments conducted individually by Heagle et al. (1973) and Mandl et al. (1973), chambers receiving charcoal-filtered air protected sensitive `Bel-W3' tobacco plants (Nicotiana tabacum L.) from ambient ozone (O_3) concentrations. Plants growing in chambers receiving unfiltered air or in ambient air plots were severely injured.

5.1.3 Air pollution level in Cape Town

During preliminary studies conducted for the City Council of Cape Town, O_3 concentrations of 0.04 to 0.28 ppm (15 minute peak values) have been recorded in the Cape Town (Dutkewicz et al., 1980). These values exceed the general threshold levels at which O_3 cause visible injury to plants (Manning and Feder, 1980). For sulphur dioxide (SO_2), monthly peak concentrations (sampling period 72 hours) of 0.02 to 0.1 ppm were recorded during 1981 and 1982 (Kemeny and Vleggaar, 1983). For nitrogen oxides (NO_x), one hour peak values of 1.39 to 1.52 ppm NO_x have been recorded in Centre Cape Town (Dutkewicz et al., 1980). The extent to which these pollutants affect agricultural crops as well as natural vegetation in this area, is largely unknown. Cape Town is bordered by important agricultural zones containing diverse agricultural practices including deciduous fruit, vineyards, wheat, tobacco, vegetable and dairy farming.

The Cape Flats Nature Reserve, which is approximately 20 ha in area and which forms part of only about 1% of the Cape Province that has conservation status (Morsbach, 1983), is located east of Cape Town in Bellville South on the campus of the University of the Western Cape (Fig. 5.1). More than 210 indigenous plant species occur in the Reserve and it is largely unknown to what extent these species are affected by urban air pollutants. The specific objectives of this study were to use a biomonitoring network, together with experiments conducted in open-top chambers to estimate the air quality in several northern and eastern suburbs of Cape Town, including the Cape Flats Nature Reserve in Bellville

<u>Fig. 5.1</u> Study area with biomonitoring stations located towards the north and east of Cape Town. Industrial areas, sites with bubbler type monitors (maintained by the Dept. of Health and the Divisional Council of the Cape) and the biomonitoring stations established during the present study are indicated. Two additional biomonitoring stations were established, one at Stellenbosch and the other at Drostersnes (control station), and are indicated on the insert.


Industrialized areas
Monitor stations (Bubbler systems)
Biomonitoring stations
N7
Blouberg Strand
STUDY AREA
Table View
Montague Gardens Ind.
Bothasig
N1
Edgemead
Loumar
Milnerton
Bellville
Table Bay
Goodwood
Parow
Bellville South Ind.
Univ. Western Cape
Elsies River
D. F. Malan Airport
CAPE TOWN
N2
N
Atlantic Ocean
Table View
Table Bay
Stellenbosch
CAPE TOWN
Drostersnes
Somerset West
Grabouw
False Bay
Cape Point
Indian Ocean
False Bay
km
0
2.5
5
10
15

South, and to make an assessment of air pollution damage to plants growing in this area. Some of these suburbs contain major industries, including a petroleum refinery, fertilizer, glass and textile factories.

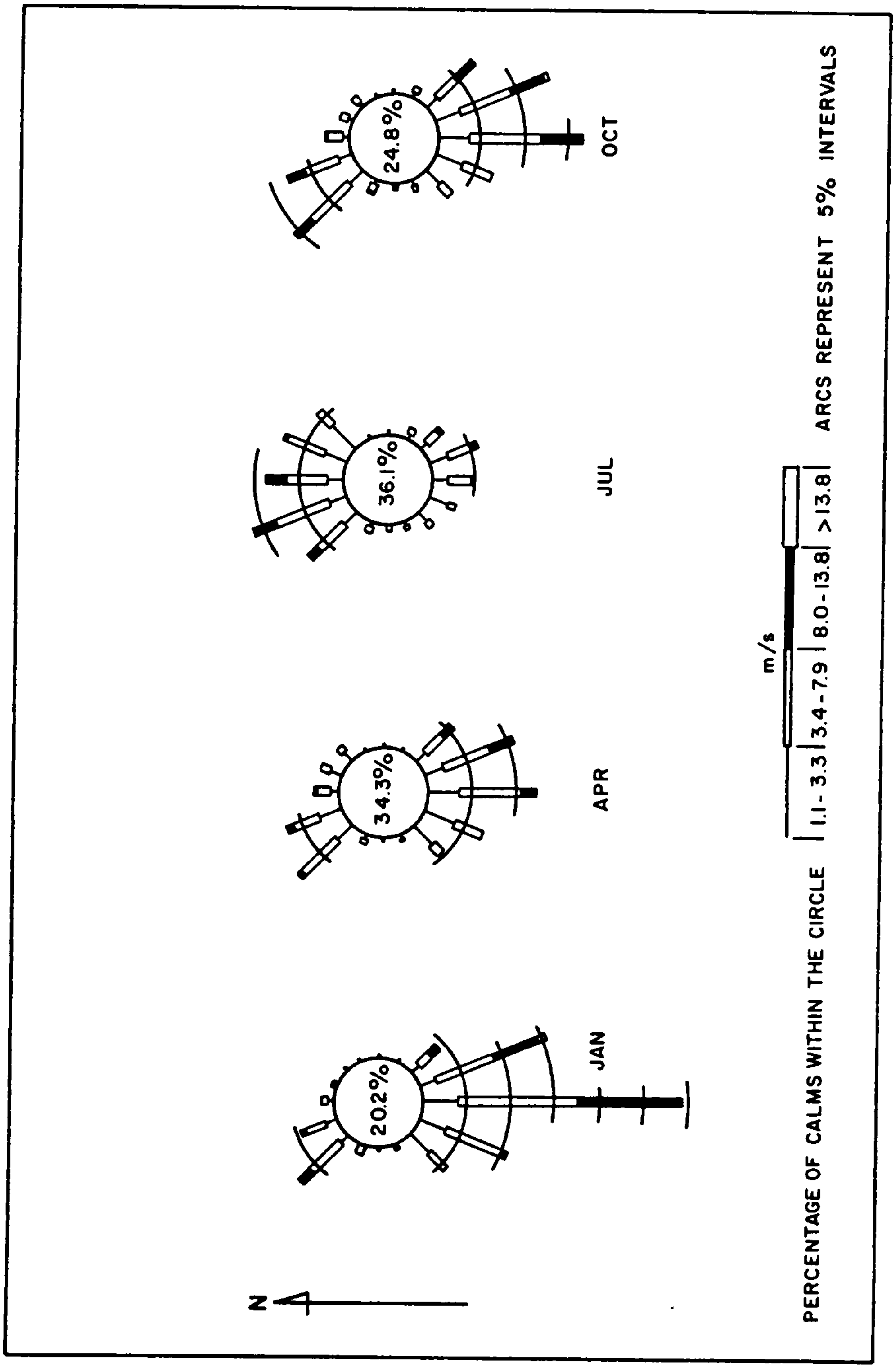
Biomonitoring network experiments were initiated in 1985, followed by open-top chamber studies in 1986. Bioindicator plants were regularly distributed in the study area until May 1988.

5.1.4 Topography and meteorology

The climate of the study area is similar to that of the rest of the Western Cape winter rainfall zone, namely a mild Mediterranean type climate with warm, dry summers and cool, wet winters. The average temperature in January is 20.4°C and 11.8°C in June. The average rainfall in the area is 535 mm per year (Weather Bureau, 1985).

The predominant wind directions, recorded at D.F. Malan airport, are south and south-south-east (SSE) in summer (December -February) and north-north-west (NNW) in winter (June -August). Wind roses for the four seasons (D.F. Malan airport data) are presented in Fig. 5.2. Maximum summer wind speeds of 7.4 to 8.5 m/s (monthly mean) are obtained from the SSE in December and January and from the ESE in February. Maximum wind speeds in winter are 6.3 to 6.6 m/s (monthly mean) in July and August and are obtained from the

<u>Fig. 5.2</u> Wind roses for the four seasons based on measurements made during the period 1956-1970 at the D.F. Malan airport, Bellville, South Africa (Weather Bureau, 1985).



JAN
20.2%
APR
34.3%
JUL
36.1%
OCT
24.8%
N
m/s
1.1 - 3.3
3.4 - 7.9
8.0 - 13.8
>13.8
PERCENTAGE OF CALMS WITHIN THE CIRCLE
ARCS REPRESENT 5% INTERVALS

NNW (Weather Bureau, 1985). Near ground wind conditions in Cape Town and vicinity were found to vary considerably within as little as a five kilometer radius (Dutkewicz et al., 1980). Wind surveys carried out by the Weather Bureau, indicated that wind directions at 10 m could be opposite to wind directions at 100 m (Dutkewicz et al., 1980). These factors may greatly influence the expected dispersion of plumes from pollutant sources. Fig. 5.3 indicates plumes being dispersed in different directions. Low lying blankets of air pollutants, trapped in atmospheric inversions, are regularly observed over the Cape Town, Bellville and Somerset West areas, especially on windless days in autumn, winter and early spring.

Topographically, the study area is located on a low undulating plain, approximately 60 m above sealevel, with a ridge of relatively low altitude that extends in a NW-SE direction east of Table View up to Bellville, where it terminates in the Tygerberg. Table mountain is situated directly south of Table Bay, with its associated mountain range extending in a N-S direction along the Cape Peninsula (Figs. 5.4 & 5.5). In addition to the biomonitoring sites established in the greater Cape Town area, an intermediary station was established at Stellenbosch, which is nestled among the foothills of the Hottentots-Holland mountain range, while a control station was established in a remote mountainous area of high elevation, on the eastern side of

Fig. 5.3 Air pollution over Cape Town, May 1988. Plumes are being dispersed in opposite directions, due to the complex air flow patterns that prevail in the area.

5.3

<u>Fig. 5.4</u> Topography of Cape Town and vicinity: Low lying area with Table Mountain on the left and Tygerberg on the right of the photograph.


5.4

Fig. 5.5 View of Cape Town and Table Mountain form Tygerberg. Biomonitoring stations were located at Parow (left side of photograph), Edgemead (centre), Bothasig (centre right), and Table View (far right side of photograph).


5.5

the Hottentots-Holland mountain range. The Hottentots-Holland mountain range extends in a NNW-S direction, approximately 30 to 40 km (19 to 25 miles) east of Cape Town. Fig. 5.6 presents a view of the low lying areas of the South Western Cape (important agricultural zones), as seen from the Hottentots-Holland mountain range (Franschhoek-pass). The mountain ranges are extremely rich in natural vegetation.

5.2 GENERAL MATERIALS AND METHODS

In this section materials and methods used to establish and maintain bio-indicator plants in a biomonitoring network as well as in open-top chambers, will be discussed. The open-top chambers were located next to a biomonitoring network station on the Air Pollution Research Site developed at the University of the Western Cape (UWC). Materials and methods that pertain to the use of specific bio-indicator species, will be discussed in chapters six and seven.

5.2.1 Biomonitoring network experiments

A bio-indicator/biomonitoring network was established in

Fig. 5.6 Topography of the South Western Cape as seen from the Hottentots-Holland mountain range (Franschhoek-pass).

5.6

the area extending from Bellville South to Table View (Fig. 5.1), to evaluate the extent to which air pollutants affect plants in the Greater Cape Town area. Considerations that influenced the choice of this area included:

1. There is a variety of industries and quite probably a variety of pollutants in the area. The industries are in close proximity to residential areas. A list of the most important industries in the area and the residential areas in their immediate vicinity is presented in Table 5.1.

2. The area extends in a direction similar to the major wind directions, which are south and south-south-east in summer and north-west and north-north-west in winter (Weather Bureau, 1985).

3. There are several sampling sites in the area where the levels of SO_2 (actually total acids), lead and particulates are routinely determined by bubbler systems and filter paper techniques respectively (Fig. 5.1). These measurements are conducted by the Dept. of Health and the Divisional Council of the Cape[1] in a Council for Scientific and Industrial Research (CSIR) coordinated program.
   Where possible, data from the bubbler system

1. Presently the Western Cape Regional Services

Table 5.1: The most important industries within the biomonitoring network area and the residential areas in their immediate vicinity. These industries generally use diesel and heavy furnace oil.

RESIDENTIAL AREA	INDUSTRIES
Bellville South	Textile factory 2 Paper and board Manufacturers Glass Works Food Industry (starch products)
Parow	2 Textile factories 2 Galvanizing works Food Industry Large hospital (coal and heavy furnace oil boilers)
Elsies River	Various textile factories and small industries.
Table View Bothasig Edgemead Milnerton	Petroleum refinery and Fertilizer factory (both at northern end of Montague Gardens Industrial) Kraft Mill (in Montague Gardens Industrial)
Edgemead	Power Station (south of Edgemead, not continuously in operation, used as standby)

measurements as well as data from a mobile automatic continuous monitoring station at which SO_2, O_3 and nitrogen dioxide (NO_2) concentrations were recorded periodically at Edgemead and Bothasig, will be compared with plant data.

5.2.1.1 Biomonitoring sites for the study of air pollution efffects on plants growing in an industrial area near Cape Town:

Various locations in the study area were evaluated for the establishment of biomonitoring stations with respect to their openness towards the major wind directions, their topography and accessibility. Six sites were chosen in the area extending from Bellville South to Table View, plus two additional sites in rural areas, namely Stellenbosch and Drostersnes (Fig. 5.1). The eight biomonitoring stations established were:

1. UWC: A 30 m^2 plot adjacent to the Nature Reserve on the campus of the University of the Western Cape (UWC), Bellville South.

2. Parow: On property of the Parow Municipality in proximity to certain water reservoirs. A CSIR bubbler system, which measures SO_2, is located at this

site.

3. <u>Edgemead:</u> A site of the Electricity Supply Commision (ESCOM), adjacent to an electrical sub-station. A CSIR bubbler system is also maintained at this site.

4. <u>Bothasig:</u> On a site of ESCOM with an electrical sub-station and next to a primary school.

5. <u>Table View:</u> At "Babylon Garden Centre", a private nursery.

6. <u>Loumar</u>: A spacious site of ESCOM with an electrical sub-station, on the eastern side of Bellville.

7. <u>Stellenbosch:</u> A site on a lower slope of Stellenbosch Mountain, on the Welgelegen Agricultural Research station of the University of Stellenbosch. The Stellenbosch biomonitoring station was established as an intermediate station between the Table View - Bellville area and the control station at Drostersnes. The station is approximately 20 km (12.5 miles) from Bellville and is situated on the outskirts of the town of Stellenbosch at the foot of Stellenbosch Mountain. Pollutants from ceramic factories (brick and tile) and other minor industries,

that accumulate in the valley over Stellenbosch, may reach this station from time to time (Fig 5.7).

8. <u>Drostersnes:</u> On an Agricultural Research Station of the FFTRI (Fruit and Fruit Technology Research Institute, Stellenbosch) located in a remote area near the rural village of Grabouw. This site was used for the control station.

The site for the control station was chosen at the experimental farm Drostersnes, which is 15 km (9.4 miles) north of the rural town of Grabouw and east of the Hottentots Holland mountain range. Drostersnes is approximately 40 km (25 miles) east-south-east of the biomonitoring network in the Greater Cape Town area (direct distance). The area is part of a large agricultural area where apples and other deciduous fruit are grown. There are no industries nearby.

All practical measures were taken to safeguard the biomonitoring stations against vandalism. All the sites were fenced, except the one at Table View, which was close to the home of a nursery employee. We are appreciative of the cooperation of the various landowners to allow establishment of the biomonitoring stations at the above locations, and especially of the help rendered by officials of ESCOM to secure some areas against vandalism.

Fig. 5.7 Accumulation of air pollutants over Stellenbosch, as seen from the Stellenbosch biomonitoring station on the lower slope of Stellenbosch mountain.

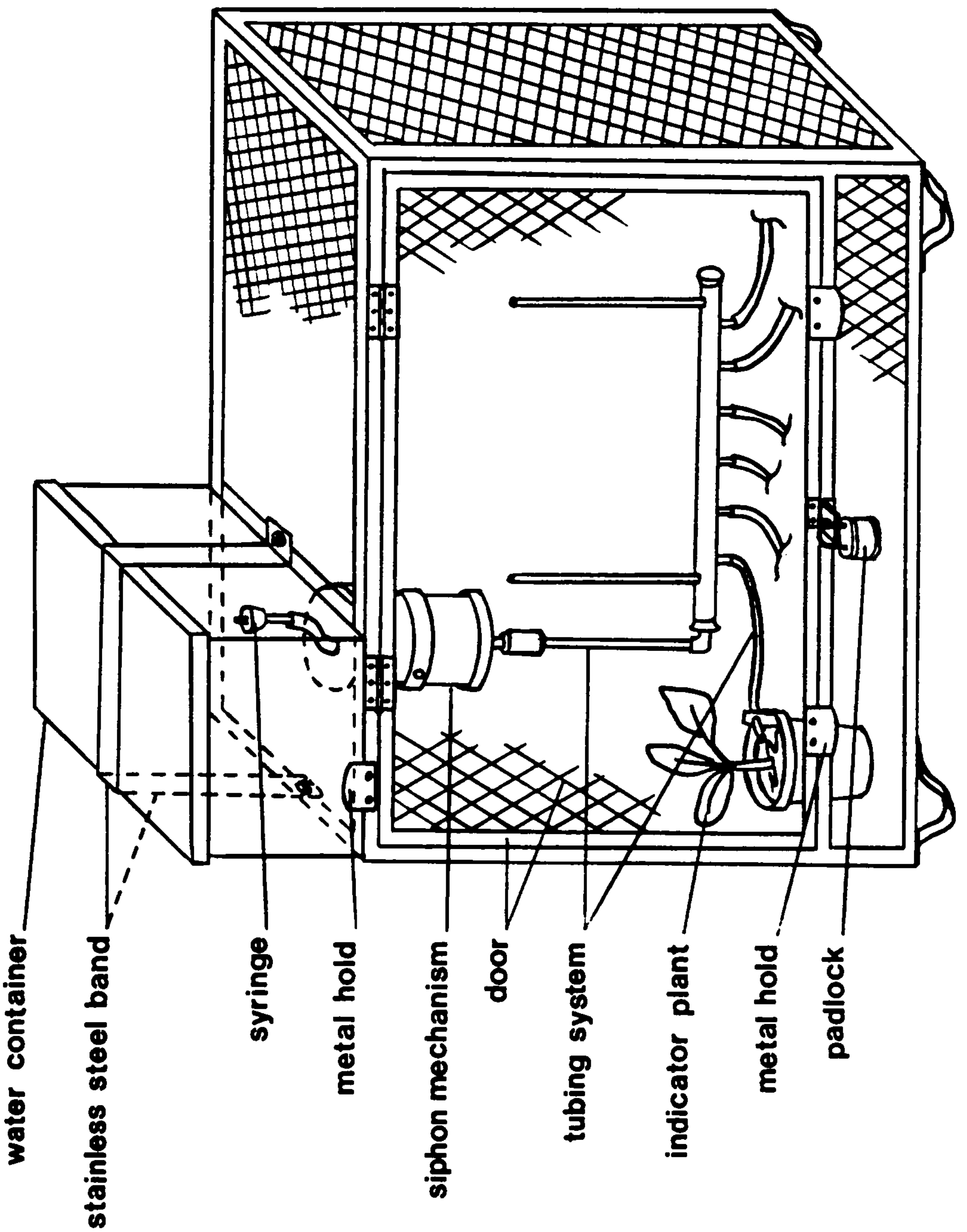
5.7

5.2.1.2 <u>Maintenance of bio-indicator plants in the field</u>:

An automatic watering device similar to that designed by Oshima (1974), was adapted and used to maintain the bio-indicator plants at the various biomonitoring stations. Details of the design is given in Figs. 5.8, 5.9 and 5.10. The use of a screw clamp to control water flow into the siphons as indicated by Oshima, was found to be unsatisfactory since it was not possible to have it deliver a set amount of water repetitively. The amount of water delivered varied during the day and also from day to day, probably due to fluctuations in ambient temperature and the viscoelastic nature of the rubber tubing. Water delivery by means of a hypodermic needle was constant and reliable. Other minor adjustments were made to Oshima's design regarding the type of water container used, and its attachment to the plant cage so that it would be difficult for prospective vandals to tamper with the water supply. Each plant cage was anchored by two two-metre long iron posts which were driven into the soil at opposite corners of the cage and attached to the cage with thick plastic coated wire. The water containers held sufficient water for the bio-indicator plants to be left unattended for up to 10 days.

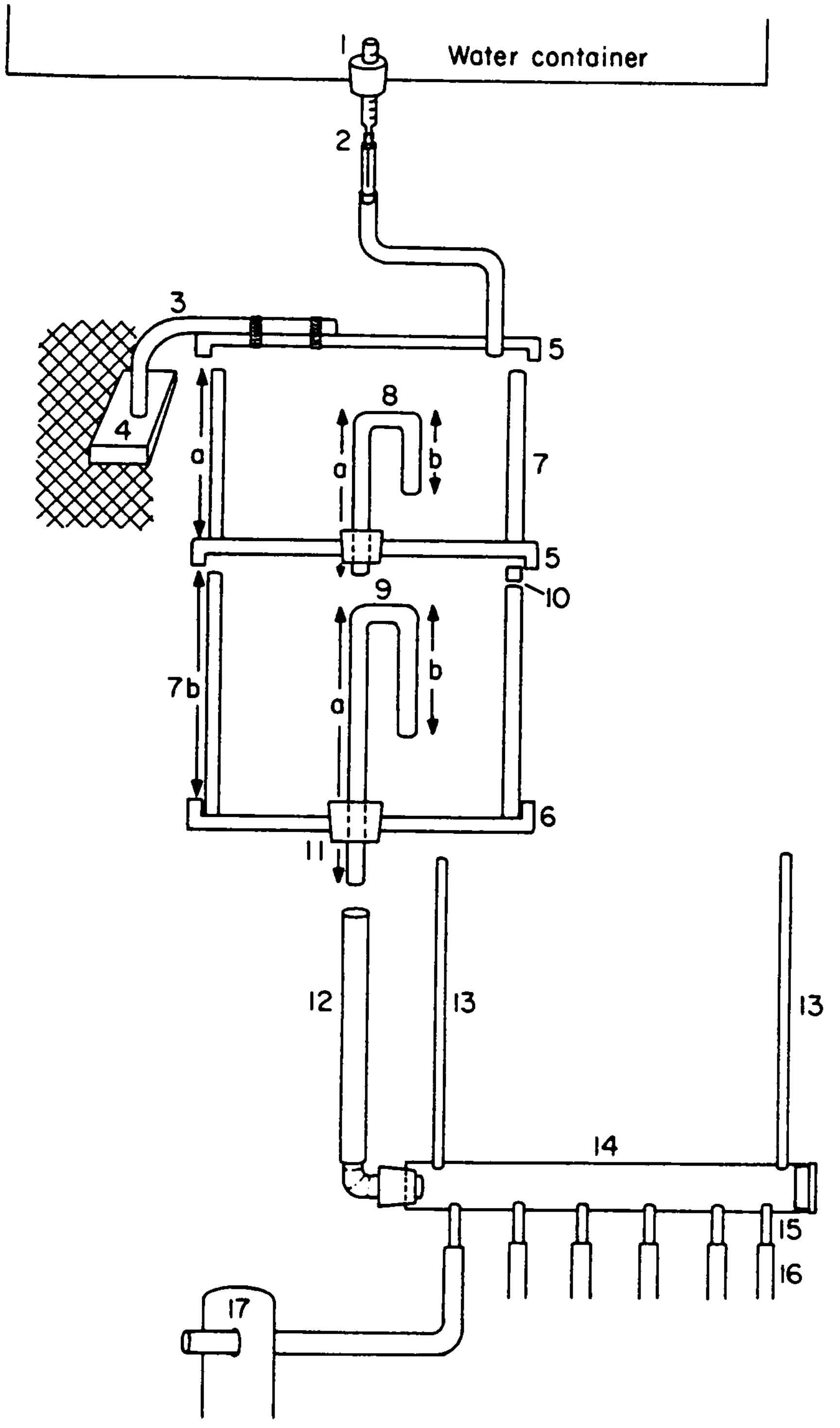
Three plant cages were set up at each monitoring site and supplied with plants to form an "Air Monitoring Biological Indicator (AMBI) Station" (after Oshima, 1974). The stations were inspected once a week. During this time the

Fig. 5.8 Diagram of a biomonitoring network station unit (plant cage). Three plant cages were used at a station. (After the Air Monitoring Biological Indicator (AMBI) station designed by Oshima, 1974).



water container
stainless steel band
syringe
metal hold
siphon mechanism
door
tubing system
indicator plant
metal hold
padlock

Fig. 5.9 The double siphon watering mechanism with attached water distribution system of a biomonitoring network station unit. 1. Detopped syringe through rubber stopper. 2. Hypodermic needle (24 gauge). 3. Aluminium hook. 4. PVC block attached to wall of cage. 5. PVC caps, held in position with plastic screws. 6. PVC cap, glued in position. 7. PVC irrigation pipe, 10 cm in diameter; a = 6 cm, b = 8,6 cm. 8. Glass tubing, 4 mm in diameter; a = 5.2 cm, b = 2.4 cm. 9. Glass tubing, 6 mm in diameter; a = 9 cm, b = 4 cm. 10. Vent. 11. Rubber stopper. 12. PVC tubing (12 mm) attached to glass tube by means of a 5 cm length of 10 mm (I.D.) surgical tubing. 13. Pressure relief tubes. 14. PVC tubing (15 mm). 15. Rigid black PVC tubing (3 mm O.D.) attached to the 15 mm PVC tube by means of connective pieces with screw thread at both ends. 16. Pliable green PVC tubing (3 mm O.D.). 17. Plant marker with hole, holding irrigation tube in position in plant pot. Components used in 12-17 are those regularly used in micro-irrigation systems.


Water container
1
2
3
4
5
8
a
b
7
5
10
9
7b
a
b
6
11
12
13
13
14
15
16
17

<u>Fig. 5.10</u> Biomonitoring network station with <u>Freesia</u> plants at the Loumar biomonitoring station in Bellville.


5.10

water containers were refilled, the siphon systems checked and the general condition of the indicator plants observed. A weekly maintenance form was completed upon each visit (Appendix 5.1). Water used for the biomonitoring stations were always from the same source, namely municipal water from a tap at the University of Stellenbosch. Indicator plants were rated for typical air pollution induced symptoms at regular intervals. Every third week each water container and siphon system was thoroughly washed and rinsed to prevent algal growth which could cause blockage of the hypodermic needle and dispensing system.

Prior to distributing the bio-indicator plants at the biomonitoring stations, they were grown to a suitable size (for example, the primary leaves half expanded in the case of bean plants) under a large shade cloth at the Welgevallen Agricultural Research Station, University of Stellenbosch. Welgevallen is located on the southern side of Stellenbosch, away from the industrial and most polluted areas on the northern and eastern sides. Pollutants, however, could possibly reach the cultivation facilities, which is in the valley area of Stellenbosch, but indicator plants were grown under the shade cloth for a limited period and no visible injury symptoms were observed on these plants. No charcoal filtered greenhouse facilities were available.

5.2.2 Open-top chamber experiments:

An Air Pollution Research Site for the study of the influence of air pollution on plants, was established next to the Cape Flats Nature Reserve on the campus of the University of the Western Cape (UWC) in Bellville South. The site was fenced, 30 m^2 in area and contained eight open-top chambers, two open-plots and the three plant cages of a biomonitoring station (Figs. 5.11 and 5.12). The open-top chambers were constructed according to the design of Heagle et al. (1973). Four of the eight open-top chambers were charcoal filtered. The first four open-top chambers, of which two were charcoal filtered, were completed in March, 1986 (Figs. 5.13 & 5.14). Four additional open-top chambers, of which two further chambers were charcoal filtered, were completed at the same site in December 1986. The chamber wall material of the first four chambers was polyethylene, which was replaced with a polyvinylchloride material (F240) when the second set of chambers were completed, so that all chambers had similar wall covers. Polyvinylchloride (Krene-KDA-224) was specified by Heagle et al. (1973), but this type of material (ultra-violet resistant PVC) was not earlier available in South Africa.

Inside the chambers the bio-indicator plant pots were sunk into the ground so that the pot soil was level with the surrounding soil, in order to minimize evaporation and have

<u>Fig. 5.11</u> Air Pollution Research Site adjacent to the Cape Flats Nature Reserve, on the campus of the University of the Western Cape (UWC), Bellville, South Africa, March, 1986.

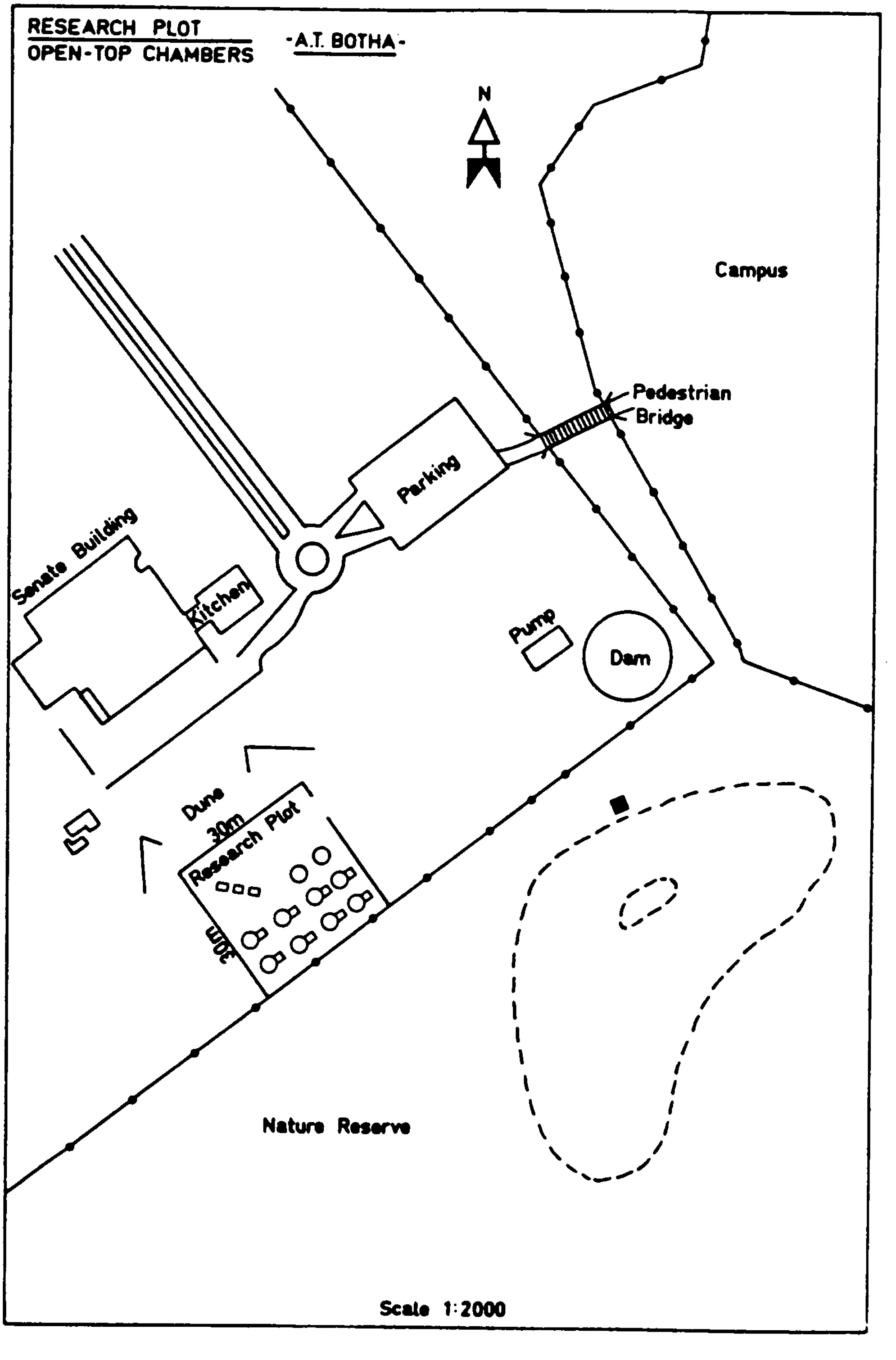
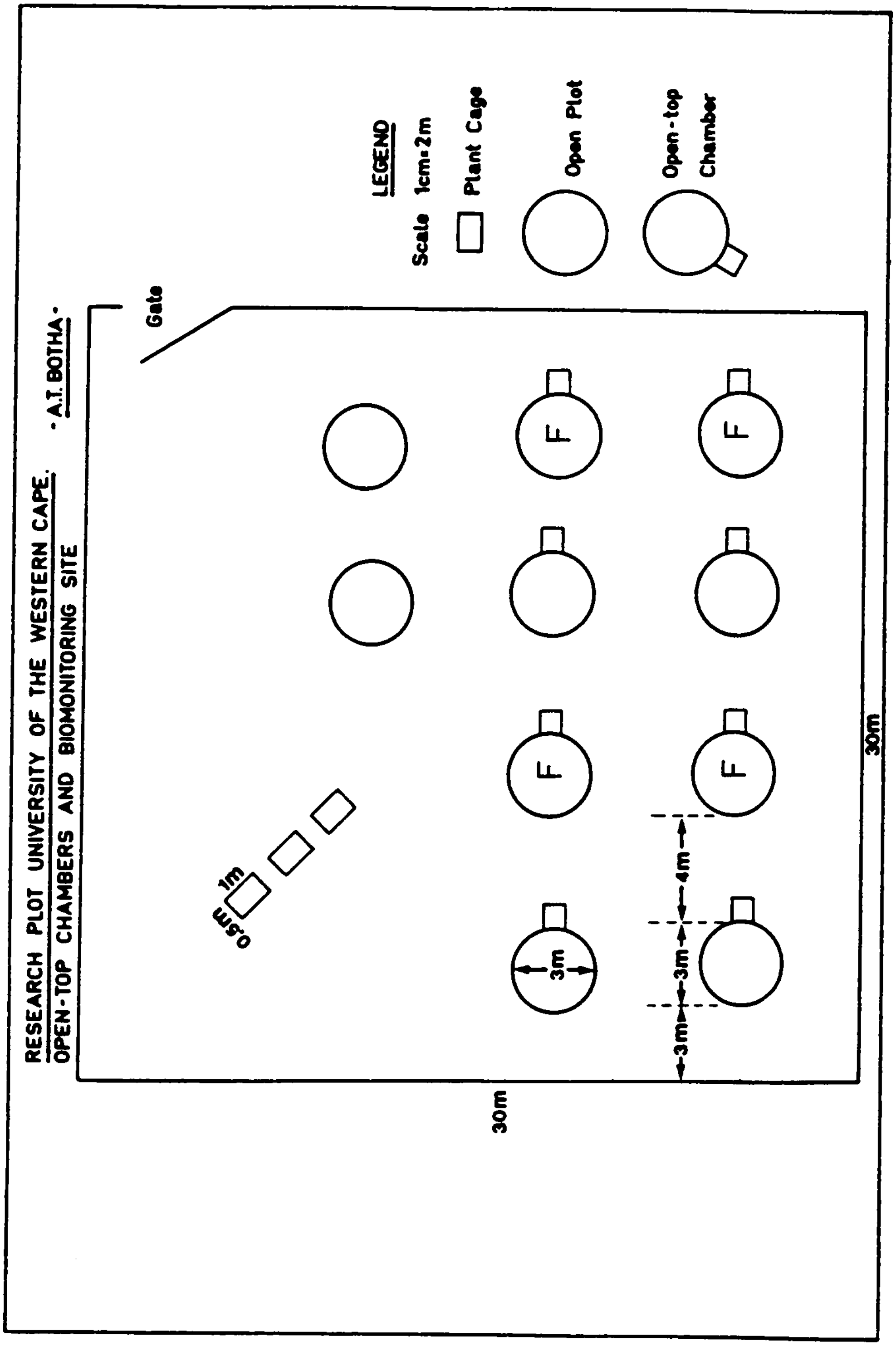

RESEARCH PLOT
OPEN-TOP CHAMBERS
-A.T. BOTHA-
N
Campus
Pedestrian
Bridge
Parking
Senate Building
Kitchen
Pump
Dam
Dune
30m
Research Plot
30m
Nature Reserve
Scale 1:2000

Fig. 5.12 Positions of filtered and unfiltered open-top chambers, open plots and plant cages (biomonitoring network station) on the Air Pollution Research Site at the University of the Western Cape (UWC).

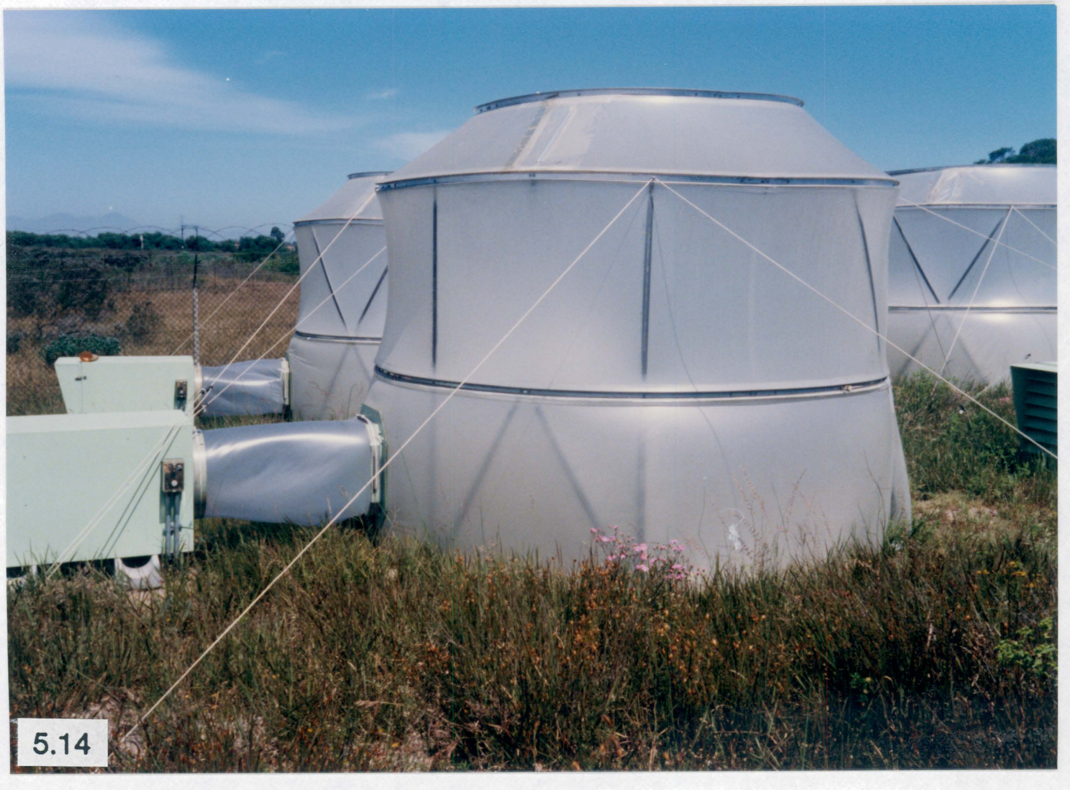

RESEARCH PLOT UNIVERSITY OF THE WESTERN CAPE.
OPEN-TOP CHAMBERS AND BIOMONITORING SITE
- A.T. BOTHA -
Gate
LEGEND
Scale 1cm=2m
Plant Cage
Open Plot
Open-top Chamber
F
F
F
F
3m
4m
3m
3m
1m
0,5m
30m
30m

Figs. 5.13-5.14 Air Pollution Research Site with open-top chambers and plant cages:

5.13 The four open-top chambers completed in March 1986 are indicated. Three plant cages of the biomonitoring network station is located towards the left front. The Cape Flats Nature Reserve with bird hide is visible behind the open-top chambers. Part of the Hottentots-Holland mountain range can be seen on the horizon.

5.14 Open-top chamber constructed according to the design of Heagle et al. (1973). (Photo: L.D. Moore, October, 1987).

5.13



5.14

the soil temperature in plant pots similar to that of the surrounding soil. The soil in this area is very sandy and to prevent the walls of the depressions from caving in, larger pots (5 litre / 1.3 U.S.gal) were sunk in the sand and the pots with plants put into these larger pots.

The four initial chambers were supplied with a temporary drip irrigation system to which water had to be transported. This irrigation system was replaced by a more reliable permanent system when the second set of open-top chambers were completed and a connection to the Bellville municipal water supply was obtained. Constant pressure drippers that dispense constant quantities of water, regardless of possible fluctuations in the pressure of the municipal water supply, were used. A timer and regulator were installed and set so that each plant would receive the same total amount of water that a plant in the biomonitoring network plant cage would receive, dispensed in two equal amounts with a 12 hours interval. While the open-top chambers and open plots received Bellville municipal water, water from the usual source in Stellenbosch was still transported to the plant cages of the biomonitoring network station at this site.

Two open plots were prepared adjacent to the open-top chambers in order to determine the effect of the open-top chambers on plant behavior. The open plots were of the same dimensions as the open-top chambers and were enclosed by a 75 cm high fence of chicken wire to keep rodents and small mammals from the plots. Plant pots were similarly sunk into the ground of the open plots as in the open-top chambers and contained the same bio-indicator species.

The objective of having the open-top chambers at the same site as one of the biomonitoring stations, was to enable comparison between plants grown in charcoal filtered air inside chambers, ambient air inside chambers, ambient air within open plots and ambient air within plant cages. The same plant species, that were used in the biomonitoring network, (plant cage experiments) were simultaneously grown in the eight open-top chambers and two open plots. An additional set of Lazy Housewife beans and a set of _Senecio elegans_ were grown in the open-top chamber system only, during the periods April-May 1988 and December-April 1988 respectively (Table 2). In addition to the cultivation and maintenance of the plants, the following aspects were attended to:

5.2.2.1 Maintenance and replacement of filter media

General maintenance procedures at the open-top chamber site included the regular replacement of faulty drippers, the repair or replacement of PVC ducts between the filter cages and the chambers, the periodic washing of dust filters and the clipping of grass. In addition, the activated charcoal of the four charcoal filtered chambers was replaced during December 1987. At this time, both sides of the PVC walls of all the chambers were also washed with a soapy solution. A 1:1 activated charcoal:purafil[1] medium was used to replace the activated charcoal that has been used for the previous 21 months in the two older chambers and for the previous 12 months in the two newer chambers respectively. A charcoal:purafil mixture was recommended for its ability to absorb a larger spectrum of pollutants and also to absorb specific pollutants such as fluorides, to a greater degree than charcoal alone (Mann, 1987). The PVC walls of the chambers were dismantled at the end of May 1988, washed and stored.

5.2.2.2 Air flow measurements

Air flow measurements were completed as part of the contract to construct the open-top chambers. The volumetric flow rate measured locally, was nominally 48 m^3/min and compared favorably with the published value of 56.6 m^3/min (Kats et al., 1985), considering the larger chamber volume in the latter case (4.27 m diameter compared to 3.1 m diameter of the local chambers).

Volumetric air flow rate through chambers without charcoal filters, but fitted with flow adjustment units, was compared with the flow rate through chambers fitted with charcoal filters. The optimum setting of the flow adjustment units was determined in order to allow air flow rates through the unfiltered chambers to be similar to that through filtered chambers. The flow adjustment units allowed positive and accurate control over the volumetric air flow through the unfiltered chambers.

Further comparisons were made by the researcher between air flow rates through the 24-month old dust filters vs. 15-month old dust filters, washed dust filters vs. unwashed dust filters and the polypleat dust filter presently used vs. a new "Fibatron" (Fibatron, Cape Town) filter with greater retention capacity. The 24-month old filters were determined to still be in good working order. The "Fibatron" filter gave satisfactory results and can be recommended for use in this system.

5.2.2.3 Light intensity measurements

Irradiance measurements were made at 12 different positions within the chambers and open plots, using a "Licor Quantum/Radiometer/Photometer" Model LI-185, in order to identify the effects of varying light intensities on plants at different positions within the chambers.

Inside the chambers the average irradiance in the four quadrants varied between 19 000 to 25 000 lux on a bright sunny day (760 to 1000 μE $m^{-2}.sec^{-1}$), 900 to 1100 lux on a heavily overcast day (36 to 44 μE $m^{-2}.sec^{-1}$), and 5200 to 7000 lux in afternoon sun (208 to 280 μE $m^{-2}.sec^{-1}$). On the open plots the light intensity of the four quadrants varied between 40 000 to 41 000 lux on a bright sunny day (1600 to 1640 $\mu E\ m^{-2}.sec^{-1}$), 4300 to 5100 lux on an overcast day (172 to 204 $\mu E\ m^{-2}.sec^{-1}$), and 1700 to 4000 lux in late afternoon shade (68 to 160 $\mu E\ m^{-2}.sec^{-1}$) .

The irradiance within an open-top chamber with polyethylene walls and one with PVC walls was compared prior to replacing all the polyethylene walls with PVC (November 26, 1986). Light measurements were made at three positions along the North-South transect through the middle of the chamber. Two measurements were recorded at each position. Average irradiance measurements made in the southern side of the polyethylene and PVC chambers were 31 and 33 $\mu E\ m^{-2}.sec^{-1}$ respectively (775 and 825 lux); average irradiance measured in the middle of each chamber were 41 $\mu E\ m^{-2}.sec^{-1}$ (1025 lux) in the polyethylene chamber and 48 $\mu E\ m^{-2}.sec^{-1}$ (1200 lux) in the PVC chamber, while average irradiances of 36 and 33 $\mu E\ m^{-2}.sec^{-1}$ (900 and 825 lux) were measured at the northern positions within the respective chambers.

5.2.2.4 Temperature and humidity measurements

A thermohygrograph was placed in the centre of each of the two open plots, two filtered chambers and one unfiltered chamber. Once a week the readings of each thermohygrograph were recorded separately and compared to temperature and relative humidity readings obtained with a swinging hygrometer ("Zeal", England).

Readings obtained with the swinging hygrometer indicate that average temperatures within the two filtered chambers were 0.70 to 2.60°C higher than in the open plots, while temperatures within the unfiltered chamber were 2.60 to 3.90°C higher than at the open plots. These temperature measurements were made in April 1988, when daily maximum temperatures were generally above 30°C. Differences between the various chambers and open plots may vary, depending on the season and climatic conditions.

Prior to replacing all the polyethylene walls with PVC walls, temperature measurements were made at three positions along the north-south transect through the middle of each of a polyethylene and PVC covered chamber, at a height of 0.5 m (November 26, 1986). Temperatures within the two chambers did not differ and averaged 32°C. Temperatures measured at the northern sides of the chambers were 0.5 to 1.0°C higher than that measured at the centre position. Temperatures at a height of 2.4 m were 1°C lower than that at 0.5 m for both chambers.

5.2.2.5 Shade net

The open tops of the chambers were fitted with 30% shade net during November 1987, in order to lessen the glare on young plants that were transferred to the chambers. This is of particular importance to the *Gladiolus* plants that had been transferred at the height of summer. The shade nets probably also decreased the incursion of ambient air through the top. Since the shade nets were installed, indicator plants had adapted better when transferred to the open-top chambers.

5.2.3 Soil mixture:

All plants were potted in a uniform soil mixture prepared from soil:peat:perlite (1:1:1) with 380 g 2-3-2 fertilizer and 200 g lime added per 30 liters of soil mixture. The soil used in the soil:peat:perlite combination consisted of 2 parts sandy soil from the Cape Flats (campus of the University of the Western Cape) and 1 part loam soil. Both kinds of soil were steam sterilized prior to mixing. Reusable squares of gauze, cut from plastic window gauze, were put on the bottom of the plant pots to prevent the loss of soil through the holes. The composition of the soil mixture used in the biomonitoring network experiments, was equivalent to that used in fumigation studies at the Virginia Polytechnic Institute and State University (Chapter 3).

5.2.4 Bio-indicator species used:

Since the plant cages were established in the field during September 1985, a set of _Freesia_ (cv. 'Mozart') plants, a set of _Gladiolus_ (cv. 'White Princess') plants and three sets of bean plants (a bush Blue Lake cv. 'GV-2', followed by a another cultivar, 'Seminole') were exposed at the various biomonitoring sites. Although results from previous fumigation studies (Chapter 3) indicated that the cultivar 'Seminole' was not as sensitive to air pollutants as some other cultivars, the only seeds that could be obtained at the time were of the cultivar 'Seminole'. During these initial experiments, problems concerning the cultivation and maintenance of the various species were elucidated and appropriate programs for the application of pesticides and fertilizer developed. A schedule was kept of the times of fertilizer and/or pesticide application to each species (Appendix 5.2). At any particular time, fertilizer and/or pesticide treatments were always administered to all plants of a species, at all locations. Details on the application of fertilizer and pesticides to the relevant species, is given in Chapter 6 for _Freesia_ and _Gladiolus_ and in Chapter 7 for beans. Among the pest problems that had to be dealt with on beans were spidermite, botrytis, brown rust and white fly. On the _Gladiolus_ plants thrips and rust had to be controlled. The _Freesia_ plants were relatively pest free.

During the summer of 1986/1987, the pole bean (climbing bean) cultivar 'Lazy Housewife', a locally popular cultivar which is apparently closely related to 'Kentucky Wonder' (personal communication with an official of Starke Ayres Seed Co., 1986), was distributed to the various monitoring sites. The cultivar 'Kentucky Wonder' was previously used in fumigation studies at the Virginia Polytechnic Institute and State University and found to be more sensitive to O_3 than the other cultivars tested, namely 'Provider', 'Wintergreen' and 'Topcrop'. Among the bean cultivars used in the biomonitoring network experiments, 'Lazy Housewife' bean plants developed more homogeneously and grew more luxuriously than the bush cultivars used previously. It was also easier to keep track of the respective trifoliates as they developed, than in the bush cultivars. The cultivar 'Lazy Housewife' was therefore used in subsequent experiments with beans.

The following species / cultivars were routinely used at the various biomonitoring stations as well as in the open-top chambers for a number of seasons during the period October 1985 - May 1988:

<u>Winter</u> (1986 and 1987): <u>Freesia</u> cv. 'Golden Melody'
(Fluoride sensitive)
Growth period: Oct.- Nov.

Summer (1985/86, 1986/87 and

1987/88): *Gladiolus* cv. 'White Princess'
(Fluoride sensitive)
Growth period: Oct-Feb

(1986/87 and

1987/88): *Phaseolus vulgaris* cv. 'Lazy Housewife'
(O_3 and SO_2 sensitive)
Growth period: ± 1 month; various batches were planted from Dec-May

Some cultivars differed from those used initially, either due to their availability (e.g. supply of *Freesia* cv. 'Mozart' bulbs were discontinued) or their ease of cultivation (bean cultivars). The time and duration of exposure for each group of plants is detailed in Chapters 6 (*Freesia* and *Gladiolus*) and 7 (beans). In addition to the cultivars mentioned above, two sets of plants of the radish cultivar 'Cherry Belle' and a set of the *Gladiolus* cv. 'White Friendship' were also distributed to the biomonitoring stations during the course of 1986 and 1987. Results of these experiments will be available in a report to be submitted to the CSIR, South Africa, during 1989 and will not be discussed here.

5.2.5. Chemical analysis of leaf material:

Freesia and *Gladiolus* leaf samples were analyzed for fluoride, using the methods described in Chapter 4. Bean leaf samples were analyzed for sulphur, using standard wet digestion procedures, followed by elemental analysis on an Inductively Coupled Plasma Spectrometer (ICP), as described in Chapter 7.

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CHAPTER 6

THE BIOMONITORING OF AIRBORNE FLUORIDE

6. THE BIOMONITORING OF AIRBORNE FLUORIDE

6.1 INTRODUCTION

Fluoride is regarded as the most phytotoxic of all the common pollutants (Weinstein and Alscher-Herman, 1982). Although the effects of fluoride have been known since the previous century (Mayrhofer, 1893; Rhode, 1895) and the technology for the prevention of harmful emissions is available, fluoride injury to vegetation is still a concern on local scales (Arndt, 1984).

The development of air quality standards for fluoride vegetation effects, by the use of vegetation fluoride content, and the presence of leaf injury and atmospheric fluoride concentration, were discussed by Hill (1969). Plant species differ greatly in their sensitivity towards fluoride and their potential to accumulate fluoride from the atmosphere or the soil. Varieties showing the most injury frequently have the lowest fluoride content. Apricot leaves containing 50 ppm fluoride may be severely damaged, while celery leaves containing several thousand ppm may be free from injury (Hill, 1969). The accumulation of fluoride by uptake through the roots varies greatly among species: values ranging from 2 ppm in turnip (Robinson and Eddington, 1946) to 255 ppm in tea leaves (Wang et al., 1949) have been recorded for vegetation growing in nonindustrial areas. According to Treshow and Pack (1970), leaves of many plant species accumulate 0.05 to 0.10 ppm fluoride under normal conditions, which should be taken into consideration when the accumulation of fluoride due to air pollution is evaluated. The fluoride content can also fluctuate in leaves due to factors such as leaching by rain and volatilization of fluoro-organic compounds (Hill, 1969). Extreme variation is also observed in the response of different varieties of the same species (Johnson et al., 1950). For example, sensitive <u>Gladiolus</u> varieties have been injured by fumigation with concentrations of hydrogen fluoride (HF) averaging as low as 0.1 ppb for five weeks (Thomas and Hendricks, 1956). Phytotoxicity also depends on the relative amounts of different forms of fluoride in the atmosphere at a location since gaseous HF is more toxic than particulate fluoride (Lacasse and Treshow, 1976). The <u>Gladiolus</u> cultivar 'Snow Princess' developed 8 to 10 times as much injury when fumigated with HF as when exposed to the same total fluoride concentration in an atmosphere in which much of the fluoride was in the particulate form (Hill, 1969).

Hydrogen flouride accumulates along leaf margins and leaf tips and the result of which may lead to marginal necrosis that begins at leaf tips and progresses to leaf bases. Chronic HF injury may result in general chlorosis or chlorosis along leaf veins (Chang, 1975; Treshow, 1971).

Moisture stress, cold temperatures and the facultative parasite, Botrytis, may cause injury that resembles fluoride injury. The expression of visible symptoms should therefore be combined with fluoride analysis of leaf tissue (Manning and Feder, 1980). Several methods for the chemical analysis of fluoride in leaves have been published (Adams, 1963; Louw and Richards, 1972; Cooke et al., 1976; AOAC, 1980). Standard methods involve the use of a fluoride ion-selective electrode, which facilitates rapid, accurate determinations (Manning and Feder, 1980).

A list of higher plants and lichens which are known to be sensitive or resistant to atmospheric fluoride and which can effectively be used as biomonitors, is provided by Manning and Feder (1980). Gladiolus hortulanus Bailey, is the most widely used bio-indicator for fluoride. The bulbs as well as the leaves accumulate fluoride, thus Gladiolus plants are suitable to use as biomonitors for one season only. If no other means of control is available, a fluoride sensitive variety e.g. \`Snow Princess' should be used together with a fluoride resistant variety such as \`Mansoer' (Manning and Feder, 1980). Other important bio-indicators are freesias (Van Raay, 1969) and lichens (Gilbert, 1973).

Van Raay (1969) used freesias to monitor fluoride in The Netherlands, where Freesia hybrida Hort. is a common horticultural plant. Comparing foliar injury symptoms, Van Raay determined Gladiolus and Freesia to be more sensitive to fluoride than to sulphur dioxide (SO_2) and clover and barley to be more sensitive to SO_2 than to fluoride. Freesia and Gladiolus are indigenous to South Africa, and whereas cultivated hybrids of these plants have often been used as bio-indicators, the great number of native species that occur in various areas in the country, presents an uninvestigated richness of potential bio-indicators.

This chapter deals with experiments in which *G. hortulanus* and *F. hybrida* were used as bio-indicators in the Southwestern Cape at eight biomonitoring stations, as well as in a system of open-top chambers.

6.2 SPECIFIC MATERIALS AND METHODS

General materials and methods concerning the locations of the biomonitoring stations and open-top chambers, the soil mixture used, and the nature and maintenance of the hardware involved, have been discussed in Chapter 5. Specific materials and methods that pertain to the use of *Gladiolus* and *Freesia* is discussed in this section.

G. hortulanus cv. 'Snow Princess' (Fig. 6.1) plants were distributed to the different biomonitoring stations during the summer months (October to May) and *F. hybrida* cv. 'Golden Melody' (Fig. 6.2) plants during the winter (June to October), from 1985 to 1988. Twice during each year, Figs. 6.1-6.2 Gladiolus and Freesia cultivars used in biomonitoring network experiments.

6.1 Gladiolus hortulanus cv. 'Snow Princess', May, 1988.

6.2 Freesia hybrida cv. 'Golden Melody', photographed at the Edgemead biomonitoring station, August 1986.

6.1

6.2

Gladiolus plants were distributed to and maintained at the various stations during each summer season (October to early February and again from February to May), except for the 1985/1986 season, during which only one study set was distributed and maintained from October 1985 to February 1986. Only one study set of *Freesia* plants was used per winter season (June to October). The results from two sets of data of each species, obtained in two consecutive years, are presented in this chapter. Results of other experiments not presented here, will be available in a report to be submitted to the Council for Scientific and Industrial Research (CSIR), South Africa.

The number of *Freesia* and *Gladiolus* plants distributed to the biomonitoring stations and open-top chamber system during 1985 to 1987, as well as the time that each set of plants were exposed in the field, is indicated in Table 6.1.

6.2.1 Cultivation

Freesia bulbs, purchased from local dealers, were uniform in size. Three bulbs were planted per 15 cm diameter plastic plant pot, with the top of the bulbs approximately 3 to 4 cm below the soil surface. Liquid fertilizer ("Chemicult") was applied in 25 ml quantities to the soil in every pot on three occasions during the growth period of the freesias, namely July, August and September. The plants

Table 6.1: The number of *Gladiolus hortulanus* cv. 'Snow Princess' and *Freesia hybrida* cv. 'Golden Melody' plants distributed to the biomonitoring stations and open-top chamber system during 1985/86 and 1987, and the period that each group was exposed in the field.

YEAR	SPECIES	No. of open-top chambers or plots			No. of pots[2]		Date placed out and Seedling stage[3]	Date returned to lab.	EXPOSURE PERIOD (weeks)
		F[1]	N	O	per chamber or plot	per cage			
1985/86	Gladiolus	-	-	-	-	3/4	Oct. 29 (Height 20-25cm)	Feb. 12	15
1986	Freesia	2	2	-	12	4	May 23 (Height 12-15cm)	Oct. 1	19
1986/87	Gladiolus	2	2	-	6	3	Oct. 30 (Height 20-25cm)	Feb. 12	15
1987	Freesia	4	4	2	7	3	June 11 (Height 12-15cm)	Oct. 20	19

1. The number of filtered (F) and unfiltered (N) open-top chambers and open plots (O) in use, varied as indicated. Three plant cages were located at each of eight biomonitoring stations.
2. Each pot contained two plants in the case of Gladiolus and three plants in the case of Freesia.
3. Seedling stage is indicated by the height of the young monocotyledenous leaves.

usually flowered in September, after which they gradually started to senesce. Plants were returned to the laboratory during October, before the occurrence of general senescence. Leaf injury was finally rated, after which the leaves were harvested and oven dried as explained in chapter 5. No pest problems were recorded on the freesias during 1986 and no pesticides were applied. During 1987 insect damage (leaves eaten), aphids, thrips (one case), and rust (one case) were recorded and treated. "Dithane M45" was sprayed in June as a preventive measure against rust, while "Malathion" and "Lannate" were sprayed in July and October and July and September respectively. In July the "Malathion" and "Lannate" were combined with a soapy solution and applied. This combination was determined to be especially effective against aphids. When even a pesticide was used, all plants at all locations were treated.

Gladiolus bulbs, obtained from local dealers, were treated against fungus infections by soaking in a "Dithane M45" and water mixture at 40-50°C for one hour. Bulbs that remained floating, injured bulbs and very small bulbs were discarded. Bulbs were subsequently rinsed in tap water and planted at a depth of approximately 10 cm in plastic plant pots of 18.5 cm diameter. Two bulbs were planted per pot. Prior to inserting the bulbs, "Bexadust" (insecticidal powder) was mixed into the soil at the 10 cm planting level. A complete liquid fertilizer ("Chemicult"), was applied in

50 ml quantities to the soil of every pot once during January, followed by a 50% "Chemicult" solution early in February. Pest problems observed on Gladiolus plants included insect damage (leaves were eaten), thrips, rust, and spider mite. These were treated with "Thiodan" (thrips), "Dithane M45" (rust) and "Oomite" (spider mite) as needed. A "Thiodan" treatment applied on November 11, 1986, was followed up by a similar treatment on November 19, 1986, to ensure extermination of small thrips developing from dormant eggs. Plants usually started to flower during mid December and started to senesce in early February. Plants were returned to the laboratory for final evaluation and harvesting of leaf material in early February, prior to the onset of general senescence.

6.2.2 Visible symptom expression and harvesting

The development of visible injury symptoms that could be ascribed to flouride as well as other forms of injury and the occurrence of pests that were observed during weekly visits to the biomonitoring stations and open-top chambers, were noted by completing the weekly maintenance form (Appendix 5.1).

6.2.2.1 Freesia

The percentage tip and marginal necrosis and chlorosis that was typical of visible fluoride injury, was rated for individual leaves of Freesia plants at two week intervals, from August 6, to October 2, 1986. The fluoride injury rating form presented in Appendix 6.1 was used for this purpose. The number of leaves in each injury category was indicated, as well as the total number of leaves on a plant. An example of leaves rated in several injury categories, is presented in Fig. 6.3. Similar procedures were followed during 1987, except that leaves were rated for typical fluoride injury on two dates only: August 25 and October 26, 1987. On August 25, 1987, only plants at the Loumar station were rated, since injury at the other biomonitoring stations was either less than 2% leaf area necrotic, or zero. In addition to the biomonitoring network experiments, a subset of plants grown in the open-top chamber system was rated. In general, very little injury occurred within the filtered and unfiltered open-top chambers and leaf injury ratings were limited to one filtered chamber, one unfiltered chamber and two open plots. The dry mass of the shoots (aerial parts) of the Freesia plants grown in the open-top chambers and open plots during 1987 was also determined.

A visible injury index, to represent the amount of fluoride injury visible on a given plant, was developed. Both the proportion of leaves and the proportion of leaf area injured were considered. An individual index was computed for each plant within a pot within a cage at a given

<u>Fig. 6.3</u> Leaves of <u>Freesia</u> <u>hybrida</u> cv.'Golden Melody' rated in several injury categories, ranging from <2 % to 30 % tip necrosis per leaf. Plant labels indicate: B1.2.3 = Bothasig, cage 1, pot 2, plant 3; L3.3.3 = Loumar, cage 3, pot 3, plant 3.


B1.2.3
<2% Inj.
B1.2.3
2-5% Inj.
B1.1.3
5-10% Inj.
L3.3.3
20-30% Inj.
6.3

biomonitoring station or open-top chamber and for a given date. The index was derived as follows: For a single plant, at a given date, the severity of injury was visually estimated for each leaf on the plant as a percentage of the total area per leaf. The visible injury index was then recorded as the "total severity" over all leaves relative to (divided by) the total number of leaves on the plant at that date. The "total severity" was calculated as the sum of the severities for each leaf of the plant and it was computed as a weighted sum of all levels of severity which were recorded. Each level of severity was weighted by its corresponding frequency of occurrence for the plant (i.e., the number of leaves with that observed level of severity). Thus, we have the visible injury index (I) for a plant at a given date as:

$$I = \frac{\displaystyle\sum_{\substack{\text{all levels}\\ \text{of severity}}} (\text{frequency of severity level}) \times (\text{severity level})}{\text{Total number of leaves}}.$$

Visible injury indices were statistically analyzed for the 1986 _Freesia_ data, both excluding dead and senescent leaves from the data set, as well as including dead and senescent leaves. Only the percentage necrosis per leaf was considered, since the percentage chlorosis, associated with fluoride injury, was generally very small. Results from the analysis excluding dead and senescent leaves will be presented here.

Visible injury indices were also statistically analyzed for the <u>Freesia</u> 1987 biomonitoring stations data, as well as open-top chamber experiment, excluding dead and senescent leaves. Finally, visible injury indices for 1986 versus 1987 biomonitoring stations data, were statistically compared. Results from statistical "repeated measures analyses", to evaluate the development of visible injury at certain biomonitoring stations over time, will be presented in a report to the CSIR, South Africa, and will not be presented here.

Subsequent to the final rating of the <u>Freesia</u> leaves, the upper third portion of all the mature leaves in a plant pot were harvested, dried at 60 - 70°C to constant weight, finely ground (40 mesh) and stored in acid washed plastic vials over silica gel in tightly covered plastic containers.

6.2.2.2 <u>Gladiolus</u>

Procedures followed to rate visible injury symptoms on <u>Gladiolus</u> were essentially the same as those used for <u>Freesia</u>, with the exception that in addition to the visual estimation of percent leaf area injured, the actual leaf area injured was also measured, employing photocopies of four middle-aged leaves per plant, using a compensating planimeter ("Koizumi" Type KP-27, Nippon Kako Seishi K.K., Tokyo) and following the technique of Vasiloff and Smith

(1974). Necrotic and chlorotic areas were summed for each leaf and the percentage injured leaf area calculated. An arcsine transformation was performed on the percentage leaf area injured prior to statistical analysis. The mean proportion of leaf area injured per leaf was determined for each biomonitoring station and presented graphically. Results from the visual estimation of injury on Gladiolus leaves will not be presented here, but a comparison between the visual estimation of leaf injury and the actual measurement of injured areas according to Vasiloff and Smith (1974) will be available in a report to the CSIR, South Africa.

Subsequent to the final evaluation of visible injury on gladiolus leaves, the top half of the same four middle-aged leaves that were used to measure visible injury, were harvested and dried at 60-70°C to constant weight. The dry leaf material was finely ground (40 mesh) and stored in acid washed plastic vials over silica gel in tightly covered plastic containers.

6.2.3 Fluoride analysis:

The upper third and upper half of Freesia and Gladiolus leaves respectively were harvested, dried and analyzed for fluoride according to the methods described in Chapter 4, par. 4.1.3.

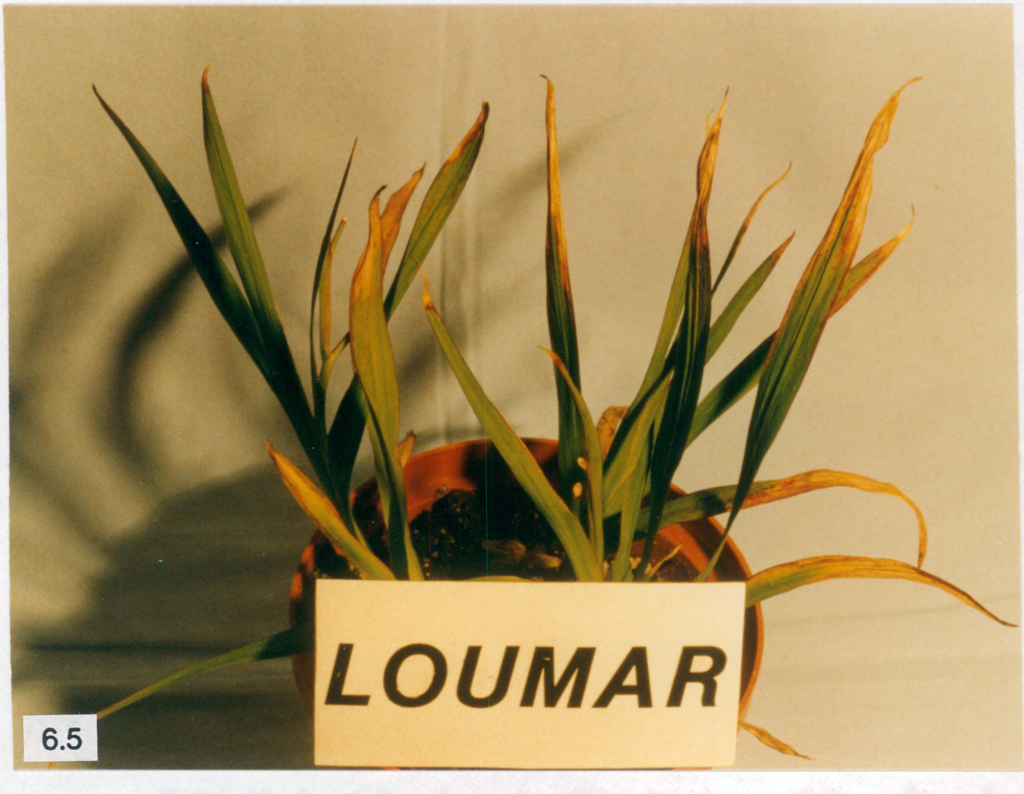
6.3 RESULTS AND DISCUSSION

6.3.1 Biomonitoring network experiments

Photographical records of visible injury observed on *F. hybrida* cv. 'Golden Melody', are presented in Figs. 6.4 to 6.7. The fluoride content of the leaves sampled, and the visible injury observed on those leaves, are compared in Fig. 6.8 for *Freesia* (May-Oct. 1986) and *Gladiolus* (Oct.-Feb. 1985/86). The fluoride content of the *Freesia* leaves, as measured for the different biomonitoring stations, correlated well with the corresponding visible injury indices. Visible injury indices determined for *Freesia* exposed during 1986 and 1987 were statistically compared and are graphically presented in Fig. 6.9. At all the biomonitoring stations, significantly more injury ($P = 0.001$) was observed during 1987 than during 1986, except in the case of plants exposed at the control station (Drostersnes), in which case the values for the two years did not differ significantly. The visible injury index determined for the various biomonitoring stations for the 1987 *Freesia* data appeared to correlate well with the fluoride content determined in the same leaves (Fig. 6.10a), except for the University of Western Cape (UWC) station, in which case the visible injury index was greater than expected. Although we

Fig. 6.4-6.5 Tip and marginal necrosis typical of fluoride injury, observed on leaves of Freesia hybrida cv. 'Golden Melody' at the Table View (6.4) and Loumar (6.5) biomonitoring stations, October 1987.

6.4



6.5

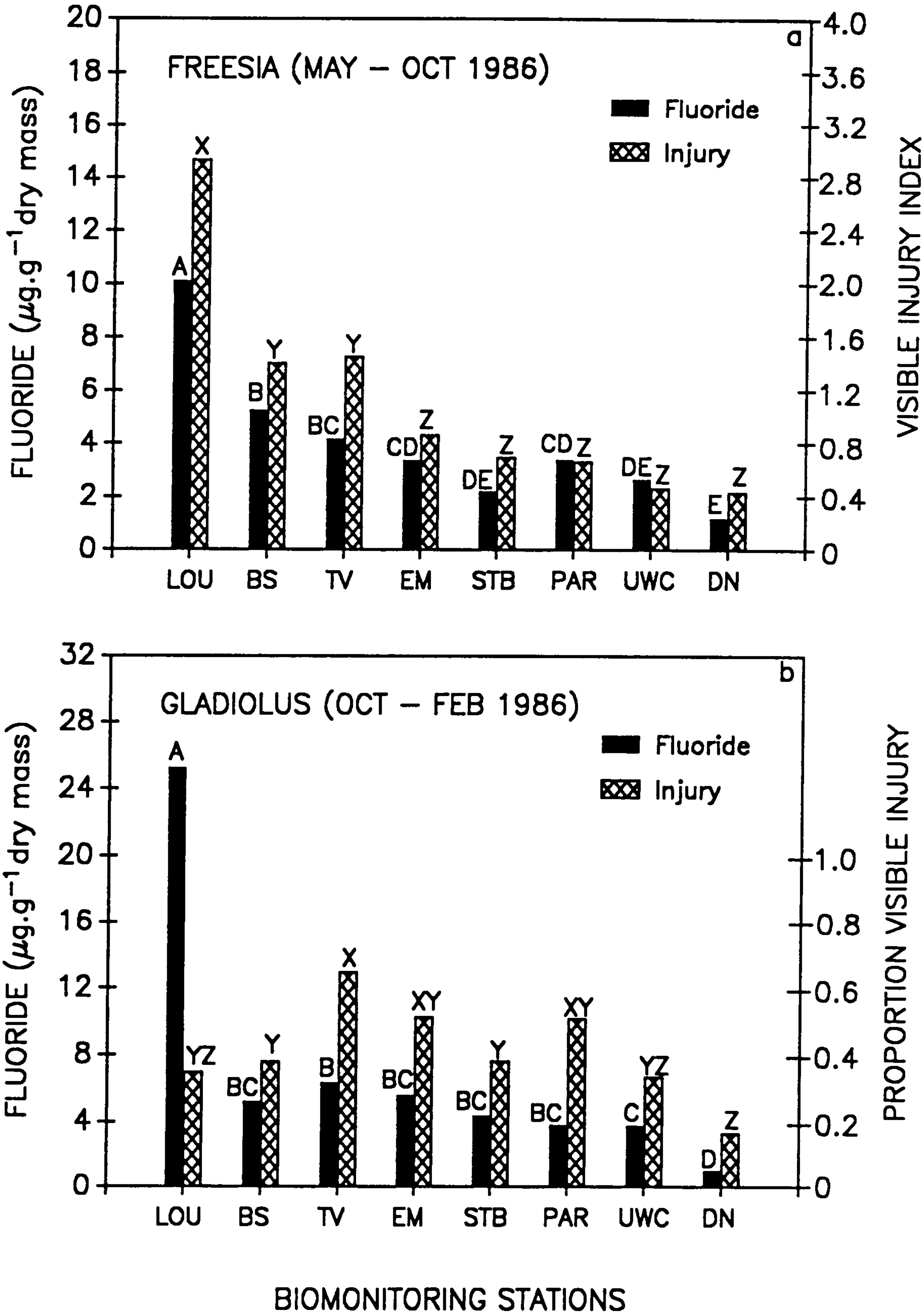
Fig. 6.6-6.7 Tip and marginal necrosis typical of fluoride injury, observed on leaves of *Freesia hybrida* cv. 'Golden Melody' at the Stellenbosch (6.6) and Drostersnes (6.7) biomonitoring stations, October 1987. Very little tip necrosis occurred on *Freesia* leaves exposed at the control station (Drostersnes).


6.6


6.7

<u>Fig. 6.8</u> a. The fluoride content of the leaves of *Freesia hybrida* cv. 'Golden Melody', exposed at the different biomonitoring stations during May - October 1986, compared to the degree of visible injury observed on those leaves. Fluoride values represent the mean (least squares means) of 10 (Drostersnes) or 12 (all the other biomonitoring stations) samples. The number of observations used to obtain the least squares means of the visible injury index, ranged from 30 (Edgemead) to 36 (Bothasig). Within a bar type, means accompanied by the same letter are not significantly different (LSMEANS (least squares means) procedure, SAS, 1989). Abbreviations for biomonitoring stations indicate: LOU = Loumar; BS = Bothasig; TV = Table View; EM = Edgemead; STB = Stellenbosch; PAR = Parow; UWC = University of the Western Cape; DN = Drostersnes.

b. The fluoride content of the leaves of *Gladiolus hortulanus* cv. 'Snow Princess', exposed at the different biomonitoring stations during October - February 1985/86 compared to the proportion of visible injury observed on those leaves. Fluoride values represent the mean of 12 samples. Visible injury values represent the mean of 32 samples. Within a bar type, means accompanied the same letter are not significantly different at $\alpha = 0.05$ (Duncan's multiple range test). Abbreviations used for biomonitoring stations are the same as in a.



FREESIA (MAY – OCT 1986)
a
Fluoride
Injury
FLUORIDE (µg.g⁻¹dry mass)
VISIBLE INJURY INDEX
20
18
16
14
12
10
8
6
4
2
0
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
A
X
B
Y
BC
Y
CD
Z
DE
Z
CD
Z
DE
Z
E
Z
LOU
BS
TV
EM
STB
PAR
UWC
DN
GLADIOLUS (OCT – FEB 1986)
b
Fluoride
Injury
FLUORIDE (µg.g⁻¹dry mass)
PROPORTION VISIBLE INJURY
32
28
24
20
16
12
8
4
0
1.0
0.8
0.6
0.4
0.2
0
A
YZ
BC
Y
B
X
BC
XY
BC
Y
BC
XY
C
YZ
D
Z
LOU
BS
TV
EM
STB
PAR
UWC
DN
BIOMONITORING STATIONS

Fig. 6.9 Visible injury indices for *Freesia hybrida* cv. 'Golden Melody' exposed at the different biomonitoring stations during 1986 and 1987. The number of observations used to obtain the least squares means of the visible injury indices, ranged from 22 (Table View, 1987) to 36 (Bothasig, 1986). For a given biomonitoring station, the 1986 and 1987 data was statistically compared At all the biomonitoring stations, significantly more injury (P = 0.001) was observed during 1987 than during 1986, except in the case of plants exposed at the control station (Drostersnes), in which case the values did not differ significantly (LSMEANS (least squares means) procedure, SAS, 1989). Abbreviations for the biomonitoring stations indicate: LOU = Loumar; BS = Bothasig; TV = Table View; EM = Edgemead; STB = Stellenbosch; PAR = Parow; UWC = University of the Western Cape; DN = Drostersnes.

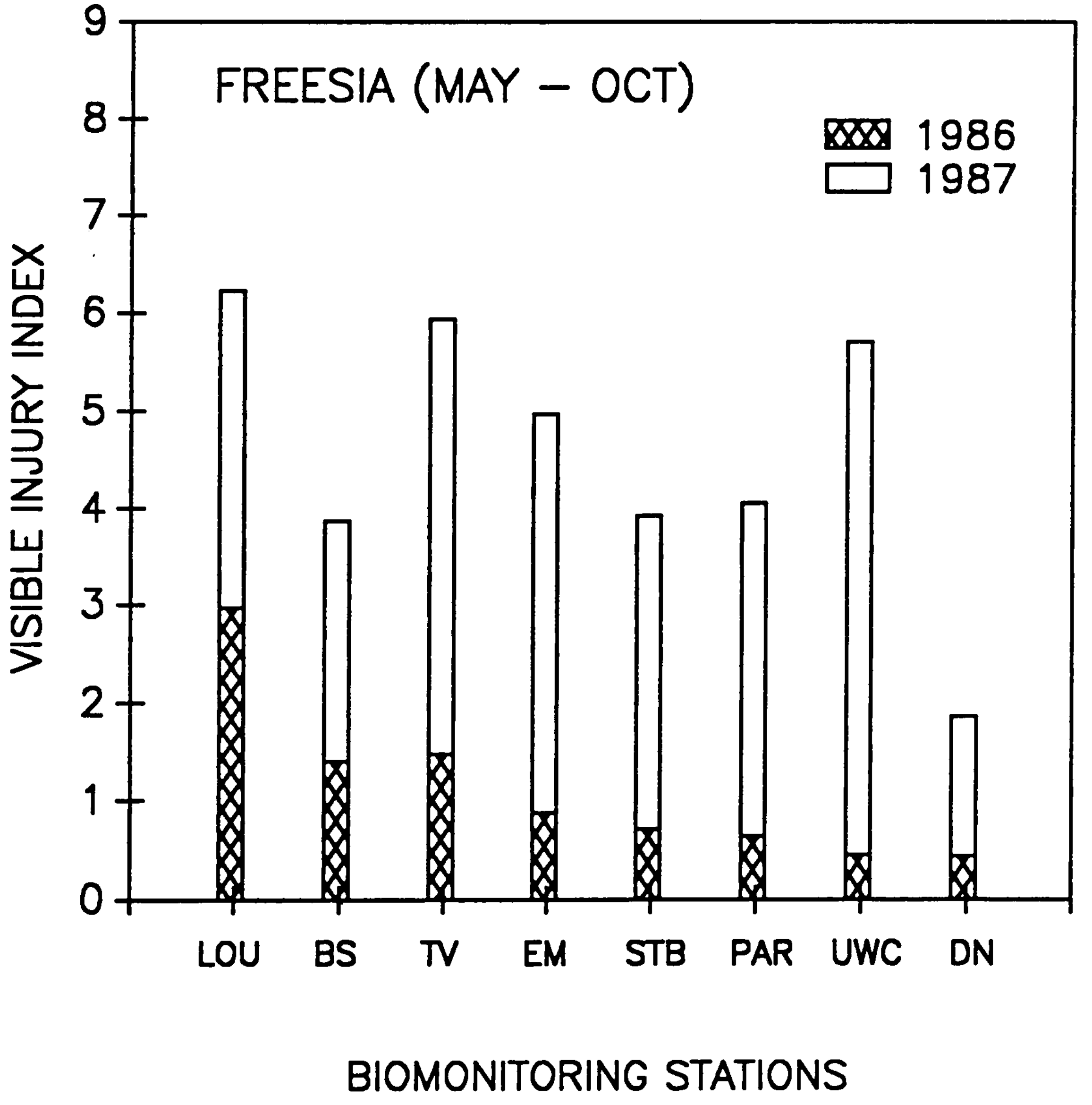
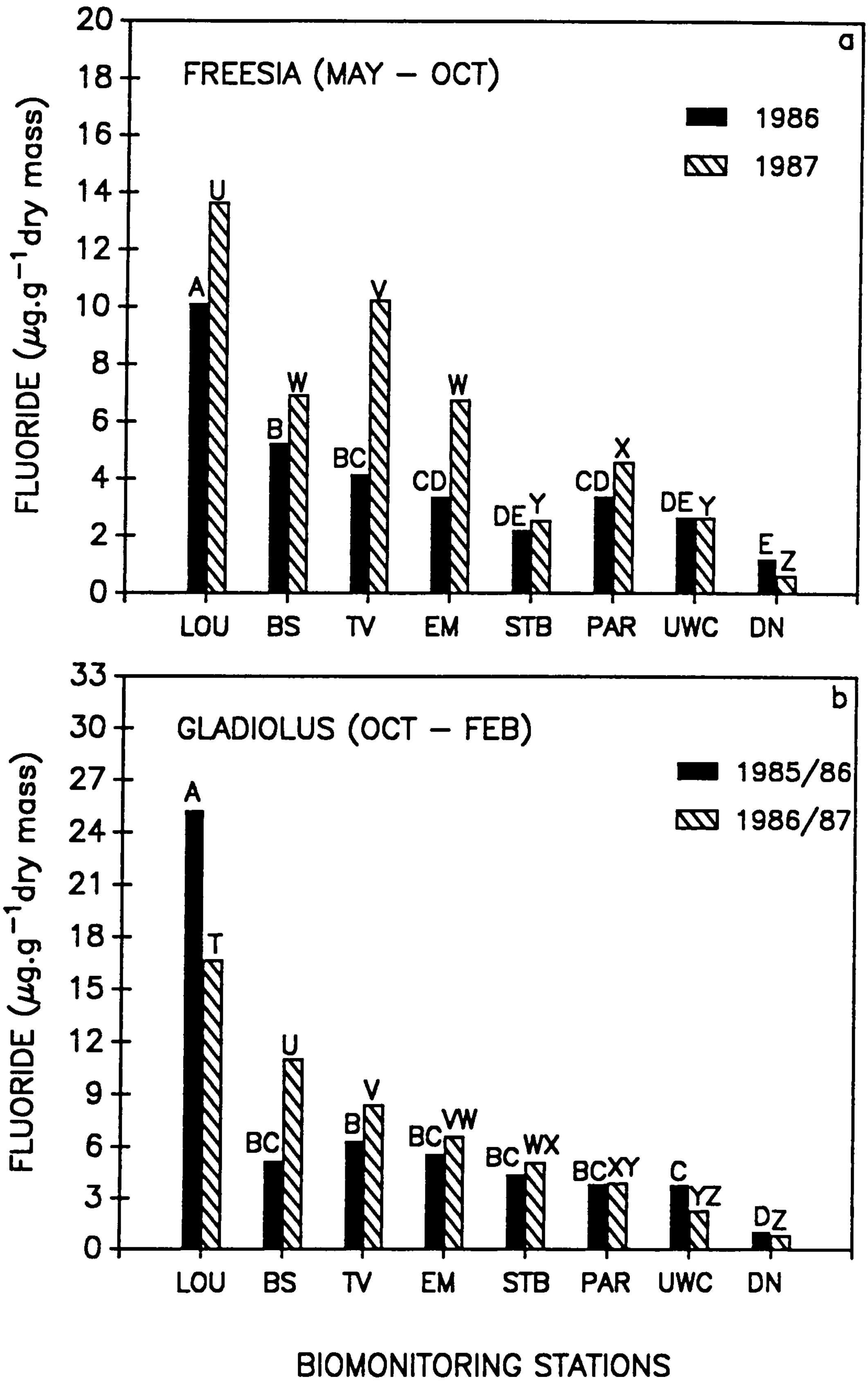

FREESIA (MAY – OCT)
1986
1987
VISIBLE INJURY INDEX
0
1
2
3
4
5
6
7
8
9
LOU
BS
TV
EM
STB
PAR
UWC
DN
BIOMONITORING STATIONS

Fig. 6.10 a. The foliar fluoride content of _Freesia_ _hybrida_ cv. 'Golden Melody' exposed at the different biomonitoring stations during 1986 and 1987. Fluoride values for 1986 represent the mean (least squares means) of 10 (Drostersnes) or 12 (all the other biomonitoring stations) samples. Fluoride values for 1987 represent the least squares means of 8 (Bothasig and Table View) or 9 (all the other biomonitoring stations) samples. Within a bar type, means accompanied by the same letter are not significantly different (LSMEANS (least squares means) procedure, SAS, 1989). Abbreviations for biomonitoring stations indicate: LOU = Loumar; BS = Bothasig; TV = Table View; EM = Edgemead; STB = Stellenbosch; PAR = Parow; UWC = University of the Western Cape; DN = Drostersnes.

b. The foliar fluoride content of _Gladiolus hortulanus_ cv. 'Snow Princess', exposed at the different biomonitoring stations during October - February 1985/86 and 1986/1987. Fluoride values for 1985/86 represent the mean of 12 samples. Fluoride values for 1986/87 represent the mean of 16 samples. Within a bar type, means accompanied the same letter are not significantly different at $\alpha = 0.05$ (Duncan's multiple range test). Abbreviations used for biomonitoring stations are the same as in a.



FREESIA (MAY – OCT)
a
1986
1987
FLUORIDE (μg.g^{-1}dry mass)
0
2
4
6
8
10
12
14
16
18
20
A
U
B
W
BC
V
CD
W
DE
Y
CD
X
DE
Y
E
Z
LOU
BS
TV
EM
STB
PAR
UWC
DN
GLADIOLUS (OCT – FEB)
b
1985/86
1986/87
FLUORIDE (μg.g^{-1}dry mass)
0
3
6
9
12
15
18
21
24
27
30
33
A
T
BC
U
B
V
BC
VW
BC
WX
BC
XY
C
YZ
D
Z
LOU
BS
TV
EM
STB
PAR
UWC
DN
BIOMONITORING STATIONS

attempted to exclude dead and senescent leaves from the statistical analysis of the data, the visible injury rated on plants at the UWC biomonitoring station was probably confounded by the influence of senescence, which had started to develop on many leaves in this group at the time that the plants were finally rated.

No correlation was observed between the fluoride content of Gladiolus leaves and the proportion of visible injury determined for the different biomonitoring stations. This discrepancy between the two parameters suggests that other factors, apart from atmospheric fluoride, were also contributing to the visible injury observed. The fact that relatively high levels (0.28 ppm) of SO_2 were periodically measured at Bothasig (Ravenscroft, 1987), together with the fact that typical SO_2 injury symptoms were repeatedly observed on beans leaves exposed at Bothasig, Table View and Edgemead (Chapter 7), suggest that SO_2 contributed to the visible injury measured on Gladiolus leaves exposed at these sites. The strong, dessicating winds from the south and south-south-east (Fig. 5.2), that usually prevail during the summer months (December to February), may also have contributed to the marginal and tip necrosis observed. Personal experience and the general appearance of the indicator plants (especially the degree to which the leaves were tattered), suggest that the Bothasig, Edgemead and Parow stations probably experienced the most and/or strongest winds.

The relatively high fluoride content determined in Freesia and Gladiolus leaves exposed at the Loumar station during both the winter (Freesia) and summer (Gladiolus) seasons of two consecutive years (Fig. 6.10 a & b), indicates that, compared to the other biomonitoring stations, the Loumar station probably experienced the highest atmospheric fluoride content throughout the year. The high fluoride content determined in leaves exposed at the Loumar station, may possibly be due to a potential source located in the Bellville South industrial area (Fig. 5.1). Plumes that probably originated from a glass factory were often seen to be transported from the Bellville South industrial area in a northern direction over the Loumar area. The predominant wind directions in the area are S and SSE during summer, NNW during winter and again S and SSE during spring (Fig. 5.2). Thus, at the Loumar station, both Freesia and Gladiolus indicator plants, were exposed to winds from the south, which probably contained fluoride pollutants. Substantial injury (>2% leaf tip necrosis), usually started to develop at the Loumar station earlier than at any other biomonitoring station.

The fluoride content of Freesia leaves exposed at the Bothasig biomonitoring station in 1986, was significantly higher than that of leaves exposed at the Edgemead, Stellenbosch, Parow, UWC and Drostersnes stations, but did not differ significantly from the fluoride content of leaves exposed at Table View. Bothasig and Table View are in close proximity (SSE and NW respectively) to a petroleum refinery and fertilizer factory located at the northern end of the Montague Gardens industrial area (Fig. 5.1). Both these industries are known sources of fluoride pollution (NAS, 1971), while petroleum refineries characteristically also emit SO_2 and hydrogen sulphide (H_2S) (Fox, 1986). During 1987 the fluoride content of Freesia leaves exposed at the Table View biomonitoring station was significantly higher than that at Bothasig and Edgemead, suggesting that southerly winds had a greater influence on pollutant distribution in this area during the 1987 than the 1986 exposure period. The fluoride content of leaves exposed at the control station (Drostersnes) did not differ significantly from that determined in leaves exposed at Stellenbosch and UWC during 1986, whereas it was significantly less than the values determined for any other station during 1987.

Results of the fluoride analysis of Gladiolus leaves exposed at the various biomonitoring stations during 1985/86 and 1986/87 (Fig. 6.10b) in general followed a similar pattern as that of the Freesia data for 1986 and 1987 (Fig. 6.10a), with the exception that the fluoride content of leaves exposed at the control station (Drostersnes) was significantly less than at any other biomonitoring station for both years. Photographical records of visible injury observed on Gladiolus leaves are presented in Fig. 6.11 to 6.16.

Figs. 6.11-6.13 Visible symptoms, typical of fluoride injury, observed on four middle aged leaves of representative plants of Gladiolus hortulanus cv. 'Snow Princess' exposed at some biomonitoring stations during the period October 1986 to February 1987. Marginal and tip necrosis are typically separated by a band of chlorotic tissue from the healthy green leaf tissue:

6.11 Injury observed at the Bothasig,

6.12 Loumar, and

6.13 Stellenbosch biomonitoring stations.

6.11

6.12

6.13

<u>Figs. 6.14-6.16</u> Visible symptoms, typical of fluoride injury, observed on four middle aged leaves of representative plants of <u>Gladiolus hortulanus</u> cv. 'Snow Princess' exposed at some biomonitoring stations during the period October 1986 to February 1987. Marginal and tip necrosis are typically separated by a band of chlorotic tissue from the healthy green leaf tissue:

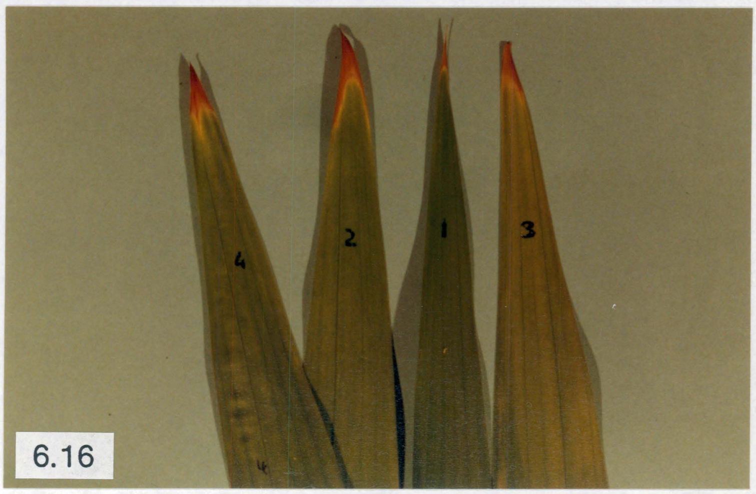
6.14 Injury observed at the Edgemead,

6.15 University of the Western Cape (UWC), and

6.16 Drostersnes (control) biomonitoring stations.

6.14

6.15



6.16

Vasiloff and Smith (1974) determined the fluoride content of washed leaves of _Gladiolus_ cv. 'Snow Princess' to range from 5.5 ppm at the control plot to 21.9 ppm 3.4 km from a fertilizer plant, with concomitant leaf injury of 0.8 % and 15.7 % per leaf respectively. During this study the fluoride content of 'Snow Princess' leaves ranged from 0.87 $\mu g.g^{-1}$ dry mass (ppm) at the control station to 7.18 $\mu g.g^{-1}$ dry mass in the vicinity of a fertilizer plant (Bothasig, Table View and Edgemead), to 20.94 $\mu g.g^{-1}$ dry mass downwind from a glass factory (Loumar). Values cited are the averages of 1986 and 1987 data. Corresponding leaf injury values of the 1986 data ranged from 16 % (control) to 51 % in the vicinity of the fertilizer plant, to 35 % downwind from the glass factory.

6.3.2 Open-top chamber experiments

The foliar fluoride content of _Freesia_ plants grown in the open-top chamber system at the Air Pollution Research Site at UWC, during 1986 and 1987, is indicated in Table 6.2, as well as the dry mass of the 1987 _Freesia_ shoots. Both years' results indicate that the fluoride content of leaves exposed in filtered open-top chambers was significantly less than in unfiltered open-top chambers. Results for 1987 also indicate that the fluoride content of leaves exposed in filtered as well as unfiltered chambers was

Table 6.2: The fluoride content and dry mass of *Freesia hybrida* cv. 'Golden Melody', grown in open-top chambers and open plots during 1986 and 1987. Values represent the mean of "n" observations as indicated. Within a column, means followed by the same letter are not significantly different at P = 0.05 (LSMEANS procedure, SAS, 1988).

TREATMENT	FLUORIDE CONTENT ($\mu g.g^{-1}$ dry mass)				DRY MASS (g)	
	---1986----		---1987----		----1987----	
	n		n		n	
Filtered chambers	13	0.53 A	28	0.45 P	28	2.351 Y
Unfiltered chambers	14	0.90 B	28	0.87 Q	28	2.327 Y
Open plots		-	14	1.24 R	14	2.062 Z

significantly less than that determined in leaves of plants grown on the open plots. The difference in foliar fluoride content of plants grown in unfiltered chambers and in open plots, may be attributed to the entrapment of pollutants by the chamber materials and presents a reduction of 30 %. Decreases in pollutant concentrations within unfiltered open-top chambers compared to ambient air, have previously been noted (Chevone, 1989). The dry mass data of 1987 indicate no significant differences between plants grown in filtered and unfiltered open-top chambers, but the dry mass of plants grown in the open plots was significantly less than both these groups. Apparently the 30 % reduction in fluoride uptake by plants in the unfiltered chambers, compared to that in ambient air, together with other possible chamber effects, were sufficient to significantly improve the growth of plants inside unfiltered chambers, as compared to the growth of plants in ambient air. The fluoride uptake by plants in filtered chambers was 52 % less than that in unfiltered chambers, but apparently this further reduction was not sufficient to significantly benefit the growth of plants in filtered chambers as compared to the growth of plants in unfiltered chambers. An analysis of the visible injury indices of plants grown in one filtered chamber, one unfiltered chamber and two open plots, revealed no significant differences between the treatments. Very little injury was observed and the injury indices ranged from

0.39 to 0.71. These values compare well with the visible injury index obtained for plants grown during 1986 in the plant cages of the biomonitoring network station at the same site (UWC), namely 0.46.

The foliar fluoride content of the plants grown in the open plots during 1987 (1.24 $\mu g.g^{-1}$ dry mass) was less than that of plants grown in the plant cages of the biomonitoring network station at the same site (UWC), namely 2.62 $\mu g.g^{-1}$ dry mass. This difference in the accumulation of fluoride between the two groups of plants can not be attributed to the difference in fluoride content of the irrigation water used for the plant cages and open-top chamber system. The fluoride content of the water used for the biomonitoring network stations (plant cages), which was always transported from Stellenbosch, was determined to be 0.1 ppm, while the pH measured 5.3. The fluoride content of the Bellville municipal water, used in the open-top chambers and open plots, was determined to be 1.4 ppm with a pH of 9.0 (Anonymous, 1988). However, the lower pH of the Stellenbosch water may cause fluoride to be more available to the plant via the root system, than in the case of the Bellville municipal water, which had a very high pH. Hani (1978) reported that when fluoride was added to an acid sandy loam, both it an aluminium increased in solution and this led to an increase in both elements in the leaves of maize.

The plants within the plant cages also experience a microenvironment different from that of the plants on the open plots. The cages provide some shading and may act as a windbreak. Stomatal conductance and the transpiration rates of plants within the cages may thus be higher than that of plants in the open plots, which may increase the foliar uptake of fluoride from the atmosphere, as well as accumulation via the roots.

The mean fluoride content ± standard error of the mean, of Freesia leaves exposed during 1987 at the control station (Drostersnes), was 0.61 ± 0.055 $\mu g.g^{-1}$ dry mass, compared to 0.45 ± 0.056 $\mu g.g^{-1}$ dry mass determined for plants grown in the filtered open-top chambers during the same period. The small difference between these two values, as well as the fact that these values are generally speaking very low, suggests that the accumulation of fluoride from the atmosphere at Drostersnes, was negligible. The foliar fluoride content of Gladiolus leaves grown in two filtered and two unfiltered chambers during 1986/87, was determined not to be significantly different and respectively averaged 1.16 ± 0.113 $\mu g.g^{-1}$ dry mass and 1.05 ± 0.166 $\mu g.g^{-1}$ dry mass. The fact that these values were not significantly different, is probably due to the disruption of the experiment by the replacement of the chamber walls and the installation of an irrigation system towards the end of 1986. The mean foliar fluoride content of plants exposed at the Drostersnes biomonitoring station during the same period, was

0.75 ± 0.192 $\mu g.g^{-1}$ dry mass, which is not significantly different from values obtained for plants grown in the open-top chambers and is similar to the value determined for *Freesia* exposed during 1987 at the same location. If the fluoride content of *Freesia* and *Gladiolus* plants exposed in the open-top chambers and at the Drostersnes biomonitoring station is considered, the conclusion can be drawn that background levels of fluoride in the relevant cultivars, under the conditions of these experiments, were probably in the range of 0.5 to 1.0 $\mu g.g^{-1}$ dry mass.

Depending on the species, fluoride analysis of vegetation, together with visible injury rating of the leaves, probably provide the best approach to the development of standards to protect vegetation from fluoride injury and to estimate trends atmospheric fluoride concentrations. For a winter growing species, such as *Freesia hybrida*, one of these parameters may suffice, since a good correlation between fluoride content and the amount of leaf injury that developed, was observed. *Gladiolus hortulanus* appeared to be more affected by environmental conditions such as the windy, dry summers experienced in the Southwestern Cape, thus necessitating both the measurement of foliar fluoride content and visible injury, in order to determine whether atmospheric fluoride concentrations have an adverse influence on the plants.

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CHAPTER 7

THE BIOMONITORING OF AMBIENT OZONE AND SULPHUR DIOXIDE WITH BEANS (*Phaseolus vulgaris* L.)

7. THE BIOMONITORING OF AMBIENT OZONE AND SULPHUR DIOXIDE WITH BEANS (*Phaseolus vulgaris* L.)

7.1 INTRODUCTION

A number of bean cultivars are sensitive towards low concentrations of ozone (O_3) (Butler and Tibbitts, 1979; Meiners and Heggestad, 1979) as well as sulphur dioxide (SO_2) (Saxe, 1983; Beckerson et al., 1979). Since the 1950's, bean plants have been used in several studies to determine the presence and relative amount of air pollutants (smog) present in an area (Middleton et al., 1955; Oshima, 1974; Feder and Manning, 1979). Manning and Feder (1980) listed the bush bean cultivar 'Tempo' and the dry bean cultivar 'Pinto III' as sensitive cultivars which do not have special cultural requirements and are suitable for use as biomonitors for O_3. In this study the pole bean cultivar 'Lazy Housewife', which is regularly planted in the South Western Cape, was used as biomonitor for O_3 as well as SO_2. Other cultivars tested during this study and the rationale for using 'Lazy Housewife', are described in par. 5.2.4.

Senecio elegans, an indigenous species to the Southwestern Cape region, which was previously determined to develop typical O_3 injury symptoms at concentration levels of 0.16 ppm O_3 (Chapter 3), was also used in an open-top chamber experiment conducted at the Air Pollution Research Site

(UWC), from November 1987 to April, 1988. Results of this experiment will be discussed briefly at the end of this chapter.

7.2 SPECIFIC MATERIALS AND METHODS

7.2.1 Cultivation:

Three to five seeds of *Phaseolus vulgaris* cv. 'Lazy Housewife' were planted per 15 cm diameter plastic pot. When the primary leaves had unfolded, the plants were thinned to one per pot, leaving the healthiest plants of similar size so that a relatively homogeneous plant set was obtained. The plants were allowed to stabilize for about five days after thinning and subsequently distributed to the biomonitoring stations. Plants were treated similarly during 1987 and 1988, except that they were distributed in the field at an earlier age during 1988 (before the primary leaves had unfolded), in order to lengthen the exposure period. The number of plants distributed and their growth stage at the time of distribution, is indicated in Table 7.1. The number of plants distributed did not necessarily correspond with the number of plants or leaves rated for injury, since some plants were lost due to unexpected death or natural hazards, including senescence, strong winds or

Table 7.1: The number of *Phaseolus vulgaris* cv. 'Lazy Housewife' bean plants distributed to the biomonitoring stations and open-top chamber system during 1987 and 1988, and the period that each group was exposed in the field.

YEAR	No. of open-top chambers or plots			No. of pots[2]		Date placed out and seedling stage[4]	Date returned to lab.	EXPOSURE PERIOD (weeks)
	F[1]	N	O	per chamber or plot	per cage[3]			
1987	2	2	2	7	3/4	Feb. 12 (Prim. exp.)	March 19	5
	4	2	2	4/5	3	April 16 (Prim. exp.)	May 20	5
1988	4	4	2	5	3	Feb. 1 (hypocotyl)	March 14	6
	4	4	2	4/5	3	March 14 (hypocotyl)	April 11	6.5

1. The number of filtered (F) and unfiltered (N) open-top chambers and open plots (O) in use, varied as indicated.
2. Each pot contained one plant.
3. Three plant cages were located at each of eight biomonitoring stations.
4. Bean plants were distributed either when their primary leaves were half to fully expanded ("prim. exp."), or when the hypocotyls have emerged.

consumption by insects.

Senecio elegans plants were grown from seed and each transplanted to a 15 cm diameter plastic plant pot when they were five to seven centimeters high. Fertilizer and pesticides were applied as necessary. The growth of *Senecio* leaves were monitored according the methods employed in the fumigation experiments discussed in Chapter 3. The leaf elongation of two opposite leaves, of which the youngest was the first leaf from the growth tip longer than 3 cm, was measured. Leaf elongation measurements were performed on the first set of leaves for the period February 12 to February 29, 1988, and on a second set of leaves for the period February 29 to April 19. After each period the chlorophyll content of the monitored leaves were determined, following the method of Knudson et al. (1977).

7.2.2 Fertilizer and pesticide application to bean plants:

A 50% solution of a complete liquid fertilizer ("Chemicult") was applied in 40 ml quantities to the soil of every plant at two-week intervals. To control pests, snail bait granules were scattered on the soil around each plant. To control white fly 1g/l solutions of "Lannate" were applied to plant foliage as indicated (the first spraying upon manifestation of the pest, followed up within three days to a week by a second spraying and repeated in two to three weeks intervals as necessary). To control and prevent fungus infections, "Dithane M45" (10g/5l) was sprayed on the foliage of all plants at two- to three week intervals. When an infestation of spider mite was observed, all plants were treated with "Oomite"(1 g/l). Treatment was repeated as necessary. All plants at the different biomonitoring stations received the same treatments, irrespective of whether individuals were actually infected. No foliar discoloration or markings were observed that could be connected to the application of pesticides or fertilizer.

7.2.3 Visible symptom expression and harvesting:

Visible symptom expression was rated on bean leaves every 10 to 14 days in 1987 and once a week in 1988. The percentage injury per leaf was rated for the primary leaves and the trifoliate leaves, individually, up to the fourth trifoliate. The percentage injury per leaf due to each kind of symptom present (eg. chlorosis, necrosis, bleaching, bronzing, etc.), was noted individually, and indicated on a form (Appendix 7.1), developed to increase consistency and efficiency during rating. The injury rating form was especially helpful when ratings could not be performed personally and an assistant had to conduct the rating. The final rating was done when the fourth trifoliates were fully expanded, at which time the plants were usually in flowering stage. At the time of the final rating, all the leaves with length greater than 3 cm were harvested, dried at 70 °C to constant weight and stored for chemical analysis.

7.2.4 Sulphur analysis:

The oven dried leaf material was ground to pass a 40-mesh sieve (0.5 mm diameter) and stored in clean, dry, tightly closed plastic bottles. These were stored with silica gel in larger plastic containers.

Leaf samples of plants that were exposed during April-May 1987 and March-April 1988 were analyzed for sulphur. These two sets were chosen since the worst pollution episodes are usually observed over the Greater Cape Town area during April, May and early June. Standard wet digestion procedures using nitric and perchloric acids were used to prepare the leaf samples for sulphur analysis (Sandel, 1950; Hern, 1979). Digested samples of leaf material, as well as two blank samples (containing no leaf material), were analyzed for sulphur on an Inductively Coupled Plasma Spectrometer (ICP) by the Soil Testing and Plant Analysis Laboratory at the Virginia Polytechnic Institute and State University, using appropriate standard solutions.

The sulphur content of each sample was calculated as follows:

$$\text{ppm S } (\mu g.g^{-1}) = (C - 0.10) \times vol/w$$

where C = ppm sulphur reading from ICP;

0.10 = ppm average background sulphur determined in two blank digested samples (i.e. without leaf material)

vol = volume of final solution (cm^3); and

w = sample mass (g).

7.2.5 Statistical procedures applied to the bean data:

All symptoms noted during the ratings of the percentage injury per leaf that might be attributed to air pollutants or that might be enhanced by air pollutants (eg. senescence and leaf fall) were entered on computer and analyzed utilizing SAS (1988). For individual symptom types, only "new" injury was entered for consecutive dates. In cases where it was clear that initial watersoaking developed into bleaching on a subsequent date, only the final amount of bleaching was taken into consideration in calculating the cumulative amounts of injury that occurred.

From initial frequency tables obtained, the frequency and time of occurrence of symptoms, such as chlorosis and leaf fall, that could be caused by natural factors such as senescence, were evaluated. If these symptoms occurred across sites and were predominant on the older leaves that could be expected to be naturally senescent, entries for these symptoms on the leaves concerned were suppressed by appropriate statements in the SAS-programme. The amounts of marginal-, tip-, interveinal necrosis and -chlorosis or general chlorosis were entered individually, but after initial evaluation these symptoms were grouped as necrosis or chlorosis, respectively, and collectively analyzed.

For each biomonitoring site: a) the occurrence of visible symptoms typical of air pollution injury was evaluated and b) the total injury (% per leaf) that developed over time until the plants were harvested, was compared to determine whether injury differed significantly at the various biomonitoring stations.

a) Evaluation of visible symptoms typical of air pollution injury:

In order to compare the severity of individual symptoms that occurred at the biomonitoring stations, the following steps were followed to express the percent injury values determined per leaf relative to the percentage frequency of injured cases. These steps were necessary since the number of plants as well as the number of leaves varied between the biomonitoring stations.

(i) The frequency (percent) of healthy versus injured cases were determined.

ii) The frequency of occurrence of individual symptoms, weighted by their rating values (% injury per leaf summed over exposure period) were determined.

(iii) The relative weighted frequencies were calculated in terms of the percentage frequency of injured cases reported, eg.:

For a given site consider the symptom 'bleaching':

For example, if the frequency of cases reported as injured = 70 %

and the percent weighted frequency summed for each rating date = 20 %
(i.e., of all injury symptoms rated, bleaching contributed 20% to the injured area):

Then the relative weighted frequency = 20 % of 70 %
= 14 %

The development of individual symptoms as they were rated over time, was illustrated graphically. The relative weighted frequencies (percent) were cumulated over time and stacked for each symptom at each rating date. Cumulative frequencies for each symptom were plotted as an 'ogive' which is a smoothed curve rather than the usual step function (Lentner, 1984), to facilitate easier comparison between symptoms. For each biomonitoring station the percentage cases reported as healthy or injured is indicated, as well as the relative percentage injury due to each individual symptom (indicated by a uniformly shaded area).

b) Comparison of total leaf injury that occurred at different sites:

The percentage new injury observed for each leaf on the different rating dates was cumulated (including all symptom types), to give the total percentage leaf area injured. A Kruskal-Wallis test was applied to the data for each leaf to determine whether leaf injury differed significantly at the various monitoring stations. Dunn's multiple comparison procedure (Hollander and Wolfe, 1973) was used to group stations, indicating whether differences among them were significant.

7.3 RESULTS AND DISCUSSION:

Results obtained with four sets of 'Lazy Housewife' beans exposed at the biomonitoring sites and in the open-top chambers during the following periods, will be discussed:

1. February - March 1987
2. April - May 1987
3. February - March 1988
4. March - April 1988

Results of additional data sets involving beans will be presented in a report to the CSIR, to be completed in 1989.

Results of open-top chamber experiments conducted with *Senecio elegans* will be discussed in par. 7.3.2.5.

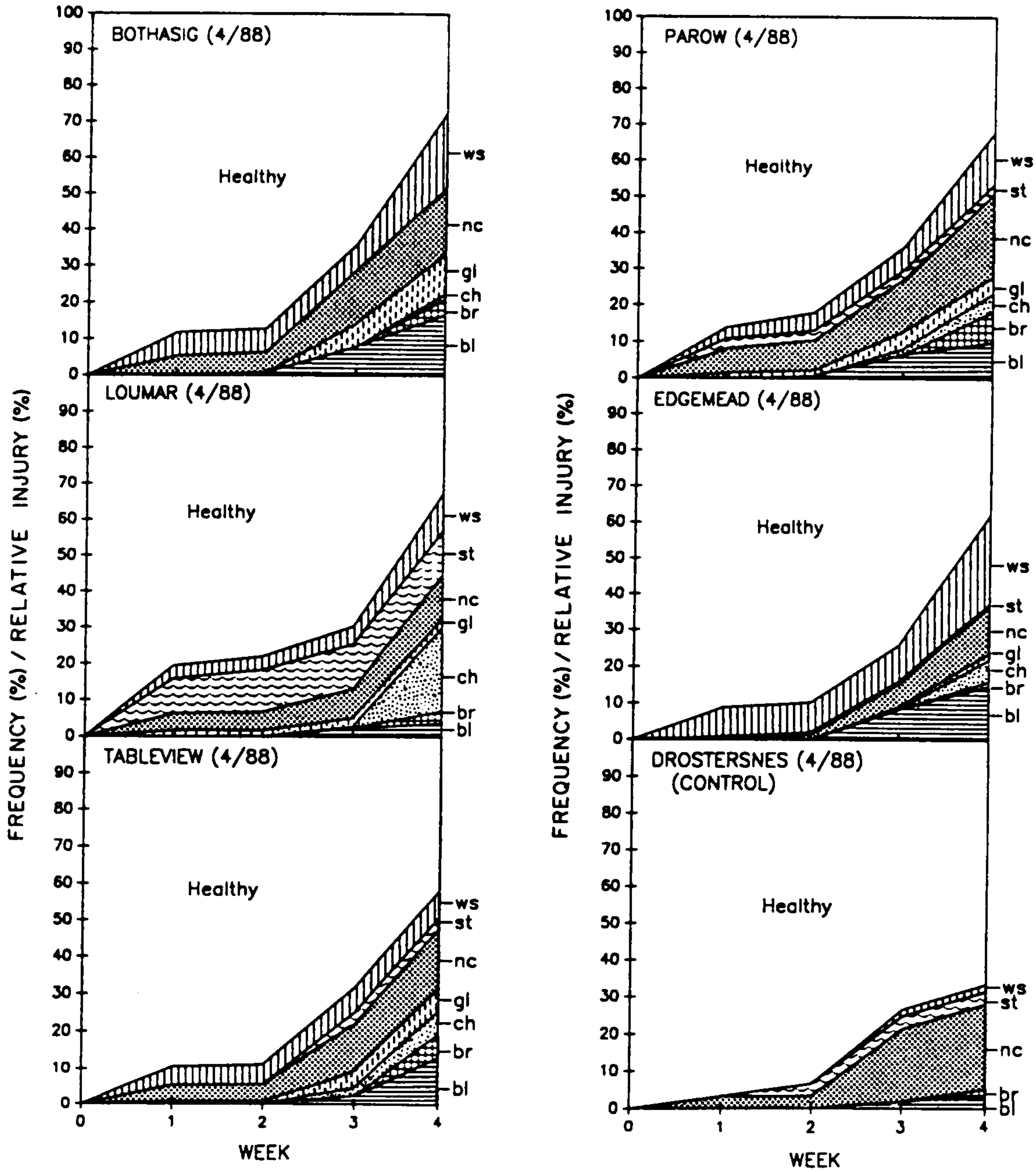
7.3.1 Biomonitoring network experiments:

7.3.1.1 Visible symptoms typical of air pollution injury:

The relative weighted frequencies of individual symptoms observed on bean leaves during March-April 1988 are indicated in Fig. 7.1, excluding data for the Stellenbosch and UWC biomonitoring stations. The Stellenbosch site experienced a strong wind storm during the biomonitoring period which caused premature leaf loss to the effect that no injury ratings could be performed during the third and fourth weeks. Symptoms at the UWC station were similar to those observed at the Table View station, except that no bronzing or glazing was observed. Each graph in Fig. 7.1

Fig. 7.1 Relative weighted frequencies of individual symptoms observed on bean leaves during March-April 1988, excluding data for the Stellenbosch and UWC biomonitoring stations.

Code of symptoms: bl = bleaching; br = bronzing; ch = chlorosis; gl = glazing; nc = necrosis; st stippling; ws = watersoaking.



BOTHASIG (4/88)
Healthy
ws
nc
gl
ch
br
bl
LOUMAR (4/88)
Healthy
ws
st
nc
gl
ch
br
bl
TABLEVIEW (4/88)
Healthy
ws
st
nc
gl
ch
br
bl
FREQUENCY (%) / RELATIVE INJURY (%)
WEEK
PAROW (4/88)
Healthy
ws
st
nc
gl
ch
br
bl
EDGEMEAD (4/88)
Healthy
ws
st
nc
gl
ch
br
bl
DROSTERSNES (4/88)
(CONTROL)
Healthy
ws
st
nc
br
bl
FREQUENCY (%) / RELATIVE INJURY (%)
WEEK

portrays the percentage cases reported as healthy and injured at each weekly rating date, as well as the relative percentage injury due to each symptom (indicated by the shaded area under each line). Week 0 represents the time that the plants were distributed to the biomonitoring stations, in this case March 14, 1988. Substantial marginal and tip necrosis occurred at all the biomonitoring stations. Necrosis can be caused or enhanced by a variety of environmental factors other than air pollution, such as high or low temperatures and strong winds. Such factors may account for the relatively high values rated for necrosis at the Drostersnes station, being located in the mountains and at a higher elevation than the rest of the monitoring stations. The expression of other symptoms varied from station to station, eg. watersoaking and bleaching were more pronounced at the Bothasig, Edgemead and Parow stations.

Individual symptoms observed during 1987 and March 1988 were similar to those observed during April 1988, with necrosis, bleaching and watersoaking being the major symptoms noted. Since necrosis can be enhanced by non-pollution factors such as heat stress, the occurrence of bleaching, bronzing and watersoaking (typical symptoms of SO_2 injury), as it occurred at the various stations during the four growing periods under consideration, have been compared in Table 7.2. The three symptoms, bleaching, bronzing and watersoaking, were most pronounced at Bothasig, followed by Parow and

Table 7.2: Relative weighted frequencies (%) of injury symptoms typically induced by sulphur dioxide pollution, observed on 'Lazy Housewife' beans. Injury was rated at eight biomonitoring stations during four biomonitoring periods in 1987 and 1988.

SITE	Bleaching			Watersoaking			Bronzing			Row total
	March 1987	March 1988	April 1988	March 1987	March 1988	April 1988	March 1987	March 1988	April 1988	
Bothasig	13	34	17	1	21	21	6	<1	4	118
Drostersnes	2	6	4	0	2	2	0	0	2	18
Edgemead	3	13	15	1	17	25	3	3	1	81
Loumar	12	13	4	1	2	10	9	6	3	60
Parow	24	14	10	1	2	14	14	3	8	90
Stellenbosch*	-	17	-	-	6	-	-	1	-	-
Table View	3	13	14	0	6	8	0	7	7	58
U.W.C.	3	8	3	0	9	13	2	2	0	40

* The Stellenbosch biomonitoring station experienced severe winds during March 1987 and April 1988, which caused substantial leaf loss and led to incomplete data sets.

Edgemead. Bothasig and Edgemead are downwind of a petroleum refinery and fertilizer factory at the northern end of the Montague Gardens Industrial area (Fig. 5.1). Petroleum refineries are known sources of SO_2 pollution, as are Kraft mills, although Bothasig, Edgemead and Parow are probably not located downwind from the Kraft mill near Milnerton.

According to measurements made by the Cape Divisional Council's mobile air monitoring unit, dominant wind directions during March and May are NW and NNW in the Bothasig and Edgemead areas (Cape Divisional Council, 1986, 1987). Levels of 0.28 ppm SO_2 have been registered in Bothasig by the mobile air monitoring unit (Ravenscroft, 1987). Since injury to vegetation may be expected at SO_2 levels above 0.05 ppm (Manning and Feder, 1976), it is highly probable that the bleaching and watersoaking observed on bean leaves at the Bothasig and Edgemead biomonitoring stations were caused, at least in part, by SO_2 immissions. Watersoaked areas usually became bleached or necrotic on subsequent dates. Examples of the typical pattern of interveinal bleaching and other symptoms as observed at the biomonitoring stations, are presented in Figs. 7.2 to 7.6.

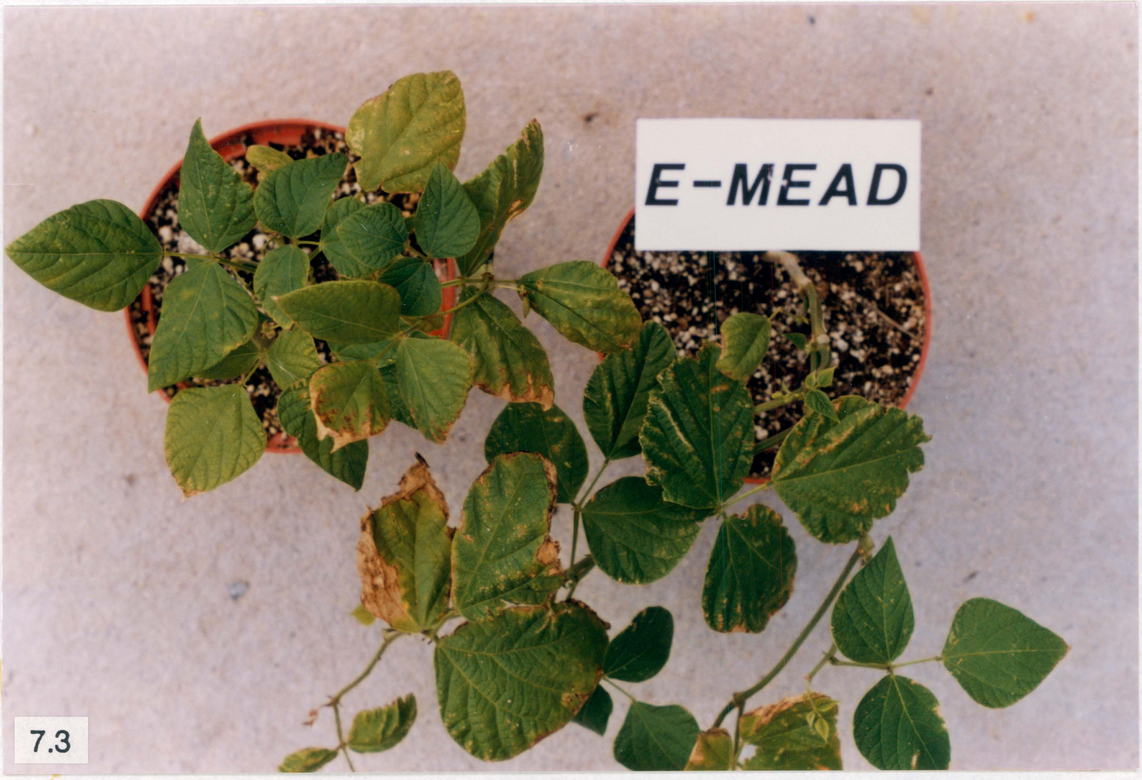
Symptoms observed at the Parow station could be caused by pollution from plumes from the refinery-area as well as from industries in the Parow and Elsiesriver industrial areas located south of the Parow biomonitoring station. Predominant wind directions measured at D.F. Malan Airport

<u>Figs. 7.2-7.3</u> Typical visible injury symptoms observed on bean leaves (Phaseolus *vulgaris* L. cv. 'Lazy Housewife') at various biomonitoring stations, March 1987:

7.2 Interveinal bleaching (Bothasig).

7.3 Marginal and interveinal bleaching and necrosis (Edgemead).

7.2



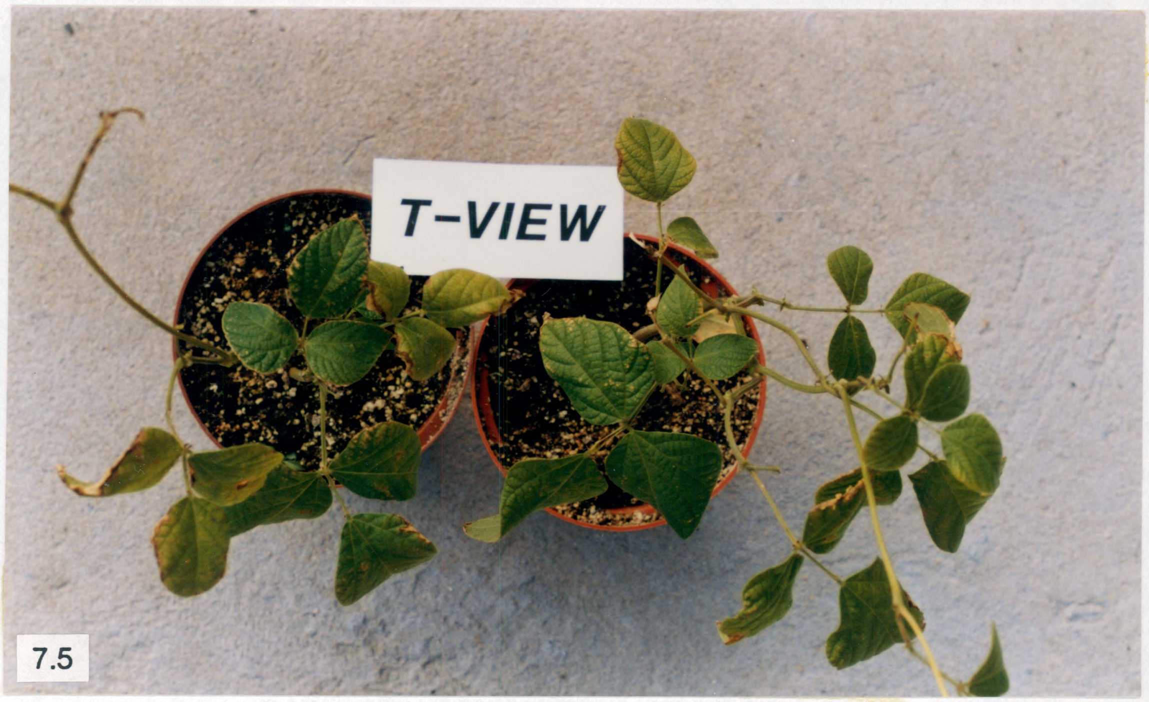
7.3

Figs. 7.4-7.5 Typical visible injury symptoms observed on bean leaves (*Phaseolus vulgaris* L. cv. 'Lazy Housewife') at various biomonitoring stations, March 1987:

7.4 Interveinal bleaching, upper surface bronzing and marginal necrosis (Parow).

7.5 Limited marginal and interveinal bleaching and necrosis (Table View).


PAROW
7.4


T-VIEW
7.5

Figs. 7.6 No injury symptoms were observed on bean leaves at the control station (Drostersnes).


D-NES
7.6

are from the S and SSE during February to April (Weather Bureau, 1985).

Symptoms observed at the Loumar station could similarly result from industrial pollution blown by southerly winds from the Bellville South Industrial area. Pollution reaching the Loumar and Parow stations is probably a mixture of urban industrial pollutants containing components of photochemical smog, thus accounting for the relative higher incidence of bronzing observed at these sites. Loewenheim (1988) analyzed available continuous monitor data recorded in 1985 and 1986 in the Greater Cape Town area and found that higher O_3 levels were generally experienced in the northerly suburbs, under southerly winds and that levels diminished under northerly winds. Data from Table View showed the more marked effect of a northerly wind (Loewenheim, 1988). According to Loewenheim (1988) O_3 concentrations equalled or exceeded the World Health Organization (WHO) 1-h goal of 0.06 ppm on 26 occasions with a maximum of 0.07 ppm, with the majority of days occurring in August.

Injury symptoms typically associated with photochemical smog are bronzing of the upper or lower leaf surfaces, stippling of the upper leaf surfaces and glazing of the lower leaf surfaces. In acute conditions, bronzing and stippling (fleck) may become bifacial (Manning and Feder, 1980; Hill et al. 1970). Bronzing and glazing reported during the present experiments with beans occurred mainly on the upper leaf surface. During April 1988 the highest incidences (relative weighted frequencies %) of glazing were reported for Parow (5%), Table View (6%) and Bothasig (11%). Glazing was also reported at most urban biomonitoring stations during March 1988, but did not exceed 3%. Glazing was not reported during March and May 1987. The amounts of stippling reported at the various stations appeared to be insignificant and, except for the Loumar (13%) and UWC (10%) stations during April 1988 and the Bothasig station (7%) during March 1987, the relative weighted frequency did not exceed 3%. Although there are indications that some sort of photochemical smog may have contributed to the injury symptoms observed on bean leaves at the urban biomonitoring stations, results are not conclusive. Due to possible antagonistic effects of air pollutant mixtures on the development of typical O_3 injury symptoms (Beckerson et al. 1979; Hofstra et al. 1985), more conclusive evidence for O_3 injury might have gone undetected in the study area. The bean cultivar used, 'Lazy Housewife', may not be among the most sensitive cultivars. It needs to be compared under controlled conditions to known sensitive cultivars such as certain 'Bush Blue Lake'. The sensitivity of many bean cultivars have been compared by Butler and Tibbitts (1979), Meiners and Heggestad (1979) and others, although many cultivars still remain to be tested.

The sensitivity of plants towards O_3 is greatly influenced by humidity and it is suggested that humidity may account in part for the greater sensitivity of plants to O_3-type injury in the eastern United States compared with the same species grown in the Southwest (Otto and Daines, 1969). Low relative humidities may also account for the lack of substantial O_3-type injury observed in the Southwestern Cape, South Africa, since the summers are dry and warm.

7.3.1.2 Comparison of total leaf injury at the different biomonitoring stations:

The percentage new injury observed for each leaf on the different rating dates was cumulated (including all symptom types), to give the total percentage leaf area injured. Results are presented in Tables 7.3 to 7.8. The first Table for each dataset indicates for each site the mean total injury rated per leaf, as well as the frequency of injury (number of cases that injury was reported as a percentage of the total number of cases evaluated). The second Table for the dataset indicates the mean rank sums calculated during the Kruskal-Wallis procedure and the results of Dunn's multiple comparison procedure.

March 1987 data: The percentage injury observed per leaf was consistently higher at the Bothasig biomonitoring station than at the Drostersnes, UWC and Table View sites (Tables 7.3 and 7.4). These differences between sites were

Table 7.3: Percentage injury per leaf of 'Lazy Housewife' beans as rated at the different biomonitoring stations. The total injury that occurred during the exposure period was summed for each leaf. Values represent the mean total injury per leaf ± standard error of the mean, arranged in decreasing order of severity from left to right, March 1987.

% INJURY[1] PER LEAF ($\bar{x} \pm s / \sqrt{n}$) MARCH 1987							
	Biomonitoring stations						
LEAF	Bothasig	Edgemead	Parow	Loumar	Drostersnes	UWC	Table View
Primary 1	6.7±3.8c	0.8± 0.6	0.8±0.4a	0.0±0.0	9.1±4.4a	4.9±3.3	2.2±1.3a
Primary 2	7.2±3.7c	13.1±11.7b	5.8±1.7	5.9±4.0	5.9±1.9b	7.9±2.7	1.6±0.8
Trifoliate 1	8.7±2.3c	2.8± 0.9	3.7±1.5	5.4±1.5c	0.7±0.5	0.4±0.3	0.4±0.3
Trifoliate 2	17.9±6.0	9.3± 3.8	11.7±4.3	9.3±2.3	4.3±1.7	5.1±1.3	9.4±5.1
Trifoliate 3	17.0±5.9a	7.2± 1.9	12.4±5.2a	8.5±2.7	2.4±0.7	0.8±0.3	1.8±0.8
Trifoliate 4	14.6±3.3a	5.2± 1.9a	3.7±0.8d	2.1±1.2b	0.8±0.4	0.9±0.9b	1.6±0.5
Column total	72.2	38.3	38.0	31.2	23.1	20.0	16.9
Frequency of injury (%)	89.1	68.7	87.5	69.2	41.9	39.1	39.2

1. Values represent the mean injury of 'n' leaves from 'n' plants, where n = 10, except in the following cases: a: n = 9; b: n = 8; c: n = 7; d: n = 6;

Table 7.4: Kruskal-Wallis mean scores of the total injury observed on bean leaves rated at each site, March 1987. Values followed by the same letter are not significantly different, using Dunn's multiple comparison procedure and an experimentwise error rate of 0.2 (Hollander and Wolfe, 1973).

SITE	PRIMARY LEAVES		TRIFOLIATE LEAVES			
	1	2	1st	2nd	3rd	4th
	RANK[1]					
Bothasig	41 AB	35 A	52 A	50 A	47 A	50 A
Edgemead	28 AB	28 A	37 AB	36 A	42 AB	36 AB
Parow	31 AB	38 A	37 AB	40 A	48 A	39 AB
Loumar	22 B	27 A	48 A	39 A	43 AB	25 B
Drostersnes	44 A	38 A	22 B	24 A	25 ABC	20 B
UWC	33 AB	37 A	21 B	30 A	17 C	19 B
Table View	32 AB	23 A	21 B	29 A	22 BC	26 B

1. Average ranks used for ties.

significant only in the cases of the first and fourth trifoliates ($P \leq 0.04$). There was however substantial variation among plants within a site as indicated by the large standard error values (Table 7.3). The general trend observed for the other biomonitoring stations was that injury observed at the Edgemead, Parow and Loumar stations was less than at Bothasig, but worse than at the Drostersnes (control), UWC and Table View stations. Injury observed on the primary leaves and second trifoliate did not differ significantly between sites, suggesting that no pollution episodes prevailed during the times that these leaves were exposed or at a sensitive stage.

<u>May 1987 data</u>: Symptom expression on the bean plants harvested during May 1987, was confounded by excessive chlorosis and premature leaf fall which could be ascribed to a cold spell and large amounts of rain that occurred during the week prior to harvesting. Attempts were made to filter these effects from the data, but no consistent results were obtained.

<u>March 1988 data</u>: For all the leaves considered, except the second primary, the percentage injury rated per leaf was significantly higher at the Bothasig biomonitoring station than at the UWC and Drostersnes (control) stations (Tables 7.5 and 7.6). For most of the leaves rated, no significant

Table 7.5: Percentage injury per leaf of 'Lazy Housewife' beans as rated at the different biomonitoring stations. The total injury that occurred during the exposure period was summed for each leaf. Values represent the mean total injury per leaf ± standard error of the mean, arranged in decreasing order of severity from left to right, March 1988.

LEAF	% INJURY[1] PER LEAF ($\bar{x} \pm s / \sqrt{n}$) MARCH 1988							
	Biomonitoring stations							
	Bothasig	Table View	Loumar	Edgemead	Parow	Stellen-bosch	UWC	Drosters-nes
Primary 1	48.1± 8.3a	37.2±11.1	40.0± 8.4	21.9± 4.3a	21.3±5.9a	1.5±0.4	9.0±5.0a	5.7±3.1a
Primary 2	43.0± 7.2	26.3±11.0	37.7± 6.0	28.9± 8.5b	14.4±4.6b	1.6±0.5	12.9±3.9a	6.9±2.2b
Trifoliate 1	52.8± 6.3	48.7± 6.7	32.8± 5.6b	41.1±10.5c	10.6±3.0a	21.6±3.5	11.7±1.4	9.2±1.8f
Trifoliate 2	55.3± 7.9	56.5±10.3c	28.6±12.4c	31.9± 9.7c	10.9±3.1	22.9±6.4b	15.2±5.6c	5.8±2.1e
Trifoliate 3	31.3± 9.8b	12.9± 3.5a	3.9± 2.6b	7.6± 2.7a	1.7±1.7	3.6±1.4	1.4±1.2	2.1±1.2
Trifoliate 4	10.9± 3.0a	2.1± 0.7	0.7± 0.7	0.7± 0.7a	0.6±0.6	0.0±0.0	0.4±0.3	0.0±0.0
Column total:	241.4	183.7	143.6	132.2	59.5	51.2	50.8	29.6
Frequency of injury (%) :	95.52	84.62	77.05	85.71	66.67	51.43	59.68	42.22

1. Values represent the mean injury of 'n' leaves from 'n' plants, where n = 9, except in the following cases: a: n = 8; b: n = 7; c: n = 6; d: n = 5; e: n = 4; f: n = 3;

Table 7.6: Kruskal-Wallis mean scores of the total injury observed on bean leaves rated at each site, March 1988. Values followed by the same letter are not significantly different, using Dunn's multiple comparison procedure and an experimentwise error rate of 0.2 (Hollander and Wolfe, 1973).

SITE	PRIMARY LEAVES		TRIFOLIATE LEAVES			
	1	2	1st	2nd	3rd	4th
	RANK[1]					
Bothasig	54 A	51 A	47 A	42 A	58 A	61 A
Table View	45 AB	35 AB	45 A	43 A	51 AB	45 AB
Loumar	49 A	48 A	35 AB	27 AB	27 BC	31 B
Edgemead	39 ABC	42 AB	40 AB	30 AB	41 ABC	31 B
Parow	37 ABCD	30 ABC	14 B	15 B	20 C	31 B
Stellenbosch	11 D	8 C	26 AB	25 AB	32 ABC	27 B
UWC	21 BCD	28 ABC	15 B	18 B	22 C	33 B
Drostersnes	17 CD	19 BC	12 B	9 B	24 C	27 B

1. Average ranks used for ties.

differences were observed among leaf injury at the Bothasig, Table View, Loumar and Edgemead stations, although injury was usually worst at Bothasig and Table View. The control station (Drostersnes) and UWC were usually among the stations at which the least injury was observed. Leaf injury ratings for the Parow and Stellenbosch stations were intermediary between ratings obtained for the stations with plants having the worst and least injuries, but did not differ significantly from leaf injury observed at the control station (Drostersnes).

April 1988 data: For most of the leaves rated, the largest amount of leaf injury was again observed at the Bothasig biomonitoring station. However, these values differed significantly from values for the control station (Drostersnes) only at the time that the second and third trifoliates were rated (Tables 7.7 and 7.8). The markedly higher injury ratings obtained for these trifoliates at the urban biomonitoring stations suggests that an air pollution episode may have occurred during the time that these leaves were exposed and at a sensitive stage.

7.3.1.3 General conclusions on visible injury that occurred at the various biomonitoring stations:

Evaluation of results from the frequency analyses, analyses of individual symptoms, mean leaf injury and

Table 7.7: Percentage injury per leaf of 'Lazy Housewife' beans as rated at the different biomonitoring stations. The total injury that occurred during the exposer period was summed for each leaf. Values represent the mean total injury per leaf ± standard error of the mean, arranged in decreasing order of severity from left to right, April 1988.

	% INJURY[1] PER LEAF ($\bar{x} \pm s / \sqrt{n}$) APRIL 1988						
	Biomonitoring stations						
LEAF	Bothasig	Loumar	Edgemead	Table View	UWC	Parow	Drostersnes
Primary 1	4.4±2.7a	4.9±1.4b	2.4±0.7	3.2±1.8	4.4±1.4c	3.3±0.1d	0.0±0.0d
Primary 2	4.1±2.8a	7.5±2.4	2.1±1.4a	2.3±1.0	8.2±2.5c	3.1±0.9b	1.2±1.2e
Trifoliate 1	10.7±4.1a	6.0±1.6	7.1±2.0	5.8±2.9	4.3±1.7b	6.4±1.9	3.4±1.7b
Trifoliate 2	19.9±2.9	18.8±9.5	16.1±4.5	15.5±5.0	13.0±6.4c	6.5±2.1	2.0±0.7b
Trifoliate 3	5.9±1.2	2.1±0.7	3.4±1.2	3.4±1.3	0.7±0.4b	1.6±0.5	0.0±0.0b
Trifoliate 4	3.0±1.0	0.5±0.3	1.4±0.9	0.5±0.3	0.0±0.0b	0.8±0.4	0.0±0.0b
Column total	48.0	39.9	32.5	30.6	30.5	21.6	6.6
Frequency of injury (%)	72.6	67.2	62.3	60.7	56.8	67.9	34.2

1. Values represent the mean injury of 'n' leaves from 'n' plants, where n = 8, except in the following cases: a: n = 7; b: n = 6; c: n = 5; d: n = 4; e: n = 3;

Table 7.8: Kruskal-Wallis mean scores of the total injury observed on bean leaves rated at each site, April 1988. Values followed by the same letter are not significantly different at an experimentwise error rate of 0.2 (Dunn's multiple comparison procedure, Hollander and Wolfe, 1973).

SITE	PRIMARY LEAVES		TRIFOLIATE LEAVES			
	1	2	1st	2nd	3rd	4th
	RANK[1]					
Bothasig	21 A	19 A	32 A	39 A	40 A	40 A
Loumar	29 A	30 A	28 A	26 ABC	26 AB	25 A
Edgemead	21 A	17 A	29 A	30 AB	32 AB	29 A
Table View	19 A	19 A	23 A	30 AB	30 AB	25 A
UWC	28 A	33 A	22 A	30 AB	17 B	19 A
Parow	23 A	23 A	28 A	18 BC	23 AB	28 A
Drostersnes	9 A	15 A	19 A	8 C	12 B	19 A

1. Average ranks used for ties.

Kruskal-Wallis analyses lead to the following general conclusions:

1. During the biomonitoring periods considered, the greatest amount of leaf injury occurred at the Bothasig station, generally followed by Edgemead and Loumar and Parow. Injury observed at the Drostersnes station (control) was significantly less than that observed at Bothasig. Injury observed at UWC and Stellenbosch did not differ significantly from that observed at Drostersnes.

2. The amount of injury observed at the Table View station relative to that observed at the other biomonitoring stations, varied substantially from one biomonitoring period to the next. In general, injury observed at the Table View station rated second to that observed at Bothasig during March 1988, but rated amongst the lowest for all stations during March 1987 and intermediary during April 1988. This variability may be linked to the directions of local winds that occurred during the relevant periods. Unfortunately no local wind data is available for these periods.

3. In most cases there appeared to be a positive correlation between the frequency and the amount of injury

observed, indicating that the symptoms observed were not isolated cases that occurred on a few plants only.

4. In spite of the correlation mentioned above, the amounts of leaf injury varied substantially at most stations as indicated by the relatively large standard error values and accounts for the fact that differences are found to be statistically significant only in extreme cases.

5. The kinds of symptoms that dominated at the worst injured stations resemble those typical of SO_2 injury. Considering the potential sources in the area, it is likely that leaf injury at these sites are predominantly caused by ambient SO_2.

6. Visible injury on bean leaves were found to be worse during February - March 1988 than during the other biomonitoring periods considered. Hourly maximum SO_2 levels recorded during February, March and April 1988 by the mobile monitor of the Cape Divisional Council were 0.02 ppm (57 $\mu g/m^3$), 0.015 ppm (39 $\mu g/m^3$) and 0.04 ppm (112 $\mu g/m^3$), respectively. During April 1988 0.04 ppm was recorded on one occasion only. At this time the mobile monitor was located in Bellville several kilometers downwind of the petroleum refinery at Bothasig, on a slope of the Tygerberg hills north-east of the Parow

biomonitoring station. Although these levels may not necessarily be representative of pollution levels at the biomonitoring stations themselves, indications are ambient SO_2 concentrations were not excessive during February and March 1988 and that injury symptoms observed during March 1988 were aggravated by a severe heat spell experienced towards the end of February. In addition to the typical SO_2 induced injury symptoms of bleaching and watersoaking observed, terminal and marginal necrosis made up a large proportion of the injury observed at the various stations.

7.3.1.4 Sulphur content:

The sulphur content of leaf material of plants exposed at the different biomonitoring stations during April-May 1987 and during March-April 1988, is indicated in Table 7.9. Leaf samples from four biomonitoring stations were analyzed: from two stations which are thought to be relatively polluted (Bothasig and Table View), from one which is thought to be relatively unpolluted (UWC) and from the control station (Drostersnes). In the case of the May 1987 dataset, leaves from the three plants in a cage were combined, since the plants were relatively small and leaf material limited. The leaf sulphur content of plants exposed at Bothasig was significantly higher than that of leaves exposed at the other three stations. During 1987 the mobile monitor of the

Table 7.9: The sulphur content of bean leaves (*Phaseolus vulgaris* L.) at four biomonitoring stations during April-May 1987 and during March-April 1988.

Monitoring Station	April-May 1987[1] Sulphur Content ($\mu g.g^{-1}$ DW) (ppm)	March-April 1988[2] Sulphur Content ($\mu g.g^{-1}$ DW) (ppm)
Bothasig	4953.3 A	3831.8 A
UWC	4184.3 B	4200.3 A
Table View	4126.3 B	3339.4 A
Drostersnes	4078.3 B	3759.0 A

1. Leaf samples from three plants within a cage were combined and values represent the mean of three replicates (cages) at a site. Means within a column, followed by the same letter are not significangly different at $\alpha = 0.05$ (Duncan's multiple range test).

2. Values represent the mean (least squares mean) of 6 (Drostersnes and UWC) or 8 (Bothasig and Table View) plants. Means are not significantly different.

Cape Divisional Council was located at a site in Bothasig, not far from the biomonitoring station. Hourly maximum SO_2 concentrations recorded by the mobile monitor peaked during April and May 1987 with values of 0.05 ppm (141 $\mu g/m^3$) and 0.11 ppm (278 $\mu g/m^3$) respectively for these months. During April 1987 the 0.04 ppm level was exceeded 5 times, while it was exceeded 15 times during May 1987. The 0.08 ppm level was exceeded 4 times during May 1987. Ambient SO_2 concentrations in these ranges are known to cause visible injury on sensitive plants and to lead to increased foliar sulphur concentrations (Linzon et al., 1979).

No records are available for wind directions at Bothasig mobile monitor during April 1987, but during May 1987 northerly winds dominated 50 % of the time, with 22 % calms. This could explain the low sulphur content measured for plants exposed at the Table View biomonitoring station.

In the case of the <u>April 1988</u> dataset, no significant differences were found between the sulphur content of plants exposed at the same four biomonitoring stations. Since the Cape Divisional Council mobile monitor was moved to a location on Tygerberg (Bellville), no records of on-site ambient SO_2 concentrations are available. The amount of visible injury observed during March-April 1988 was comparatively low (Tables 7.3, 7.5 and 7.7), although injury observed at Bothasig was significantly more than at the control site (Drostersnes) for the 2nd and 3rd trifoliates, possibly coinciding with ambient SO_2 peaks registered at Tygerberg during April 1988. However, these differences were not reflected in the sulphur content of the leaves, probably masked by a dilution effect, since all the leaves on a plant were pooled for sulphur analysis.

7.3.2 Results and discussion: Open-top chamber experiments

7.3.2.1 Visible injury symptoms:

March 1987 data: The mean frequency of injured cases reported for plants exposed during February-March in filtered chambers, unfiltered chambers and open plots, was 30 %, with no significant differences apparent between the three treatments. The injury observed occurred mostly on the primary leaves, and could for the greatest part, be attributed to senescence. Injury observed on plants exposed in the plant cages (biomonitoring station, UWC) at the same location, similarly showed relatively little injury (Table 7.3), with injury occurring mainly on the primary leaves and second trifoliate (5 %). In the case of the open-top chamber experiment, injury on the second trifoliate did not exceed 2 %.

May 1987 data: Only a few cases of injury were reported on plants exposed during the open-top chamber experiment conducted in April-May 1987. The primary leaves exhibited senescence on the final rating date or were shed, while the only other symptoms reported were three incidences of necrotic spots (<2 % per leaf) in all the chambers, and four incidences of necrosis in the open plots (3 times <2 %; 1 time 2-5 %). This data was not subjected to further statistical analysis.

March 1988: Substantial injury was observed on plants exposed in the open-top chambers and open plots during February-March 1988 (Table 7.10). The major individual symptoms observed included chlorosis and necrosis, while bleaching and bronzing occurred to a lesser extent. These symptoms occurred similarly on plants in filtered and unfiltered chambers as well as on plants in the open plots. The cause of this injury can probably be related to heat stress, since unusually high temperatures occurred during a heat wave in February 1988. The frequency of injury observed on plants in the open plots and on plants in the adjacent plant cages (biomonitoring network station) was very similar, i.e. 57.5 % and 59.7 % respectively (Tables 7.10 and 7.5). The frequency of injury observed on plants in the filtered chambers was somewhat lower than that observed on the open plots (50.1 %), while that in the unfiltered chambers was somewhat higher (69.2 %).

For the individual leaves rated, differences between the

Table 7.10: Percentage injury on primary and trifoliate leaves of 'Lazy Housewife' beans grown in filtered and unfiltered open-top chambers as well as on open plots. All new injury that occurred during the exposure period was summed for each leaf. Values represent the mean total injury per leaf ± standard error of the mean, March 1988.

	% INJURY PER TRIFOLIATE ($\bar{x} \pm s / \sqrt{n}$)					
	n	Filtered chambers	n	Unfiltered chambers	n	Open plot
Prim. 1	19	15.0±4.3	20	25.1±5.1	10	14.2±3.1
Prim. 2	18	13.3±4.1	20	23.1±5.5	10	18.1±4.4
Trif. 1	18	10.1±2.6	20	21.8±5.7	8	16.0±9.3
Trif. 2	17	22.3±5.7	13	35.4±9.3	5	8.4±6.0
Trif. 3	15	1.5±1.2	16	11.3±3.7	8	4.1±2.0
Trif. 4	19	1.5±0.9	20	1.7±0.7	8	0.0±0.0
Column total		63.7		118.2		60.8
Frequency of injury (%)		50.1		69.2		57.5

chambers were not statistically significant, except in the case of the third trifoliate (P = 0.003). However, the high average rating for unfiltered chambers in the case of the third trifoliate appeared to be linked to a chamber effect rather than to a pollution episode, since injury ratings in one of the unfiltered chambers were significantly higher than in the other three. Results of the biomonitoring network experiments (Table 7.5) also do not indicate that there were an episode that might have caused significant injury on plants located at the U.W.C. biomonitoring station.

April 1988 data: The leaf injury observed during the open-top chamber experiment conducted in March-April 1988 is indicated in Table 7.11. Differences observed between filtered chambers, unfiltered chambers and open plots were not statistically significant. As with the March 1988 dataset, the frequency of injury observed on plants in the open plots and on plants in the adjacent plant cages (biomonitoring network station) again was very similar, i.e. 60.6 % and 56.8 % respectively (Tables 7.11 and 7.7). The frequency of injury observed on plants in the filtered and unfiltered chambers was somewhat lower, i.e. 44.2 % and 46.0 % respectively.

Although the amounts of injury observed during March-April 1988 were less than during Feb-March 1988, the major individual symptoms observed were again necrosis and

Table 7.11: Percentage injury on first four trifoliates (Trif.) of 'Lazy Housewife' beans grown in filtered and unfiltered open-top chambers as well as in open plots. All new injury that occurred during the exposure period was summed for each leaf. Values represent the mean of 'n' plants ± standard error of the mean, April 1988.

	% INJURY PER TRIFOLIATE ($\bar{x} \pm s / \sqrt{n}$)					
	n	Filtered chambers	n	Unfiltered chambers	n	Open plot
Trif. 1	18	6.9±2.2	16	8.9±2.3	10	12.6±5.3
Trif. 2	18	4.6±1.9	16	6.8±3.5	10	9.8±3.2
Trif. 3	18	0.0±0.0	16	3.1±2.9	10	0.6±0.3
Trif. 4	18	0.5±0.4	16	0.0±0.0	10	0.0±0.0
Column Total		12.0		18.7		23.0
Frequency of injury (%)		44.2		46.0		60.6

chlorosis, while bleaching and bronzing occurred to a lesser extent. Again these symptoms occurred similarly on plants in filtered and unfiltered chambers as well as on plants in the open plots.

7.3.2.2 <u>General conclusions on visible injury observed during open-top chamber experiments</u>:

1. Except for the experiments conducted in February-March 1988, bean plants exposed in the open-top chambers and open plots and plant cages (biomonitoring station) at UWC exhibited small amounts of visible injury. (Injury symptoms observed during February and March 1988, were probably enhanced by a heat spell that occurred during February 1988). The conclusion can be drawn that air pollution levels that occurred at UWC during the biomonitoring periods were relatively low and did not have a significant effect on the visible appearance of bean plants grown at this site. UWC was always among the biomonitoring network stations at which the least injury was observed, and the amount of injury observed at UWC did not differ significantly from that observed at the control station (Drostersnes).

2. The types of symptoms and amounts of injury that occurred during the experiments conducted in 1987 and 1988, did not differ significantly between filtered open-top chambers, unfiltered open-top chambers and open plots. With the low levels of air pollutants that apparently prevailed at the Air Pollution Research Site at UWC, the possible reduction in pollutant concentration inside the filtered open-top chambers did not have a marked effect on the visible symptom expression of the bean leaves. Pollutants are not expected to be reduced inside the filtered chambers to less than 30 % of the ambient concentrations (Heagle et al., 1973; Mandl et al., 1973). At low ambient air pollution levels, the effective pollutant concentration inside filtered and unfiltered chambers may differ relatively little.

7.3.2.3 Sulphur content:

The sulphur content of leaf material of plants exposed in the filtered and unfiltered open-top chambers and open plots during April-May 1987 and March-April 1988, is indicated in Table 7.12. In the case of the 1987 experiment, the

Table 7.12: The sulphur content of bean leaves (*Phaseolus vulgaris* L.) exposed in filtered and unfiltered open top chambers and open plots during April-May 1987 and during March-April 1988.

Treatment	April-May 1987[1]		March-April 1988[1]	
	n	Sulphur Content ($\mu g.g^{-1}$ DW) (ppm)	n	Sulphur Content ($\mu g.g^{-1}$ DW) (ppm)
Filtered Chambers	16	4255.1 A *	17	3746.3 A *
Unfiltered Chambers	8	5013.4 AB **	16	3798.1 A *
Open plots	9	5916.7 B ***	10	4047.2 A *

1. Values represent the mean (least squares mean) of n plants. Values followed by the same letter or sign (*) are not significantly different at $\alpha = 0.05$ or $\alpha = 0.1$ respectively.

sulphur content of plants grown in the filtered chambers was significantly less than that of plants grown on the open plots ($P = 0.05$). At a probability level of $\alpha = 0.1$ the sulphur content of all three groups differed significantly, indicating a chamber effect which caused plants in unfiltered chambers to absorb less SO_2 than plants in open plots. In the charcoal filtered chambers, the uptake of SO_2 was further reduced. It is known that air pollutants are also reduced, although to a lesser extent, inside unfiltered open-top chambers, probably by adsorption to the chamber materials, or by virtue of the air movement through the system (Chevone, 1989).

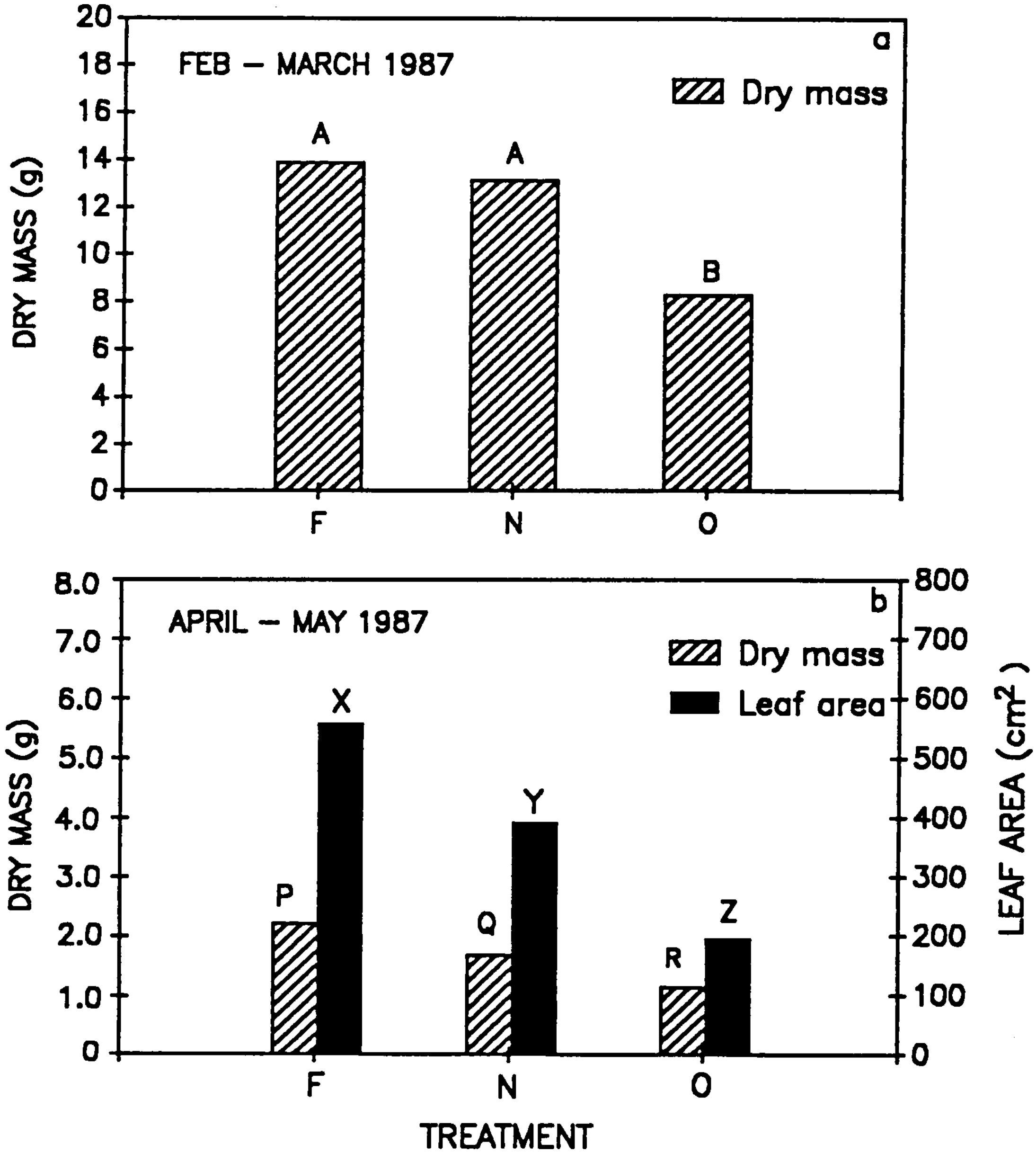
In the case of plants exposed during March-April 1988, no significant differences were obtained between the sulphur content of plants grown in the various open-top chambers and open plots.

7.3.2.4 <u>Shoot dry mass and total leaf area of plants</u>:

Among the groups of plants exposed in the open-top chamber experiment conducted in February-March 1987, there were no significant differences between the dry mass of plants grown in filtered and unfiltered chambers, while the dry mass of those grown in the open plots, was significantly less (Fig. 7.7a). In the case of the beans exposed during April-May 1987, the dry mass of plants grown in filtered chambers was significantly greater than that of the plants

<u>Fig. 7.7</u> a. The shoot dry mass of 'Lazy Housewife' beans grown in the filtered and unfiltered open-top chambers and open plots during February-March 1987. Values represent the mean obtained with 12 bean plants. Bars accompanied by the same letter do not represent significantly different means at the 0.05 probability level.

b. The shoot dry mass and total leaf area of 'Lazy Housewife' beans grown in the filtered and unfiltered open-top chambers and open plots during April-May 1987. Values represent the mean obtained with nine bean plants. Within a bar type, bars accompanied by the same letter do not represent significantly different means at the 0.05 probability level.



20
18
16
14
12
10
8
6
4
2
0
DRY MASS (g)
FEB – MARCH 1987
a
Dry mass
A
A
B
F
N
O
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
DRY MASS (g)
APRIL – MAY 1987
b
Dry mass
Leaf area
X
Y
Z
P
Q
R
800
700
600
500
400
300
200
100
0
LEAF AREA (cm2)
F
N
O
TREATMENT

grown in the unfiltered chambers and open plots. Measurements of the total leaf area of these plants supported the dry mass data, namely that the plants grew more luxuriously in filtered than in unfiltered air or on the open plots (Fig. 7.7b).

The level of air pollutants that occurred at the Air Pollution Research Site at UWC during the period February-March 1987 was apparently not sufficient to inhibit the production of dry mass by the beans while air pollution during April-May 1987 was indeed sufficient to inhibit growth (Figs. 7.7a and b). This observation was supported by the finding that the sulphur content of plants grown in filtered open-top chambers during April-May 1987, were lower than that of plants grown in unfiltered chambers and open plots (par 7.3.2.3), implicating SO_2 as an air pollutant that contributed to the inhibition of growth in unfiltered air. Results from the rating of visible injury on these plants suggested that air pollution levels were reasonably low during both the periods monitored (par 7.3.2.2).

The shoot dry mass of plants grown in the unfiltered open-top chambers during the biomonitoring periods February-March 1988 and March-April 1988, was not significantly reduced compared to that of plants grown in filtered chambers. In both cases the dry mass of plants grown in the open plots was significantly less than those grown in the open-top chambers. During a subsequent experiment conducted in April-May 1988 during which the dry mass as well as the total leaf area of plants were determined, similar results were obtained, i.e. comparisons of dry mass and leaf area measurements revealed no significant differences between plants grown in unfiltered and filtered chambers, whereas the measured effects on plants grown in the open plots were significantly less. During the period February-May 1988, ambient air pollution levels at the Air Pollution Research Site in Bellville South (UWC) were apparently not sufficient to cause marked effects on the growth of 'Lazy Housewife' bean plants.

Evaluation of both year's data obtained with 'Lazy Housewife' beans indicate that the atmosphere at the Air Pollution Research Site in Bellville South was relatively clean during most of the biomonitoring periods. Whereas there were seldom differences between the dry mass and total leaf area of plants grown in filtered and unfiltered open-top chambers, these parameters were usually significantly smaller in the case of plants grown on the open plots. As mentioned earlier, the lack of significantly different responses between plants grown in filtered and unfiltered open-top chambers, may also be attributed to the trapment of air pollutants inside the unfiltered chambers, probably by adsorption to the chamber materials. The difference between responses obtained in open-top chambers and open plots may thus point towards the presence of ambient pollutants, but at such low levels that it can not be identified by the comparison between filtered and unfiltered chambers.

Also, the open-top chambers tend to minimize the effects of strong wind. Moreover, temperatures inside the chambers tend to be somewhat higher than ambient temperatures. These factors could respectively result in less mechanical stress on the plants, faster growth rates and higher dry mass production inside the chambers. In general, at low pollutant concentrations, plants that grow at a slower rate, may metabolically be inhibited to a larger extent than plants growing at a faster rate (Chevone, 1989). Due to the cooler autumn weather, the bean plants exposed during April-May 1987 apparently had slower growing rates than those exposed during February-March when high summer temperatures prevailed, as indicated by the much smaller amounts of dry mass produced. This may explain why significantly different responses were obtained between plants exposed during April-May 1987 in filtered and unfiltered chambers, and not between similar groups of plants exposed during other periods.

Saxe (1983) studied various responses of bean plants (cv. 'Processor') to low concentrations of SO_2. Biomass and yield of all plant parts were reduced at and above approximately 0.1 ppm SO_2 (250 $\mu g\ m^{-3}$). Chlorophyll and starch was also reduced in the leaves, while the sulphur content of leaves and fruit increased with exposure time and concentration. Beckerson et al. (1979) indicated that a mixture of 0.15 ppm SO_2 with 0.15 O_3 generally caused leaf injury on bean plants to be less severe than the effect of O_3 alone. Such antagonistic effects on bean plants were also demonstrated by Hofstra et al. (1985) and may explain the lack of development of typical leaf injury symptoms at the Air Pollution Research Site at UWC, where a mixture of low level pollutants are expected, although "hidden" injury (reduction in growth and other internal parameters) still occurred.

7.3.2.5 Results obtained with the open-top chamber experiment conducted with *Senecio elegans*.

Leaf elongation measurements: No significant differences were obtained among the leaf elongation measurements conducted on leaf sets of plants grown in filtered open-top chambers, unfiltered open-top chambers and open plots.

Chlorophyll analyses: Results obtained from the chlorophyll analyses indicate that, for the leaves harvested in February, there were no significant differences between the chlorophyll content (chlorophyll a as well as chlorophyll b), of the leaves of plants grown in filtered open-top chambers, unfiltered open-top chambers and open plots. The chlorophyll content of the leaves of plants grown in the open plots during April was significantly higher than that of leaves of plants grown during the same period in filtered and unfiltered open-top chambers. Again no significant differences were obtained between the chlorohyll content of leaves of plants grown in the filtered and unfiltered open-top chambers.

Data from both the leaf elongation measurements and the chlorophyll analyses suggest that during the period January to April 1988, the levels of pollutants in the unfiltered open-top chambers were not sufficient to reduce the leaf elongation or the chlorophyll content of the monitored leaves. The comparatively high chlorophyll a and b content of leaves harvested from the open plots in April may be attributed to the onset of cooler weather conditions and the fact that average temperatures in the open plots were determined to be lower than that inside the chambers (par. 5.2.2.4). Lower temperatures would be more favorable to the plants, since the natural vegetative stage of _Senecio elegans_ in this area is in winter.

No visible symptoms typical of O_3 injury was observed on _Senecio_ leaves, neither the stippling and glazing previously observed to have been caused by a mixture of pollutants (Chapter 3). Results obtained with open-top chamber experiments conducted with _Senecio_ suggest that, during the relevant period, ambient O_3 concentrations experienced at the Air Pollution Research Site at UWC, were not high enough to have a marked effect on _Senecio_ _elegans_. Previous fumigation studies indicated that O_3 concentrations of 0.16

ppm (5 days, 4 hours per day) and a mixture of pollutants (0.16 ppm O^3 + 0.5 ppm SO^2 + 1.0 ppm NO^2), administered for five days, four hours per day, caused a reduction in growth as well as typical visible injury symptoms (Chapter 3). Thus it can be deducted that air pollutant levels at the Air Pollution Research Site at UWC in general probably did not reach the levels referred to above.

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CHAPTER 8

SUMMARY

8. SUMMARY

The potential influence of urban and industrial air pollution on vegetation was investigated in selected areas in South Africa by means of field surveys and biomonitoring network experiments.

Prior to the commencement of the investigations in South Africa, fumigation studies were conducted at the Virginia Polytechnic Institute and State University, during which the effects of known concentrations of sulphur dioxide, ozone and mixtures of sulphur dioxide, ozone and nitrogen dioxide, were determined on various indigenous South African species as well as on some crop plants.

In South Africa, two unrelated field surveys were conducted in the greater Cape Town area: one in the northern suburbs, in the immediate vicinity of two industries, and the other in a southern suburb, where plantations of _Pinus radiata_ exhibited unexplained dieback symptoms. In addition, the Eastern Transvaal area was visited twice in order to investigate the occurrence of visible symptoms on pine trees, which could possibly be associated with air pollution injury.

The field survey conducted in the Table View - Bothasig area (northern suburbs of Cape Town), indicated that airborne fluoride was one of the major pollutants emitted in the area. Visible symptoms on leaves were typical of

fluoride injury and could be related to the fluoride content of the leaves. Moreover, the foliar fluoride content could be related to the distance and direction of the sampling sites from the pollutant sources, as well as the predominant wind directions. Among the species investigated in the survey, two *Eucalyptus* species proved to be the best indicators of fluoride pollution under the given circumstances.

The cause of the decline of *Pinus radiata*, investigated during the field survey conducted in the Tokai Forest Station, which is located at one of Cape Town's southern suburbs, could not be established. Although some of the dieback symptoms observed in pine trees were similar to those described in the literature for decline due to acid deposition, symptoms that could be related to one or more specific air pollutants, were not observed. Evaluation of all available information, including limited data on pollution levels measured in the area and growth regulators used on neighboring vineyards, could not satisfactorily explain the decline. The need for a detailed plant physiological study was indicated.

The most probable cause for the injury symptoms observed on pine needles in the Eastern Transvaal Highveld and escarpment regions, was identified as acid deposition, including gaseous air pollutants, with acidic mist probably playing a major role in the development of the extensive chlorotic and necrotic mottling observed. The injury symptoms were determined not to be related to biotic pathogens and corresponded with that described for injury on pine trees associated with acid deposition and concomitant pollutant gases in the U.S.A. The available knowledge of pollutant levels in the Eastern Transvaal Highveld, the meteorology and the presence of major pollutant sources, all support the conclusion that acid deposition may have played a major role in the decline observed on pine trees in this area. However, more detailed studies are needed in order to quantify and explain the observed phenomenon.

In order to evaluate the extent to which air pollution episodes affected vegetation in the Cape Town metropolitan area (population between 1.5 and 2 million people), and to identify the occurrence of air pollution as well as pollutant gradients, a network of six biomonitoring stations was established towards the east and north-east of Cape Town. Two additional biomonitoring stations were established in rural areas located in an eastern direction from Cape Town. At one station, (located at the Cape flats Nature Reserve, University of the Western Cape, Bellville South), an Air Pollution Research Site was established which, in addition to the biomonitoring network station, contained four charcoal filtered open-top chambers, four unfiltered open-top chambers and two open plots. Symptom expression on plants grown in the open-top chambers was compared with that on plants grown in the adjacent plant cages of the biomonitoring network station. The same plant species as were used in the bio-monitoring network (plant cage) experiments, were simultaneously grown in the open-top chamber system.

Summer-growing as well as winter-growing bio-indicator species, each sensitive to a specific pollutant or pollutants, were exposed in the biomonitoring network stations and open-top chamber system, over a period of three years. The development of characteristic visible injury symptoms, that could be ascribed to phytotoxic air pollutants, were described for various locations, as well as the occurrence of pollutant gradients as exemplified by the foliar accumulation of certain pollutants.

Experiments conducted with _Freesia_ and _Gladiolus_ plants as bio-indicators (winter and summer seasons respectively), indicated that the Loumar biomonitoring station apparently experienced the highest atmospheric fluoride concentrations throughout the year, compared to that at the other biomonitoring stations, followed by the Bothasig, Table View and Edgemead stations. The foliar fluoride content of plants grown at these locations was determined to be consistently significantly higher than that of plants grown at the control station at Drostersnes. A positive correlation was observed between the foliar fluoride levels of _Freesia_ and the visible injury ratings of the leaves. _Gladiolus_ plants appeared to be more affected by environmental conditions and the presence of other potential pollutants, such as sulphur dioxide, than *Freesia* plants.

Results of experiments conducted with bean plants indicated that industrial sulphur dioxide emissions are a potential cause for concern at the Bothasig biomonitoring station. Characteristic visible injury symptoms, typical of sulphur dioxide injury, were regularly observed at this location, and were usually determined to be significantly worse than at the other biomonitoring stations. Determination of foliar sulphur content exposed during April-May 1987, confirmed these observations, in that significantly higher sulphur levels were present in the leaves of plants exposed at the Bothasig biomonitoring station, than at the other stations evaluated.

Results obtained with the various bio-indicator species grown in the open-top chamber system, were compared with those obtained with the relevant groups of plants exposed simultaneously at the biomonitoring network stations. Results indicated that the levels of pollutants encountered at the Air Pollution Research Site, were generally very low and appeared to be in the same range as those encountered at the control biomonitoring network station (Drostersnes), which was located in a distant, rural area, removed from any known sources of pollutants. Ambient pollutant concentrations were apparently reduced inside filtered open-top chambers, as indicated by higher biomass production and lower foliar fluoride and sulphur levels in the relevant bio-indicator species grown in the filtered open-top chambers, compared to that of plants grown in the open plots. The trapment of pollutants by the chamber materials as well as moisture which often accumulated between the two lower panels of the open-top chambers, appeared to have reduced the pollutant concentrations inside unfiltered chambers to the extent that no significant differences were obtained between the responses of plants grown in filtered vs. unfiltered open-top chambers. It is suggested that future open-top chamber experiments should be conducted at a more polluted site and that the necessary equipment to monitor air pollutant levels inside the chambers, be obtained.

In the absence of sufficient continuous monitoring instrumentation, the use of biomonitoring network stations together with open-top chamber studies, provided baseline data related to atmospheric air pollution levels. This methodology may be beneficially applied in further studies in South Africa, to aid in air pollution control strategies.

* * *

<u>Appendix 5.1</u> Weekly maintenance form, completed upon each visit to the biomonitoring network stations and open-top chambers.

BIOMONITORING STATIONS: WEEKLY MAINTENANCE:

Date: ....

Indicator Sp: ....

General Remarks: ....

....

Pest Control: ....

Fertilizer: ....

Distance Covered: ....

Route: ....

Name: ....

SITE:	LOUMAR	UWC	PAROW	EDGEMEAD	BOTHASIG	TABLE VIEW	STELLENBOSCH	DROSTERSNES
TANKS WASHED?								
NEEDLES REPLACED?								
SIPHONS WASHED?								
REMARKS:								

OPEN-TOP CHAMBERS								OPEN PLOTS	
A (Filtered)	B (Filtered)	C	D	E (Filtered)	F (Filtered)	G	H	I	J

GENERAL REMARKS: ____

<u>Appendix 5.2</u> **Form for pesticide and fertilizer schedule.**

PESTICIDE SCHEDULE

Date	Pesticide	Conc.	Pest	Plant Sp.	REMARKS

FERTILIZER SCHEDULE

Fertilizer	Conc.	Amount per Pot	Plant sp.	REMARKS

Appendix 6.1 Visible symptom rating form for typical fluoride injury symptoms on *Freesia*. The percentage leaf area exhibiting chlorosis and/or necrosis were estimated on individual leaves and the number of leaves in each injury category were indicated. The total number of leaves per plant was also indicated.

FLUORIDE INJURY ON FREESIA HYBRIDA CV. "GOLDEN MELODY"

SITE .... CAGE: .... POT: .... PLANT: ....

			NO. OF LEAVES EXHIBITING SYMPTOMS												REMARKS
	DATE	TOT. NO. OF LEAVES	CHLOROSIS		TERMINAL AND MARGINAL NECROSIS										
			No.	%	<2%	2–5%	5–10%	10–15%	15–20%	20–30%	30–40%	40–50%			

Appendix 7.1 Rating form for indicating the percentage injury on individual bean leaves (*Phaseolus vulgaris*) during weekly visits to the biomonitoring network stations and open-top chambers. Each kind of possible air pollution symptom that may be encountered was rated separately.

SYMPTOM EXPRESSION ON PHASEOLUS VULGARIS CV. "LAZY HOUSEWIFE"

H = Healthy
S = Stippling
C = Chlorosis
WS = Watersoaking

T/M/N = Tip/Marginal/Necrosis
BR = Bronzing
BL = Bleaching
MI = Mechanical injury + Necrosis
G/C = General chlorosis

Surface affected:-
U = Upper
L = Lower
BF = Bifacial

Site:-

Date:-																			
Cage	Pot	Symptom Code	Primary 1	Surf aff	Primary 2	Surf Aff	Symptom Code	Trifoliate 2	Surf aff	Symptom Code	Trifoliate 2	Surf Aff	Symptom Code	Trifoliate 3	Surf Aff	Symptom Code	Trifoliate 4	Surf Aff	REMARKS
		N					N			N			N			N			
		C					C			C			C			C			
		S					S			S			S			S			
		B					B			B			B			B			
		WS					WS			WS			WS			WS			
		N					N			N			N			N			
		C					C			C			C			C			
		S					S			S			S			S			
		B					B			B			B			B			
		WS					WS			WS			WS			WS			
		N					N			N			N			N			
		C					C			C			C			C			
		S					S			S			S			S			
		B					B			B			B			B			
		WS					WS			WS			WS			WS			

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