Ministry for the
Environment
Manatū Mō Te Taiao

The Effects of Air Pollution on New Zealand Ecosystems

Interim Conclusions and Recommended Investigations

Air Quality Technical Report No. 2

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TABLE OF CONTENTS

INDEX OF TABLES

Air Quality Effects on New Zealand Ecosystems

A Discussion of the Potential Effects on Ecosystems and Areas Requiring Further Work

1. INTRODUCTION

A review (Report to the Ministry for the Environment on the Effects of Air Quality on New Zealand Ecosystems) has been carried out on the existing information regarding effects and impacts of air pollution on ecosystems, (where "ecosystem" is defined as excluding direct impacts on human health only), which has focused on applying this knowledge to the forthcoming review of the current Ministry for the Environment's Ambient Air Guidelines. The aim is to incorporate the findings when new guideline values are set. To date the work has of necessity been concerned largely with examples documented in other parts of the world, mostly in the northern hemisphere. One outcome of the work will be to provide recommendations for future research in New Zealand on the potential for effects of air pollution on New Zealand ecosystems.

1.1 Fundamental Differences

Two important aspects influence the impact of air pollution on an ecosystem. These are:

A. The levels of pollution producing an effect

B. The likelihood of these levels occurring

An evaluation of guidelines essentially examines the levels of pollution producing the effect; and those aspects affecting these levels in the New Zealand situation are

climate

soils

vegetation (all "A" issues)

while geography and land area are mostly a "likelihood", or "B" aspect.

It is very important when comparing New Zealand ecosystems with those in other countries to include in the context the following points;

"A" issues

- in most cases, where air pollution has had a serious impact on flora, the growing conditions of the plants or trees has been a contributing factor, and these conditions are very different from those experienced in most parts of New Zealand

- plants are more sensitive to damage from acid pollution during the winter, under conditions of low light intensities and high soil moisture when they have their stomata open, than in conditions of high light and low soil moisture

- where acid precipitation has had a serious impact, the properties of the receiving environment are also a contributing factor to the seriousness of the impact

- the small size of New Zealand restricts to potential for the formation and long range transport of large scale pollution "plumes", thereby reducing the potential for oxidation and formation of acid precipitation, as has been the case where major air pollution impacts have occurred on large continents

- however, there is little knowledge of the potential for air pollution to affect flora and fauna under the New Zealand conditions, and

- virtually nothing is known of the sensitivities of any of New Zealand's native species to such impacts.

"B" issues

- ambient air pollution levels in New Zealand are at least an order of magnitude lower than those in the parts of the world where air pollution has had a significant impact

- New Zealand has few situations for the development of significant pollution "plumes". Where this is a possibility, e.g Auckland and Christchurch, the pollutants are usually blown out to sea

2. AIR POLLUTION POTENTIAL

Acid gases such as SO_2 and NO_x are emitted from both natural and anthropogenic sources. They are transformed in the atmosphere to sulfuric and nitric acids, which can be further transformed into aerosols. The acids, the gases and their aerosol products are returned to the earth's surface via two main mechanisms:

- wet deposition in rain or snow (known as acid rain);

- dry deposition, in which particles and gases are deposited directly on water, soil, vegetation or other surfaces.

The natural sources of acid gases contribute to the global nutrient cycle. Acid deposition is often taken to refer to situations where the anthropogenic contribution overwhelms the natural component. In New Zealand, the substantial level of volcanic activity, the relatively low level of fossil fuel combustion (especially for power generation) and the relatively small distances to open seawaters would suggest that the potential for acid deposition is generally limited compared to other industrialised countries. However, localised effects may occur.

Acids and their precursors typically have atmospheric residence times of a few days, and tend to be deposited within a distance of several hundred kilometres of the source.

The transport of acids, gases and aerosols depends on the three-dimensional flow characteristics of the lower atmosphere, which can be highly complex in regions of coastal and mountain terrain, both of which are common in New Zealand. Trajectories of plumes are influenced not only by the prevailing winds, but also by blocking and diversion effects near hills and mountains, slope flows, seabreezes, landbreezes and other effects. In such situations, plume material can be very widely and unevenly dispersed.

Studies in Australia have indicated that for very large SO_2 sources, dry deposition levels are elevated above background to about 40 km. The dry deposition process is strongly influenced by the role played by atmospheric turbulence in mixing the plume to ground level. The rate of deposition is a function of many individual factors, only some of which include plume concentration, aerodynamic roughness, atmospheric stability, friction velocity, temperature, humidity and stomatal resistance.

Often included in the definition of dry deposition is cloud water deposition. Acid aerosol can be absorbed into cloud water, and deposition occurs when clouds impact on terrain. Vegetation often acts as an efficient collector of cloud water. In New Zealand, with a dominance of humid cloudy climates and complex terrain, the potential exists for this mechanism to be locally significant in relation to acid deposition if the source and receptor relationships are satisfied.

Wet deposition is an efficient process for removing water-soluble gases, aerosols and particles from the atmosphere. It proceeds through two possible pathways: washout and scavenging. Washout refers to the process by which the gas or aerosol is absorbed by cloud droplets and eventually falls to the surface in precipitation. In the scavenging process, the precipitation absorbs the gas or particle after it has commenced its descent from the cloud.

2.1 Dry Deposition

The term “dry deposition” covers both deposition of particulate material on plants and soils, and uptake of gaseous constituents from the air. Generally, in relation to effects on plants from air pollutants, the potential for effects to be detected as a result of dry deposition of gaseous pollutants will be limited to local effects, as New Zealand does not have the levels of pollutants required to contribute to regional plume dispersion. The largest affected areas will be associated with the cities of Christchurch and Auckland which have the highest pollutant emissions, followed by other smaller, less polluted cities. Within these areas, there will lie more localised areas of pollutant effects, originating from single point sources, from industries such as fertiliser works. Other local point sources occur outside these metropolitan areas, which the major ones in New Zealand, can be conveniently listed:

Table 1: Some Major Pollution Sources in New Zealand

Region	Source	Pollutant Species
Southland	Aluminium Smelter	Sulfur Dioxide, fluoride, particulate
	Fertiliser Works	Fluoride, particulate
	Dairy factories	Sulfur dioxide, nitrogen oxides, particulate
Otago	Open cast Gold mine	Particulate
	Fertiliser Works	Sulfur dioxide, particulate
Christchurch	Fertiliser works	Sulfur dioxide, particulate
West Coast	Coal Mining	Particulate
Nelson/Marlborough		
Wellington		
Taranaki	Petrochemical industries - 3	Nitrogen oxides, particulate
	Natural gas wells	Nitrogen oxides, particulate
	Thermal Power Station	Sulfur dioxide, nitrogen oxides, particulate
	Combined cycle Power Station	Sulfur dioxide, nitrogen oxides, particulate
	Dairy Factories	Sulfur dioxide, nitrogen oxides, particulate
Bay of Plenty	Kraft mill	Reduced sulfur, particulate
	Geothermal power development	Reduced sulfur, nitrogen oxides, particulate,mercury
Waikato	Kraft Mill	Reduced sulfur

	Fertiliser works	Fluoride, particulate
	Combined cycle power station	Sulfur dioxide, nitrogen oxides, particulate
	Thermal Power Station	Sulfur dioxide, nitrogen oxides, particulate
	Dairy Factories	Sulfur dioxide, nitrogen oxides, particulate
	Open Cast Gold Mine	Particulate, sulfur dioxide, nitrogen oxides
Auckland	Steel Mill	Particulate
Northland	Oil Refinery	Sulfur dioxide, particulate
	Geothermal power development	Reduced sulfur, particulate, mercury
	Dairy Factories	Sulfur dioxide, nitrogen oxides, particulate

Vehicular traffic flows are heaviest in the major cities, particularly Auckland, on the main routes in and out of Auckland, with State Highway One between Auckland and Hamilton the busiest section of highway on the country.

Studies of the wind fields and meteorology of the Auckland region (NIWA, 1995) show a complex system, which often produces sea-to-land breezes from both sides of the Auckland isthmus, resulting in a sea breeze convergence zone which, while it generally follows the land mass, can move either east or west. Pollutants in the convergence zone become advected aloft, to be moved on, and if conditions permit undergo photochemical reactions. The influence of drainage flows from the hills in the region can move the air mass on to other areas. Therefore there is the potential for the Auckland pollution plume to impact on the Whangaporoa Peninsula to the northeast, the Waitakere Ranges to the southwest, the Pukekohe and Bombay Hills areas, the Hunuas to the southeast and the Firth of Thames and Coromandel Peninsula.

2.2 Wet Deposition

Wet deposition is dependent on the processes (described above) of washout or scavenging, and the rate of removal is largely dependent on time. The long trajectory paths seen on large continents is certainly conducive to this process.

If we consider a hypothetical situation relevant to NZ, of an ambient air concentration of 1ugm^3 SO_2, and we allow this to travel on average for 10 hours before being blown offshore 0.1ugm^3 of the SO_2 will have been oxidised to sulfuric acid. Assuming that 10% of the sulfuric acid formed is on average washed out by rainfall (probably an over estimate), this means that at the downwind end of the oxidation range acid deposition will be equivalent to the oxidation of 0.01ugm^3 SO_2 out of the annual average of 1ugm^3.

Precipitation of nitric and sulfuric acids resulting from rain washout or scavenging has been implicated in foliar injury, growth retardation, forest decline, and tree death in the northern hemisphere. As more understanding has been gained, it is apparent that acid precipitation is only one of several factors contributing to forest decline, and that predisposing conditions have also been responsible. Most important in these has been soil buffering capacity. In European forests, acidification of soils following air pollution acid precipitation was preceded and therefore accelerated by

- soils which formed from acid parent rock

- removal of the replacement organic material which is so important in these forests in contributing to the alkaline buffering capacity of the soil, by woodsmen for domestic purposes, over centuries

In North America, large scale acidification of fresh water lakes is the result of long range transport of high levels of sulfur and nitrogen oxides from intensely industrialised areas to wilderness areas, where it is washed out to drain into streams, ponds and lakes. In limestone country, the acids are neutralised, but where little or no neutralising capacity exists, the lakes have slowly become crystal clear and acid. The first warning signs are depleting fish stocks, particularly small species and juveniles, which very often results in lakes which are stocked only by large fish. Ultimately, the system is capable of supporting only primitive and sparse lifeforms.

In New Zealand, it is likely that areas of soils with relatively low buffering capacity exist, one example being the pakahi soils of the northern kauri forests. It is also likely that in areas where relatively (for New Zealand) high pollution levels coincide with periods of high rainfall, that some acid deposition occurs. Examples of this would be the Waitakere and Hunua Ranges near Auckland, and the Port Hills of Christchurch.

2.2.1 Recommendations for Future Work

Further investigation into the potential for acid precipitation formation, and the identification of soils with low buffering capacity would be required to identify the risk of damage from acid precipitation, if any. A logical approach would include;

- identification of soils with low buffering capacity
- review of available information on precipitation composition in New Zealand
- modelling of potential acid deposition from known sources
- collection/analysis of precipitation after review of available information
- identification of critical information needed to assess acid rain potential - e.g. NH_3 levels etc.

2.3 Photochemical

There is an increasing recognition of the potential for ozone formation, which relates mostly to increasing motor vehicle numbers and consequential air pollution. McKendry outlines the potential for photochemical pollution in New Zealand (NIWA, 1996), and ranks Auckland, Hamilton and Christchurch as having significant ozone episodes, with meteorological conditions making Hamilton the most severely affected.

The sea breeze convergence is seen as a significant influence in the horizontal and vertical distribution of pollutants from Auckland. The Whangaporoa Peninsula, Rangitoto, Motutapu and Waiheke Island, as well as the Coromandel Peninsula are possibilities for exposure to photochemical pollutants. An evaluation is needed of crops grown in this region which may be sensitive to ozone; but equally, there is a possibility of incidents of damage to the forests of the Coromandel.

While Hamilton has less vehicular traffic than Auckland or Christchurch, it is the least ventilated with the highest potential for persistent photochemical incidents. This affect may be offset, however, by greater vertical mixing.

Christchurch sits in a pollutant “trap”, affected by sea breezes, the Banks Peninsula and Port hills drainage, and the Southern Alps. A complex hierarchical series of processes produce a complex wind regime with “marked temporal variability, a layered vertical structure and the frequent occurrence of convergence lines and shear zones” (McKendry et al, in NIWA, 1996). For the most part, Christchurch is well ventilated during summer months, but the potential for ozone formation comes into play when winds over the city are relatively light and the photochemical precursors drift slowly to the north-east or south-east (NIWA, 1996).

2.3.1 Recommendations for Future Work

Very little is known of the real potential for ozone formation and consequential damage in New Zealand. A responsible approach to over come this situation would be;

- to establish the risk of ozone impact in New Zealand, modelling of the potential for ozone incidents and locations should be carried out, followed by comprehensive measurements of ambient ozone levels at the identified locations.

- a planned comprehensive background measurement program to be established in the areas identified as “at risk”. This program would ideally consist of a few real time measurements supplemented by many passive or active samplers - some would employ remote triggering to catch “events” which could be predicted from a “weather-and-pollution-watch” program

- bioindicactor plants could be deployed to potential “hot spots” alongside analysers or passive samplers, and any effects seen compared with other plants growing in the area, to assist in identifying local species which may be sensitive to ozone

2.4 Spray Drift

It is not intended for the more regulatory aspects, or the potential dispersion mechanisms of spray drift to be examined in this review, but rather to highlight aspects which relate to potential impacts on ecosystems. Studies have been conducted overseas which have shown birds nesting in hedgerows have suffered casualties to the very young from the effects of spray drift, and similarly, butterflies visiting field flowers and hedgerows have declined in numbers due to spray application.

2.4.1 Recommendations for Future Work

There are no reports of similar effects in New Zealand, although they undoubtedly occur. It is suggested, that an investigation be undertaken to identify where particular species may be vulnerable to, or badly affected by spray drift.

3. SPECIES SENSITIVITIES TO AIR POLLUTION

3.1 Plants

New Zealand has considerably better air quality than most other industrialised countries. The population centres in New Zealand also have a significantly different climates to those countries which have experienced severe effects from air pollution, and this results in two major effects: for the most part, better dispersion of the relatively low pollutant levels, and optimum growing conditions for many plant species which limits the severity of impact from air pollution. Plants are worst affected during the colder months, when stomata tend to be open, than in the warm months when greater control is exercised over stomata aperture, in order to conserve water. For these reasons, the potential for plants to show any acute effects due to NO_x and SO_2 emissions over wide areas is minimal, and only likely to arise from local sources, under extreme circumstances.

When measurements of ambient air concentrations of NO_x and SO_2, where NO_x was higher than SO_2, were compared with forest canopy uptake, it was found that NO_2 uptake was higher than SO_2 uptake. The cellular capacity for the reductive detoxification of NO_x is high, and the fluxes of NO_x are low, and it is apparent that NO_x poses far less of a threat to cellular survival than SO_2. While the cellular demand for reduced nitrogen is high and ambient NO_x levels are low, NO_x acts as a fertiliser. However, increased nitrogen availability (soil and air) has the potential to accentuate nutritional imbalances, particularly if other essential elements such as Mg are in short supply (Lange et al,1989).

Plants neutralise and immobilise atmospheric SO_2 by sequestering in a variety of organic compounds via either oxidative or reductive detoxification. Oxidative detoxification of SO_2 can produce cation deficiencies in the plant, which reduce the ability to take up important elements. Long-term resistance to SO_2 using this pathway requires the plant to mobilise cations in the root system on a proton/cation exchange basis. Therefore, cation availability of the soil becomes an important issue, which often requires some form of fertilisation in order to save the plant (Heber and Huve, 1998).

One important strategy involved in sequestering SO_2 involves reductive detoxification. This has significant benefits to the plant, including avoiding the acidification issues which can result from other routes of sulfate accumulation. Herbercaceous plants tend to have a lower carbon/reduced sulfur ratio than woody trees. Maize, for example has a 600:1 carbon to reduced sulfur ratio, and spruce trees, 10,000:1. Therefore, for the same deposition of carbon in biomass, maize can deposit much more SO2 as reduced sulfur, than spruce. Plants with lower carbon/reduced sulfur ratios are expected to be less sensitive to atmospheric SO_2 (Heber and Huve, 1998).

The pollutants which cause severe effects from short term exposures are ozone, fluoride and PAN. Fluoride will only occur close to local sources, and it is unlikely that any real problems from the formation of PAN will occur, because the precursor levels are very low. However, in New Zealand, the greatest potential for damage to plants is from ozone formation, and this potential is increasing along with increasing vehicle ownership and kilometres travelled.

Plants are most vulnerable to damage from ozone during growing periods, when their metabolism and gas exchange is active. Ozone enters the plant leaf through stomatal pores. Once within the leaf it can react with many organic molecules but is preferentially consumed by fast reactions with certain compounds (Lange et al. 1989). In particular the double bonds of lipids in membranes are preferred substrates and most ozone entering the cell is trapped in the plasmalemma and very little reaches the vacuole. Lipid destruction and oxidation of membrane proteins make the plasmalemma the main target of ozone attack. The biomembranes of cell organelles like chloroplasts also contain a high proportion of unsaturated fatty acid residues. However, the intracellular ozone concentration decreases rapidly with distance from the plasmalemma so that the organelles are normally in little danger. When air ozone levels are very high there can be considerable pigment bleaching and damage to thylakoids in the chloroplast. There can also be oxidation of SH-groups which maintain structure in proteins with the consequence of both structural and enzymatic failure.

Considerable levels of antioxidants do exist within the cytosol of cells and there are also repair mechanisms with the result that low levels of ozone, even if persistent, do not cause any damage.

3.1.1 Recommendations for Future Work

- an assessment of plants, including commercial, native and exotic species, to determine which may possibly be sensitive to air pollution, refer also to Table 2, this document, crop species which have demonstrated affects from air pollution, and/or other plants which, virtue of their common location are likely to be exposed to ozone (for example, cabbage tree, pittosporum, pseudopanax, and other species prized as decorative garden plants, and also pohutukawa, which is frequently grown along highways, especially on the Coromandel Peninsula)

- the ranking of the “at risk list” to determine priorities for study followed by the planning and instigation of fumigation studies to determine the direct effects.

3.2 Assessment Criteria

There is a need to understand more fully and even to rank the effects and progression phases of air pollution on plants. Many studies have reported “an effect” at certain concentrations over defined periods, but it is equally important to understand the consequences or seriousness of the effect. An effect may range from a minor metabolic adjustment with very little if any consequence, a reduction in yield which in crop species is relatively serious, to visible injury and death from which there is no recovery. At one end of the scale, the consequences are minimal if any, and at the other, fatal. This is particularly important when these effects are incorporated into setting guideline levels.

Assessing the physiological responses of plants to pollution exposure is far more satisfactory than waiting to identify visible injury resulting form exposure, for the reason that, by the time visible injury occurs, the plant is already in a stressed condition which will be difficult to recover from. Detection of physiological changes can be made at the “early warning” stage, when it is more desirable and easier to prevent further damage.

Physiological tests applied routinely to plants in order to estimate their condition or responses to stresses should posses several characteristics. Mohammed *et al.* (1995) examined methods for determining the physiological condition of tree seedlings prior to field planting. Whilst the plant attributes of greatest interest for forest establishment are not identical to those for assessing the response of plants to pollutant stress, the criteria for assessment can be adapted to pollutant effects research and monitoring. The scheme of Mohammed *et al* (1995) is produced in Table 1, with modification of the Speed of Assessment and Applicability to Monitoring categories.

Table 2: Criteria that may be used to assess field response of plants to air pollutants (after Mohammed *et al*. 1995)

Characteristic	Weight	Ranking criterion
Speed of Assessment	3 2 1	< 1 h < 1 day > 1 day
Simplicity	3 2 1	anyone can use requires technician requires scientist
Cost	3 2 1	< US$100 US$100-1000 >US$1000
Reliability	2 1 0	very reliable reliable not reliable
Sample disturbance	2 1 0	no damage partial damage specimen destroyed
Quantitative	2 1	results can be analysed statistically qualitative analysis only
Diagnostic utility	2 1	able to determine cause of problem not able to determine cause of problem
Basis of measurement	2 1 0	physiology is measured directly physiology is inferred non-physiological assessment
Adaptability	3 2 1 0	useful for more than one function and season useful for more than one function useful at more than one time useful at one time in the growing season
Predictability	3 2 1 0	high predictability of future condition and long prediction span highly predictable somewhat predictable not predictive of future condition
Applicability to Monitoring	3 2 1 0	highly useful for monitoring moderately useful slightly useful not useful

For the determination of tree seedling condition, chlorophyll fluorescence was ranked the highest, closely followed by photosynthetic gas exchange, the differences being the relative simplicity and diagnostic ability of the chlorophyll fluorescence approach, and the greater adaptability of gas exchange. Mohammed *et al* (1995) indicated that sampling procedures must be determined very carefully, and where plants are growing in highly polluted environments, the ambient conditions may be unsuitable for sensitive instruments (Saarinen and Liski 1993), attention must also be paid to sample storage and pre-treatment.

3.2.1 Long-term, Low-level Exposures

The general understanding of damage to plants caused by air pollution is of some kind of visible injury, as this was the first recognised symptom. However, a plant will have sustained considerable “invisible” injury by the time it becomes detectable. When plants are exposed to air pollutants such as SO_2, they must re-organise their metabolic processes to cope with what is essentially an internal chemical imbalance. This most likely involves a re-direction of reserves, which has the potential to adversely affect production, and can have serious consequences if it happens at some critical period, such as during seed-set. An active area of research is the study of the effects of air pollution on the genetic potential of future generations.

This research attempts to understand the consequences of damage to seed and the genetic potential, and therefore survival ability of future generations. One of the problems of understanding all of the effects is the very long lifespan of the subjects, and therefore, sophisticated computer modelling is called for, which has given rise to such models as “Eco-gene” (Degen and Scholz, 1998).

While there is undoubtedly huge potential for air pollution exposure to affect the genetic variability passed on in seeds, survival strategies, such as the production of vast seed banks, may overcome these negative influences. Even for healthy, unaffected seeds, germination is very much dependant on having the most favourable conditions at the right time, as is survival beyond germination. The reality most often is that only the very fittest specimens survive to maturity anyway, and this may potentially overcome the adverse affects of air pollution impact.

Plants are sessile organisms, therefore unable to move to escape adverse conditions. Plants which are short-lived can adapt from one generation to the next. Trees are long-lived sessile organisms, and to succeed in an environment which will change many times during the lifetime of a tree (10s to 100s of years) must possess a balance between sufficient adaptation to the prevailing conditions, and enough genetic potential to be able to adapt to future environmental conditions. In forest systems, individuals, as well as the population must possess a high degree of genetic multiplicity. Indeed, many studies have shown that forest trees have a higher degree of genetic variation than other organisms which are either able to adapt from one generation to the other (short lived) or are mobile, and able to escape adverse conditions.

3.2.2 Survival and Selection

Large natural populations are likely to have many genotypes with differing sensitivity to environmental stress. Two questions have been posed as fundamental to the understanding of the management of air pollution effects on plants, and in particular, trees:

- the nature and extent of the effect of the environmental stress on a plant, and the variation between plants in a population

- if variation exists, does it lead to successful adaptive processes? (Gregorius 1989b)

There has been much investigation of the first question, but very little is known of the second, even though this may be more crucial to the maintenance of species in a constantly changing environment. Gregorius used adaptation to indicate both a general condition which represents the capacity of the species to survive and reproduce under changing environmental conditions, and a particular trait of a species which enables it to survive under defined conditions.

3.2.3 Synergistic and Additive Effects

It is very rare for nitrogen pollutant species to exist in isolation. Most often, they are in association with sulfur dioxide and ozone, both of which are phytotoxic. Summarised reviews of plant responses to exposure to these combined pollutants show that the effects are additive, synergistic or antagonistic (WHO, 1987).

Studies on a few plant species have shown again how important climatic conditions are on the overall effect of exposure to mixtures of pollutants. Concentrations which are damaging in winter can be negligible or even beneficial in summer conditions. NOx combined with SO_2 will generally produce an overall reduction in growth, as well as visible foliar injury at concentrations much lower threshold concentrations than either pollutant alone.

Studies on the combined effects of ozone, SO_2 and NO_2 have suggested a threshold for injury as low as 28.5ug/m^3 NO_2 in association with similar levels of SO_2 (40ug/m^3) and ozone (60ug/m^3).

Peak concentrations of $NO_{2,}$ are often associated with elevated SO_2 levels, but low ozone, due to the scavenging of ozone by nitric oxide. Under these conditions, it has been shown (WHO, 1987) that sensitive plants are adequately protected from adverse nitrogen dioxide effects if the four hour average does not exceed 95ug/m^3.

3.2.4 Recommendations for Future Work

- undertake a ranking of effects of air pollutants on plants
- undertake fumigation tests which include ranges of exposure times and levels to determine the progression of response by plants to air pollution
- a more extensive literature review of what is known on the potential for low level air pollution effects to occur
- identification of New Zealand ecosystems or populations which may be subject to changes in functional diversity
- the inclusion of additive and synergistic pollution effects carried out in conjunction with other fumigation tests (3.1.1)

3.3 New Zealand Plants

The limited information available concerning the sensitivity of New Zealand plants to atmospheric pollutants is the result of the limited impact of pollutants up to the present time. From field investigations near fluoride sources in the South island, it has been possible to construct a partial list of plant species with their fluoride sensitivities determined either from investigations elsewhere, or estimated from field surveys. These are summarised in Table 2.

Table 3: Shrub and tree species encountered in field surveys in New Zealand, with fluoride sensitivity classes as determined by previous information or correlation with species of known sensitivity.

Species	**Common name**	**Fluoride sensitivity class**
Acacia dealbata	Silver wattle	intermediate
Acaen novae-zelandiae	Bidibid	intermediate*
Acer campestris	Sycamore	sensitive
Acerpalmatum dissectum	Laceleaf maple	sensitive
Aciphylla horrida	Spaniard grass	tolerant*
Agathis australis	Kauri	intermediate*
Actinidia chinensis	Kiwifruit	intermediate*
Agapanthus africanus	Agapanthus	tolerant*
Azalea indica	Azalea	sensitive
Betula alba	Silver birch	sensitive
Blechnumpenna-marina	Hard fern	sensitive*
Callistemon citrinus	Bottlebrush	intermediate
Camellia japonica	Camellia	tolerant
Camellia sasanqua	Camellia	tolerant
Species	Common name	Fluroide sensitivity class

Cedrus atlantica	Atlantic cedar	sensitive
Chamaecyparus lawsoniana	Lawson cypress	indeterminate
Chionochoa rubra	Red tussock	tolerant*
Coprosma arborea	Mamangi	tolerant*
Coprosma cheesemanii	Spreading coprosma	intermediate*
Coprosma grandifolia	Kanono	intermediate*
Coprosma lucida	Karamu	tolerant*
Coprosma propinqua	Mingimingi	intermediate*
Coprosma tayloriae		sensitive*
Cordyline australis	Cabbage tree	intermediate*
Cyathodes juniperina		sensitive*
Dactylis glomerata	Cocksfoot	intermediate*
Dahlia X	Dahlia	tolerant
Discaria toumatou	Matagouri	intermediate*
Dodonaea viscosa	Akeake	tolerant
Eucalyptus cinerea	Spinning gum	intermediate
Eucalyptus globulus	Tasmanian blue gum	intermediate
Eucalyptus gunnii	Cider gum	intermediate*
Eucalyptus leucoxylon	Yellow gum	intermediate
Eucalyptus nicholii	Nichol's peppermint	intermediate
Euycalyptus nitens	Shning gum	intermediate
Species	Common name	Fluoride sensitivity class

Eucalyptus obliqua	Messmate stringybark	sensitive
Eucalyptus viminalis	Manna gum	intermediate
Euphorbia peplus	Petty spurge	tolerant
Fagus sylvatica cv. *purpurea*	Copper beech	intermediate
Fuchsia excorticata	kotukutuku	tolerant*
Gladiolus x hybridus	Gladiolus	very sensitive
Hebe speciosa	Veronica	tolerant*
Hedera helix	Ivy	tolerant
Hymenanthera alpina	Porcupine shrub	tolerant
Hymenanthera crassifolia		intermediate*
Ilex aquifolium	Holly	tolerant
Larix decidua	European larch	sensitive
Leptospermum ericoides	Kanuka	tolerant*
Leptospermum scoparium	Manuka	tolerant
Magnolia grandiflora	Magnolia	intermediate
Melicytus crassifolia		intermediate*
Olearia ilicifolia	Tree daisy	intermediate*
Olearia paniculata	Akiraho	tolerant*
Phormium tenax	Native flax	intermediate
Species	Common name	Fluoride sensitivity class
Picea abies	Silver fir	sensitive

Pinus patula	Patula pine	indeterminate
Pinus radiata	Radiata pine	intermediate
Pinus sylvestris	Scots pine	sensitive
Pittosporum eugenioides	Lemonwood	sensitive*
Podocarpus totara	Totara	intermediate*
Populus alba	White poplar	intermediate
Polulus nigra var. *italica*	Lombardy poplar	sensitive*
Prumnopitys ferrugenea	Miro	intermediate*
Prunus armeniaca	Apricot	sensitive
Prunus persica	Peach	sensitive
Prunus X *pissardi*	Cherry plum	sensitive
Pseudopanax ferox	Toothed lancewood	tolerant*
Pseudowintera colorata	Horopito	sensitive*
Pteridium aquilinum	Bracken fern	intermediate
Quercus lusitanica	Portuguese oak	indeterminate
Quercus robur	English oak	intermediate
Rhododendron X	Rhododendron	sensitive
Ribes sativum	Common currant	intermediate
Species	Common name	Fluoride sensitivity class
Rosa X	Rose	intermediate
Rubus squarrosus	Bush lawyer	sensitive*

Sophora japonica	Black locust	sensitive
Sophora tetraptera	Kowhai	tolerant*
Taxus baccata	English yew	sensitive
Vitis vinifera	Grapevine	sensitive
Weinmannia racemosa	Kamahi	sensitive*

* Sensitivity ranking interpolated in New Zealand field surveys.

In the native species encountered none were classified as very sensitive, which would require the imposition of the special land use zones identified in the ANZECC (1990) guidelines for their protection.

A list of species sensitivities was not easy to construct, because of the interaction between he effects of fluoride and other natural stresses, particularly wind or salt spray. However, some generalisations can be made, based upon the consistency of response of plants in Australia and New Zealand:

- Small-leaved plants are often more tolerant than large-leaved plants. This may be a function of the much more limited redistribution of fluoride in small leaves, and its consequent accumulation in the leaf extremities.

- Slow-growing plants are often more tolerant than fast-growing plants. This may be associated with generally slow rates of gas uptake (including fluoride) from the air.

- Salt-tolerant species tend to be fluoride tolerant. Tolerance of one halide ion is probably associated with some general tolerance to the group. Otherwise, there is not a clear association between ecological niche and fluoride tolerance.

- The association between the fluoride concentration in foliage and the appearance of injury is commonly weak, even within a species, so that fluoride accumulation is not a good indicator of incipient visible injury.

3.4 Animals

Animals differ from plants in being mobile, and therefore able to move away from situations which cause discomfort. With the exception of spray drift exposures, the most severe effects to animals which have resulted from air pollution have been by way of secondary effects, which have arisen as flow on effects when the entire ecosystem has been subjected to prolonged and acute exposures, and where serious chemical imbalances which the system cannot accommodate have resulted. Examples are decline in fish populations in lakes which have become acidic; and in the case of birds, changes in forest species diversity and therefore habitat has resulted in changing bird populations, both in terms of declining numbers for some species, and proliferation of others.

Acid deposition has been linked with loss of calcium in the diet, which has resulted with birds, in decreased eggshell strength and subsequent reduced fledgling viability.

There have been relatively few studies on the physiological responses of animals to pollution exposure. In this respect, most studies have been carried out on birds. In the case heavy metals, the exposure is mostly secondary, through diet rather than via inhalation, either from eating food which has particulate matter deposited on it, or eating food which has taken up heavy metals, and thereby increasing the levels of exposure through concentration.

Ambient air levels of metals are shown to influence the body burden of non essential elements, such as Pb, Cd and Hg, but the essential elements, such as Zn, Cu and Fe are not necessarily influenced, and are likely to be subject to homeostatic control mechanisms. Severe reproductive inhibition has followed elevated Hg intake in birds. In the case of young quail, effects were seen following intake of 2ppm; while in chickens, levels of 125ppm in drinking water resulted in depressed fertility, and increases above this level lead to mortality. As with Hg, increased levels of Pb affected young birds more severely than adults. Reproduction becomes affected by dietary levels above 100ppb. Starling reared in highway verges where dietary exposure levels are around 90ppb showed decreased brain weights.

Studies have been carried out which show that passerine (perching) birds do show physiological changes following exposure to air pollution. Passerine birds have larger numbers of erythrocytes and higher levels of haemoglobin than other birds and animals, which is thought to be a physiological adaptation to the high metabolic requirements of flight. Exposure to annual average SO_2 levels up to 50 ugm^3 (monthly averages between 16 and 974 ugm^3) produced decreased erythrocyte levels accompanied by increased corpuscular volume and corpuscular haemoglobin in some birds. In the same study area, small birds and wood mice showed altered tracheal epithelium, which was ascribed to SO_2 and NO_2 inhalation from the nearby coal fired power plant.

While these studies do show an effect, it has not been established what levels of air pollution are required before an effect is seen. In particular, there is no information on the relationship of particulate deposition to dietary intake. This is especially the case when concentration effects occur through the food chain.

3.5 The New Zealand Situation

There is a dearth on information on the potential effects on air pollution on animals of any kind in New Zealand. In the case of gaseous pollution, in overseas situations where metabolic and physiological changes can be measured, the pollution levels are considerably higher than those encountered in New Zealand. Bird populations most affected were inhabiting areas which were exposed to significant local sources of pollution; and the only similar situation which may occur in New Zealand appears to be birds nesting close to major highways suffering the effects of exposure to NOx and SO_2.

Effects resulting from particulate deposition and concentration through food chains may be possible in isolated cases. Fish have proven overseas to be very good early warning indicators of imbalances to ecosystems at risk. New Zealand has a high incidence of volcanic activity which results in significant particulate deposition, some of which can be toxic. Although there have not been any reported studies on negative ecological changes by way of chemical imbalances to date from volcanic eruptions, the potential for this to occur should be kept in mind.

3.5.1 Recommendations for Future Work

- Identify, measure and map significant metal particulate sources

4. BIOMONITORING

To be useful, a biomonitor must

1. respond reproducibly to the pollutants of concern, and the response

2. must be easily determined, by observation or measurement

Biomonitoring has great appeal, being perceived as a very sensitive, easy, economical, readily available or easily comprehended means of determining the presence, the quantity or the effect of a pollutant in the environment. These characteristics of biological monitoring need not be mutually exclusive, but neither are they always congruent, and it is important to recognise that determination of a pollutant impact on complex biological systems is rarely simple, rapid, unequivocal, convenient or inexpensive (Zonneveld 1983, Jeffrey and Madden 1991).

The suitability of a biological monitor for a particular application first needs to be established. For many members of the public, the combined effects of all pollutants may be more important than the effects of each constituent of a pollutant mixture. For emitters, the effects of the pollutant for which they are most responsible will be of principal concern. Regulators may be interested in biological monitoring as a supplement to other means of pollutant assessment. These three social groups are likely to have very different, and possibly irreconcilable requirements of biological monitoring, so an acceptable technique or techniques must be developed for clearly defined purposes.

Several requirements for implementation of biological monitoring may be summarised as:

1. Definition of the purpose of environmental description;

2. Recognition of attributes of the species that influence their utility as monitors;

3. Identification of the most reliable and efficient means of collecting and analysing the required information.

4.1 The Purpose of Biological Monitoring

The most important step in establishing a program of biological monitoring is to identify the purpose of sampling, as this must justify all subsequent steps. Smith (1994) identified four purposes of biological monitoring related to pollutants which included advance warning of threats to other species, and detection of episodic emissions of pollutants. These purposes are clear, but may be more restrictive than is desirable for wide application to terrestrial environments. Four purposes of routine biological monitoring that include those presented by Smith, but express concerns in a more general manner are:

1. to estimate ambient concentrations of a pollutant;

2. to protect ecosystem health and environmental well-being through indication of the risk of significant harm to certain species;

3. to prevent significant harm to an existing commercial activity through indication of the risk of significant harm to that activity;

4. to establish a historical record of a biological parameter.

Continual testing of the assumptions and methods of biological monitoring is essential if biological monitoring is to be useful to society (Ramamoorthy and Baddaloo 1991), as every organism is affected by many environmental factors, and not only by the component that is the objective of monitoring. The separation of these interacting factors is often difficult, but it is critical to the reliable development and application of biological monitoring.

4.2 Overall summary

1. Bioindicators should provide an excellent, effective and cost-effective method for monitoring air pollution. Useful species are likely to be found in all environments and those used would depend on the environment to be monitored.

2. Bioindication would seem to be particularly useful for air pollution studies where potential polluting sources may not yet be identified or where long-term monitoring is needed. Used in conjunction with suitable calibrating systems it should be possible to get indicative values for air pollution from organisms within the affected habitats.

3. Bioindication relies, to an extent depending on the organisms and methodology used, on specialists skilled in the identification of the organisms. This will normally place constraints on the use of bioindicators in New Zealand unless some simplified sampling procedure can be developed. Constraint will be particularly severe where community structure and species occurrence are used to calculate pollution indices. Constraint is less severe but still present where analyses of elemental composition are used. It is still normally necessary to be able to identify the organism to be analysed but, in this case, a very common or particularly obvious organism can be used.

4. Lichens would seem to be very useful organisms for air pollution studies with both active (change in community structure) and passive (elemental composition) systems being suitable. Transplantation also provides the opportunity to detect local sources of pollution even where lichens may not be present due to lack of suitable substrate. It is unfortunate that the pollutant to which lichens are most sensitive, SO2, is not normally a problem in New Zealand. There is also the problem that the sensitivity of the organisms in relation to those in the Northern Hemisphere (where most studies have been carried out) is not yet known. The limited evidence available would suggest that New Zealand plants could be many times more sensitive than those in long-polluted Europe or North America.

5. a. Passive monitoring involving the analysis of organisms would seem to have the greatest potential in New Zealand. Used correctly it would combine effectiveness with economy.

   b. Lichens or bryophytes would be the best organisms to use since they are proven to be more tightly linked to the air in their elemental composition than trees or other higher plants which source most nutrients from the soil.

   c. Passive monitoring can be applied in two ways both of which would have their uses in New Zealand. First, lichens or bryophytes in situ can be collected and analysed; second, samples of known composition can be placed in the area to be monitored for a selected time and then analysed to determine the change in composition.

   d. The first method is an excellent and cost-effective method for monitoring large areas against rare events. Base-line composition data should be collected on a regular basis (multi-annual intervals would probably be satisfactory) and this should be complemented with a secure sample collection that can be analysed later, if required, to enhance information. If such a data set had been in place for the central North Island then the effects of the recent eruptions would have been easily monitored.

   e. The second method is highly suitable for concentrated or long-term monitoring of selected areas. In this system bags containing a suitable organism, a bryophyte is usually the best, of known composition is hung in the area and then later analysed. This system has the advantage that it is cheap, little more than the cost of the analyses, unobtrusive and very low-tech, the high-tech part stays in the laboratories. The time period for optimal results would need to be determined by trials. This system is suitable for most pollutants since it does not rely on a reaction by the organism. It would be especially suitable for monitoring drift from horticultural and agricultural spraying. Everything from superphosphate to the most advanced herbicide could be monitored.

4.2.1 Recommendations for Future Work

- Passive monitoring schemes be developed to:

  a. obtain background composition values in as many areas as possible.

  b. a system involving the use of bryophytes in bags as indicators of pollution be developed. This would involve choice of the most suitable bryophyte, production of a bryophyte bag unit with a constant composition, calibration of the method against air pollution measurements using accepted international technology.

  c. the system to be trialled against normal air pollutants eg: heavy metals, sulphur dioxide, fluoride and nitrogen oxides and, as well, against spray drift from agricultural and horticultural practices.

- That the relative sensitivity of selected New Zealand plants, including important groups like lichens, be determined for important air pollutants such as sulphur dioxide and ozone. Determination of the sensitivity would allow recommended upper pollutant levels determined from the northern hemisphere to be adapted for New Zealand use.

5. AIR QUALITY GUIDELINES

Using the information currently available on the effects of ambient air pollution on ecosystems, any changes considered will be driven by the effects on plants, rather than animals. However, there remains also the potential for ecosystem “flow-on-effects” caused by chemical imbalance, which can affect both plants and animals.

One of the most important factors to consider when comparing overseas effects on plants and forests with the New Zealand situation, is the conditions under which the plants are growing. It has been shown that effects of sulfur dioxide and nitrogen oxides are markedly more serious when high levels of pollution exposure coincide with growing conditions of low light intensities and high soil moisture when plants metabolic rate is low and their stomata open, than in conditions of high light and low soil moisture, and increased metabolism. For the most part the New Zealand winter conditions are significantly different to the northern hemisphere boreal forest conditions, where high pollution episodes coincide with very cold climatic conditions. However, there is very little information available on the effects of air pollution to plants in the New Zealand situation, and certanly none on the sensitivity of New Zealand species.

5.1 Effects on Plants

For plants, adverse effects may be, in approximate decreasing order of severity: death, failure of reproduction (e.g. flowering and seed set), failure of regeneration (e.g. germination and establishment), significant reduction in functional leaf area and vegetative growth, significant reduction of reproductive growth (e.g. fruit yield), accumulation of substances toxic to the plant, accumulation of substances toxic to animals that may consume the plant, disturbance of the normal pattern of growth (e.g. premature loss of foliage), and alteration of the appearance of vegetative parts.

In vegetation managed for commercial purposes, significant reduction of vegetative or reproductive growth, and the accumulation of toxic substances are the effects most likely to be of concern. The determination of a significant reduction is not specified, but the simplest would be a reduction attributable to the specified pollutant that could be established statistically at an prescribed level of probability. Such a demonstration would require that plants are grown under appropriate and equivalent management conditions over the growth cycle of the plants, at the site in question and at an identical site except for the presence of the pollutant.

In vegetation managed for conservation purposes, such as a National Park or World Heritage Area, an adverse effect may be described as follows. Taking account of the normal variation in species composition and in vegetation structure that occurs in both space and time in a natural environment, an adverse effect is one that can be attributed to a specified pollutant, and can be established statistically at an prescribed level of probability. Such a demonstration would require detailed observation over a sufficient number of growing seasons to establish the normal variation between years in the nature and extent of regeneration processes, species succession, and structural change in plant communities. The observations would be required both in the polluted area and in an identical area, except for the presence of the pollutant.

Pollutant accumulation by plants may be important when the plants or plant parts are eaten by humans or other animals. Dietary intake of the pollutant is the essential variable, and this will depend n both the concentration of pollutant in the plant material and the quantity of plant material eaten during a given period. For fluoride, relationships have been established between average forage fluoride concentration and the period for which these concentrations are acceptable. Where dietary selection may result in forage intake in different proportions from the representation of species in the pasture, sampling of the pasture may not necessarily indicate the dietary intake of the pollutant.

Where the principal function of the vegetation is aesthetic, the occurrence of visible injury to foliage may be used to establish the existence of an adverse effect. For many pollutants, the percentage of leaf area affected by necrosis has been used to indicate effect, and the extent of other symptoms, such as chlorosis, may also be used. In general, there is an association between the type and degree of visible injury and effects on plant growth and survival. However, there is not a single pattern of association for all species, and even for a single species, there is not a single relationship between the degree of exposure to a pollutant and the extent of development of various injury symptoms. Visible injury symptoms, whilst they are accessible to everybody, are not often easy to interpret, and this interpretation must be carried out with great care.

Empirical injury categories may be developed for particular species and particular pollutants, and these may be related to other aspects of plant functioning for the purposes of assessment of adverse effects. An attempt to develop injury categories and to define adverse effects has been made recently for New Zealand vegetation, and in reproduced in part in Table 4. In principle, the occurrence of an adverse effect on vegetation in domestic gardens has been associated with the purpose for which the plants have been grown. It has been proposed that three purposes of garden plant cultivation be recognised: competitive, dedicated, and casual. These categories would be associated with increasing degrees of visible injury before an adverse effect was recorded. The difficulty of defining the purpose of gardening remains, but at present it is suggested that there is no better alternative for quantifying an adverse effect on aesthetic grounds.

It is unlikely that severe effects from air pollution will be seen in New Zealand. However, there is potential for plants to be affected by ozone exposure in some parts of the country; and a high awareness of the phytoxicity potential of sulfur dioxide should be retained.

5.2 Nitrogen

The case of nitrogen toxicity to plants is somewhat different in that all nitrogen compounds, not only nitrogen dioxide, have the potential to cause adverse effects. Visible injury from NOx is extremely rare and only produced by extremely high concnetrations. Plant response to NOx is species and variety dependent as well as dose dependent. The toxicity of nitrogen depends on the nitrogen nutrient status of the plant or ecosystem at the time of exposure. In the case of individual plants, nitrogen deposition in the New Zealand situation is most likely to occur in situations where plant growth is nitrogen limited, and therfore act as a fertiliser promoting plant growth and production. There is a potential for negative impacts where this nutrient loading is excessive, particularly in ecosystems adapted to low nutrient status, where changing the nutrient status will result in “ecological shift”, when plants best able to cope with higher nitrogen nutrition will out-compete and ultimately replace those adapted to low nitrogen status. Such risks increase with increased deposition, and any account of this must include other nitrogen compounds. In particular, ammonia, which has increased in Europe as a result of stack control legislation (Alan Green, pers com). Subsequently, plants are stimulated to faster growth and productivity, but when other nutrients (Mg, K, Ca) become limited they cannot cope, and death is often the final result.

In the northern hemisphere with high levels of NOx pollution in combination with sulfur dioxide, nitrogen dioxide has been responsible for 30% of acid deposition. As detailed previously, it is very unlikely that acid precipitation on such scales will occur in new Zealand.

For moderate levels of NOx pollution, plants are well equiped to cope. Because all atmospheric nitrogen compounds are potentially taken up by plants, they are all potential contributors to the load. Therefore, it is recommended that for ecotoxicological effects the WHO 1996 approach be followed, where critical nitrogen loadings are used:

NOx ctitical level	30 ugm^{-3}	annual average
N critical load	15 - 35 kgNha^{-1}yr^{-1}*	annual average

Oligotrophic ecosystems should be identified, and more precise critical loadings to protect nutrient status calculated for them.

5.3 Sulfur Dioxide

Sulfur dioxide has been shown to be 2 - 2.6 times more phytotoxic than nitrogen dioxide. It has also been the main contributor to acid deposition in other parts of the world. Long term exposures of around 20 40 ugm3 have resulted in visible foliar injury to *Picea abies, Pinus sylvestrus* and *Betula pubescens*; and reduced productivity in tobacco and cucumber was recorded following 28 days exposure at 55 ugm3. This is some of the evidence which suggests that the existing MfE guidelines should be reduced to protect plants.

It is recommended that the critical loading approach to protect ecosystems, taken by WHO, 1996, be followed:

SO$_2$ critical level	10-30 ugm^{3}*	annual average
S critical load	250-1500eq ha^{-1}yr^{-1}*	

5.4 Ozone

Ozone may decrease plant growth rates even at natural ambient levels. If so, it will not be possible to establish a concentration below which there is no adverse effect, and guideline recommendations would need to be based on levels of effects judged to be significant for either economic or ecological reasons. Such guidelines would need to balance the costs of control measures needed to limit ozone concentrations against the benefits of limiting growth inhibition. Since the frequency of meteorological conditions conducive to photochemical ozone formation vary with geographical location, the costs of control to any particular cumulative ozone exposure will also vary for different locations, so that it may only be possible to establish location-specific guidelines. These would presumably have to be based on a airshed photochemical models.

Ozone injury is a function of concentration and duration of exposure, combined with plant growth and metabolic activity. Plants must be metabolically active for O_3 to have any effect, and since O_3 forms in sunny dry conditions, O_3 effects on plants is likely to be seasonal in most parts of the world. Previous recommendations of 200ugm3, 1 hour average; 65ugm3, 24 hour average; and 65ugm3, 100day O_3 as being safe thresholds to avoid injury to plants have been shown to be inadequate. Many species have shown both visible foliar injury and reduced productivity at levels around 80ugm3, and reduced productivity has been shown at levels between 25 and 45 ppb. Plants vary greatly in their response to ozone, and can respond negatively to levels close to ambient. It would seem that the best approach is to follow the WHO, 1996 recommendation:

ozone critical level	0.5-10ppm.h	5d - 6m

It is not clear what the 5d - 6m designation means. If we assume that this means that the exposure over any 5 day period should not exceed the guidelines during a six month period, for a 10 hour photoperiod,

0.5ppm.h is equivalent to 10ppb

and 10ppm.h is equivalent to 200ppb

The 10ppb level is below the usually expected ambient level, so that more information about the definition of these guidelines is needed.

**The WHO 1996 guidelines are available only as a table giving the guideline recommendations. Publication of the full guideline book has been delayed, and attempts to obtain access to the rationale and interpretation of the guidelines has been unsuccessful so far. In particular, the guidelines for ecotoxic effects are dependent on the types of vegetation, soil and ecosystem, but no guidance on which of these are more or less sensitive is included in the summary released.*

5.5 Synergistic and Additive Effects

While there is no doubt that there is potential for air pollution in combination to have negative impacts at lower concentrations, consideration must be given to the fact that this happens under winter conditions, when low metabolic rates limit the manufacture of the enzymes required by the plant to carry out detoxification. Studies which investigated the combined effects of ozone, SO_2 and NO_2 have suggested a threshold for injury as low as 28.5ugm^3 NO_2 in association with similar levels of SO_2 (40ugm^3) and ozone (60ugm^3) - no period of exposure given (WHO, 1987). There is no description of the injury or what process is involved. In New Zealand, climatic conditions equivalent to those of Europe and North America where plants have suffered serious injury from air pollution, will exist only at high altitudes, or in the southern-most parts of the country. New Zealand is very limited in emission sources large enough, and the size and shape of the country prohibit the formation and transport of large scale pollutant plumes. It is very unlikely that ambient pollution will occur at high enough levels at locations where these effects could occur.

5.6 Fluoride

The first approximation would be to adopt overseas standards, bearing in mind:

- the small size of most NZ industrial sources in comparison with many in the northern hemisphere.
- the dispersed nature of industrial centres, and the limited risk of transmission of pollutants from one industrial location to another.
- the existing application of internationally accepted environmental standards.
- under the most common weather conditions, the short path length for pollutant travel before it leaves the country.

5.7 Ambient Air Quality Guidelines for Fluoride

Ambient air quality guidelines for fluoride were established by ANZECC (1988), recognising three land use categories for which different guidelines should apply. The General Land Use category adopted the standard applied in several states of the USA, notably the Washington standard. To assist evaluation of these guidelines, the 90-day average concentration of 0.5 μg/m^3 will be used.

A Specialised Land Use guideline was established to protect commercially valuable plant species that have been demonstrated to be very sensitive to fluoride, including grapevines and stone fruits. The guideline values were established at half of the General Land Use values, i.e. 0.25 μg/m^3.

A third guideline was introduced to protect plant species in conservation areas "..where the sensitivity to fluoride of a number of plant species is not known..". This guideline is set at 0.1 μg/m^3, or one-fifth of the General Land Use value.

As noted in the Ambient Air Quality Guidelines (1994), "Neither the guideline not the test method specifies whether total fluorides or gaseous fluorides are to be measured. From discussion with Australian authorities, it appears that the guidelines were meant for gaseous fluorides."

Because of the limited solubility in water of most particulate fluorides, the fluoride in air that has the greatest impact on plant functioning is the gaseous component (Weinstein 1977). Consequently, the air quality guidelines should be based on the gaseous component, rather than simply the total fluoride concentration. In some situations, particularly for the determination of potential fluoride ingestion by grazing animals, it is important to record particulate as well as gaseous fluoride.

Therefore, it is recommended that consideration be given to the reporting of total ambient fluoride concentration, but that air quality guidelines be based on the gaseous component. The double paper sampling method AS 3580.13.1-1993 and the specific ion electrode method AS 3580.13.2-1991 permit this information to be gathered.

5.7.1 A New Zealand Standard for Fluoride

The Ambient Air Quality Guidelines (1994) indicated that the ANZECC guidelines should be used in the absence of sufficient data on New Zealand native plant species.

Studies carried out at three locations in the South Island within the past two years have enabled some information on New Zealand native species to be gathered. This information suggests that the range of sensitivity of New Zealand native species is not greater than that established for Australian native plant species.

Given the stringent guideline already established for the protection of plant species in conservation areas, it is recommended that no additional requirements be applied.

Table 4. Symptom categories used to establish semi-quantitative injury assessment for *Pinus radiata*, monocotyledons with linear leaves, and *Rhododendron* species.

Species	Injury	Foliage age	
	category	current season	one-year-old
All species	0	no visible injury	no visible injury
Pinus radiata	1	no visible injury	tip necrosis < 5%
	2	tip necrosis < 5% length	tip necrosis < 10%
	3	tip necrosis < 10%	tip necrosis < 25%
	4	tip necrosis < 25%	tip necrosis < 50%
	5	tip necrosis < 50%	tip necrosis > 50%
	6	tip necrosis > 50%	needles dead
grass-type	1	tip necrosis < 5% length	tip necrosis < 10% length
monocotyledons	2	tip necrosis < 10%	tip necrosis < 20% length
	3	tip necrosis < 15%	tip necrosis < 30% length
	4	tip necrosis < 20%	tip necrosis < 40% length
	5	tip necrosis < 30%	tip necrosis < 50% length
	6	tip necrosis > 30%	tip necrosis > 50% length
Rhododendron species	1	no visible injury	slight marginal and interveinal chlorosis
	2	no or very slight marginal and interveinal chlorosis or very slight cupping	distinct marginal and interveinal chlorosis, tip necrosis < 5% leaf length, marginal necrosis < 3 mm
	3	slight marginal and interveinal chlorosis, slight cupping	distinct marginal and interveinal chlorosis, tip necrosis < 10% leaf length, marginal necrosis < 5 mm
	4	distinct marginal and interveinal chlorosis, slight cupping	prominent marginal and interveinal chlorosis, tip necrosis < 25% leaf length, marginal necrosis < 5 mm
	5	prominent marginal and interveinal chlorosis, distinct cupping, tip necrosis < 5% leaf length	severe general chlorosis, tip necrosis > 25% leaf length, larginal necrosis > 5 mm
	6	severe marginal and interveinal chlorosis,	leaves absent

		prominent cupping, tip necrosis > 5% leaf length	

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