LICHEN, MOSS AND FOLIAGE BIOMONITORING IN THE PACIFIC AND YUKON REGION FOR FORESTRY CANADA

FIDS 95-8

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July 1994
Revised October 1994

ABSTRACT

This report presents the most recent biomonitoring data for the Pacific and Yukon Region with references to data collection over the past 8 years. The Pacific and Yukon ARNEWS/Biomonitoring system was the first to draw attention to moderate sulphur contents in the lichens as far back as 8 years ago. The panboreal distribution of many species of lichens and mosses adds a relevance to this system in that the sample size and comparability between regions becomes all the more robust when plots from Newfoundland can be compared to plots in central B.C. In this paper, foliar and lichen/moss data are reviewed for air quality indications in the Pacific and Yukon Region. A review of the data presented in this paper is as follows;

- Foliage from all the plots indicates that the Capilano, Shawnigan, Salt Spring Island, U.B.C. Research Forest and Coquitlam plots have obvious outlying (ie. high) Sulphur ppm datapoints.

- Trembling aspen also has high Sulphur in the two interior plots (Kelowna and Dawson Creek).

- Within-species foliar data indicates that Coquitlam, and the Vancouver area generally, has a higher S accumulation than other B.C. and Yukon ARNEWS plots. When S is considered for Western Hemlock, Scheffe's test results indicate that the order of S levels in foliage (from lowest to highest) is as follows (from Enns 1991);

  Terrace < Capilano < Jones Lake, Chilliwack < Lower Seymour < Coquitlam Upper Watershed < Coquitlam Lower Watershed.

  For Douglas-fir;

  Campbell River < Seymour Upper Watershed < Seymour Lower Watershed < Penticton

- There is a tendency for coastal samples of lichen species to have higher Sulphur contents than interior samples, on average. However, there are selected interior plots that have relatively high Sulphur contents in lichen tissue.

- Lichen sulphur contents range from below that of industrial sulphur deposition to above industrial levels, provincially.

The report makes recommendations for management of the biomonitoring system in the Pacific and Yukon Region, including a plotwize discussion of methods and tools of bioidication.

Acknowledgements

The authors wish to thank Dr. Allan Van Sickle of the Canadian Forest Service, Pacific and Yukon Regions for his administration of the ARNEWS plot biomonitoring data base and reporting system over the past years. Several other Canadian Forest Service personnel have contributed to the background information and ideas in this paper. All are listed as personal communications, however, Anne Van Niekirk, Yash Kalra, Colin Wood, Rod Turnquist, Bob Erickson, Dennis Clark, Brenda Callan and many others from the Pacific and Yukon Region and the Northern Region were particularly helpful. Also, communication with regions outside the Pacific Northwest were very important for the authors understanding of the linkage between national and regional biomonitoring concepts and problems. Denis Lachance, Les Magasi and others assisted in ways that we are sure seemed small to them but was very important to us.

Staff from various provincial and U.S. government agencies also provided support and encouragement. In particular, Julia Beatty Spence, Philip Ross, Mohammed Rafiq and Dave Sutherland of the B.C. Provincial Ministry of Environment provided their thoughts and concerns about the biomonitoring needs of their respective regions. Industrial contributors were especially supportive and encouraging for the need to include biomonitoring as part of general air pollution abatement programs. Contributors include Cominco, Alcan and Celgar Pulp Company Limited, among others.

Several experts outside the sphere of industry or government have contributed to this paper. They include Jim Case of Bovar Concord and Roy Krouse, University of Calgary. Professor Hocking of the University of Victoria Chemistry Department provided advise regarding pulp mill emission impacts on vegetation. Michael Goldstien of SOILCON Laboratories Limited provided a copy of his detailed protocol for provincial soils sampling. Fred Rhoades of Western Washington University discussed lichen chemical analysis and correlation with symptomologies in Douglas-fir.

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1.0 INTRODUCTION

The Canadian Forest Service (CFS) Acid Rain National Early Warning System (ARNEWS / Biomonitoring) is a nation-wide biological monitoring system for the effects of acidic precipitation on conifer resources. It uses primarily biological and pedological data to indicate any potential long range transport of acid rain and other air borne pollutants from point sources at various distances from the plots themselves. Canada started with small number of plots approximately a decade ago. The numbers of plots have increased to the point where similarities between groups of plots allow for assessment of regional trends in LRT (Maynard and Fairbarns 1994, Enns 1993, Enns 1994).

There is no complete compendium of air quality conditions and effects on vegetation for the Pacific and Yukon Region, although there are partial summaries (Concord Environmental, 1991, B.H. Levelton and Associates 1992). While there is no shortage of interest in regional air quality, the data are held by a number of different agencies. As a result there is little consistency of information and a large number of gaps and uncertainties. At present none of these agencies are prepared for a crisis in long range transported air pollutants, either locally or regionally, although the Canadian Forest Service is the only agency to take a regional perspective and to build a baseline database. There are a number of initiatives to correct this; a protocol for provincial soils chemistry (Soilcon 1993), a background soils sampling program (Goldstien pers comm 1994), and a proposal to develop Gas and Oil guidelines concerned with sulphur biomonitoring for the Northeast of B.C. (Sutherland pers. comm. 1994).

2.0 OBJECTIVES

The purpose of this study is as follows;

- to present the most recent phase of baseline studies; the foliar ash analysis from the newest Pacific and Yukon biomonitoring plots (#916 - 927)
- to provide an overview of past data and discuss trends in recent air quality monitoring
- to make some recommendations on what procedures should be emphasized in the future biomonitoring program

While it was hoped to provide ash analysis for a set of lichen and moss samples from ARNEWS /Biomonitoring plots #916 - 927) this sampling has been delayed while the ICP process is brought underway at the Pacific Forestry Centre. There are some exceptions, data from the Bulldog Creek plot near Rossland and additional species composition information is available from these plots. More complete ash analysis of cryptogams will completed in the next phase of this project.

3.0 METHODS

Foliage samples were collected by the Federal Insect and Disease Survey Rangers in the most recently established ARNEWS/Biomonitoring plots (a list of all plot numbers and locations are given in Appendix 1). Recent-years growth foliage from five trees per species per plot was collected and stored in separate plastic bags for drying and grinding. Processing and analysis of foliage by CFS followed precisely the methods outlined by Kalra *et al.* (1989).

Results from the mineral ash analysis are presented as Tukey's boxplots. The data are also available for independent review and summary in the Pacific and Yukon Regional Foliage soils and lichen ash analysis database (BiomonDB). Boxplots were used to obtain a graphical summary of the data distribution for individual elements of interest, plotwise and by conifer species.

The ARNEWS/Biomonitoring system is primarily designed to be compared within plots over time, although some between-plot comparisons are useful for determining regional trends. Statistical examination of the data are presented here as a suggested format for future maintenance of the system. The ARNEWS boxplot data indicated a significant difference between foliage from different species of trees within ARNEWS plots (eg. trembling aspen samples had significantly higher S contents than the group of lodgepole pine samples, all from the same ARNEWS plot). In order to compare foliar mineral content geographically, the foliage values for a given species by element were examined in one factor analysis of variance. This was only possible for widespread species such as Douglas-fir and Western Hemlock. Tukey's HSD pairwise comparisons tests were run to determine where the differences in foliar S, Mn, etc. occurred (Appendix 2). Probability plots of the variable residuals from the ANOV were used to determine if errors were normally distributed. These are also presented in Appendix 2. In order to have a normal distribution and valid statistical significance, the residuals should fall approximately on a diagonal straight line (Wilkinson et al. 1992). Sample sizes must be large enough to determine if heteroscedasticity (irregular outliers and non-homogeneous variance) is an impediment to the use of parametric statistics. The Tukeys HSD is useful for determining where the differences lie in the field of ARNEWS/species combinations.

Lichen and moss tissue samples for ash analysis were collected from selected coastal plots. Plant ecological information was collected in selected plots in order to supplement the ash analysis data. Plant species lists (including vascular plants) and field examination of air quality bioindication via lichen and moss species presence/absence, pathological condition and ecological influences on species/pathology were noted in each of the selected plots. These data will be presented in a subsequent paper.

A case study is briefly discussed where comparisons were made between lichen tissue analysis for a series of plots in a low elevation valley system to analysis from the ARNEWS / Biomonitoring plot at Bulldog Creek.

Some trends in biomonitoring initiatives in B.C. were examined through a series of interviews with experts throughout the Pacific Northwest.

4.0 RESULTS AND DISCUSSION OF THE 1993 SURVEY

Some results of the most recent sampling of foliage in the ARNEWS/Biomonitoring plots 916 - 927 are presented in Figures 1 and 2. With the exception of ARNEWS plot 916 (Saturna Island), all of the data displayed in Figures 1 and 2 are from interior plot locations in the Pacific and Yukon Region. (For plot locations please refer to Appendix 1 and Figure 4.) The data displayed in Figure 3 shows the most recent sulphur contents in foliage for all the ARNEWS plots in the Pacific and Yukon Region. This figure includes the data from Figure 1 and the most recent foliage analysis for the remainder of the plots. (Readers should be aware that some of the data in this figure is more than 2 years old). In future analysis of these data, this information will have greater relevance in a time sequence within plots, but the following figures are useful in that they show the distribution of sulphur and other minerals and they allow for some examination of potential LRT.

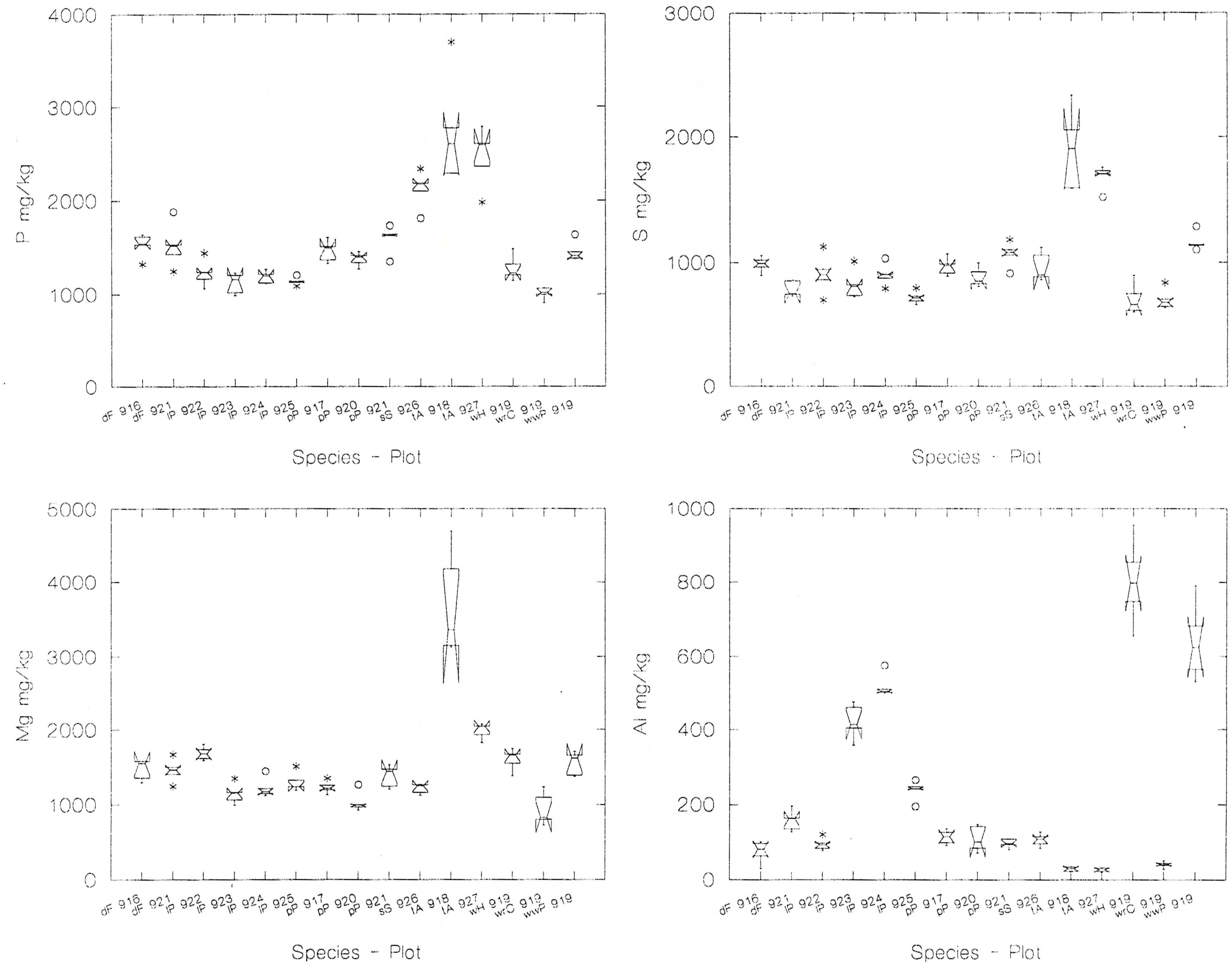

Figure 1. Phosphorous, Sulphur, Magnesium and Aluminum content distribution in five samples of foliage from each species - ARNEWS /Biomonitoring plots 916 - 927. dF = Douglas-fir, lP= lodgepole pine, pP = ponderosa pine, tA = trembling aspen, wh = western hemlock, wC = western redcedar, wwP = western white pine. Plots established in 1992-93, sampled in 1993

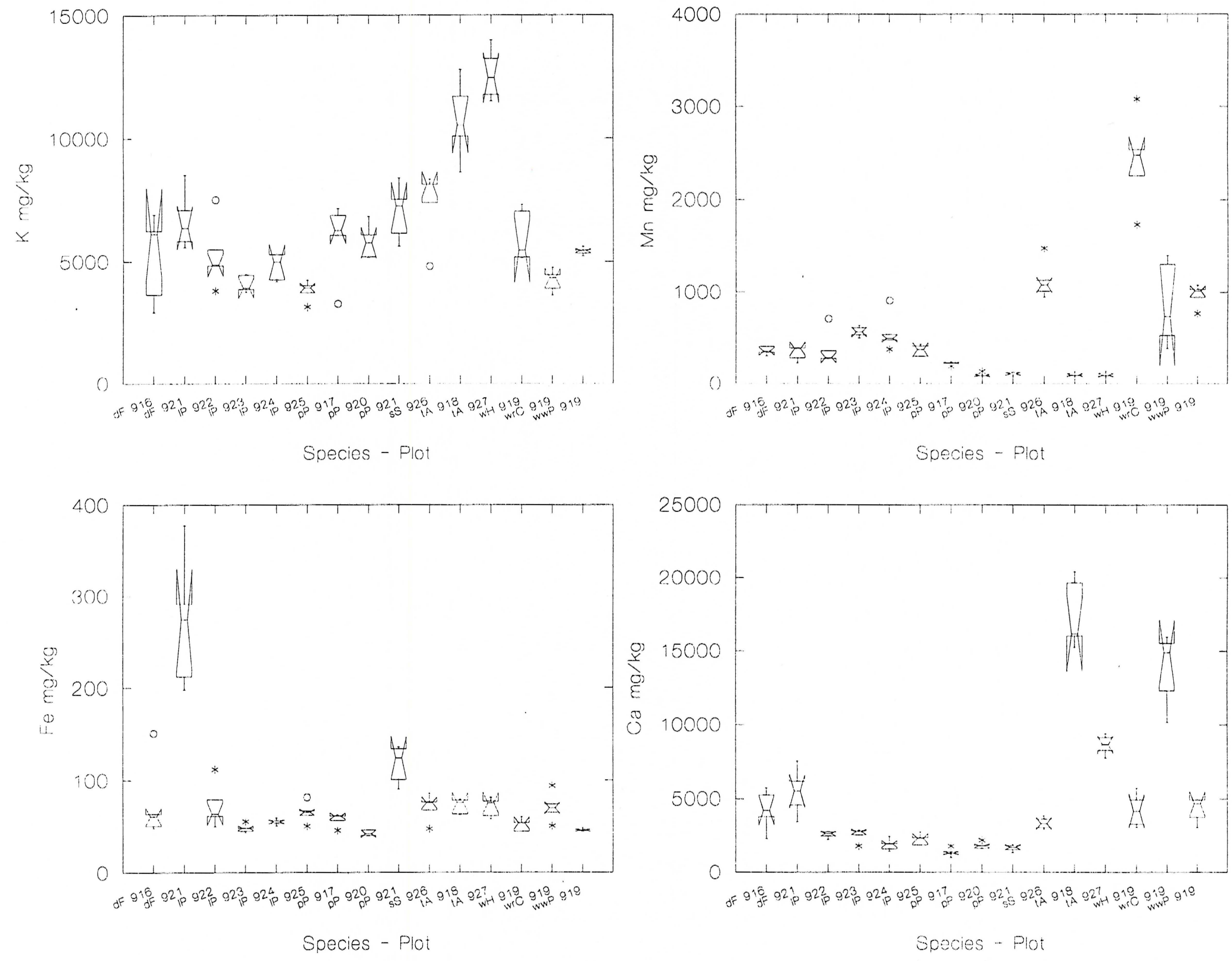

Figure 2. Potassium, Manganese, Iron, and Calcium in five samples of foliage from each species - ARNEWS /Biomonitoring plots 916 - 927. dF = Douglas-fir, lP= lodgepole pine, pP = ponderosa pine, tA = trembling aspen, wh = western hemlock, wC = western redcedar, wwP = western white pine. Plots established in 1992-93, sampled in 1993

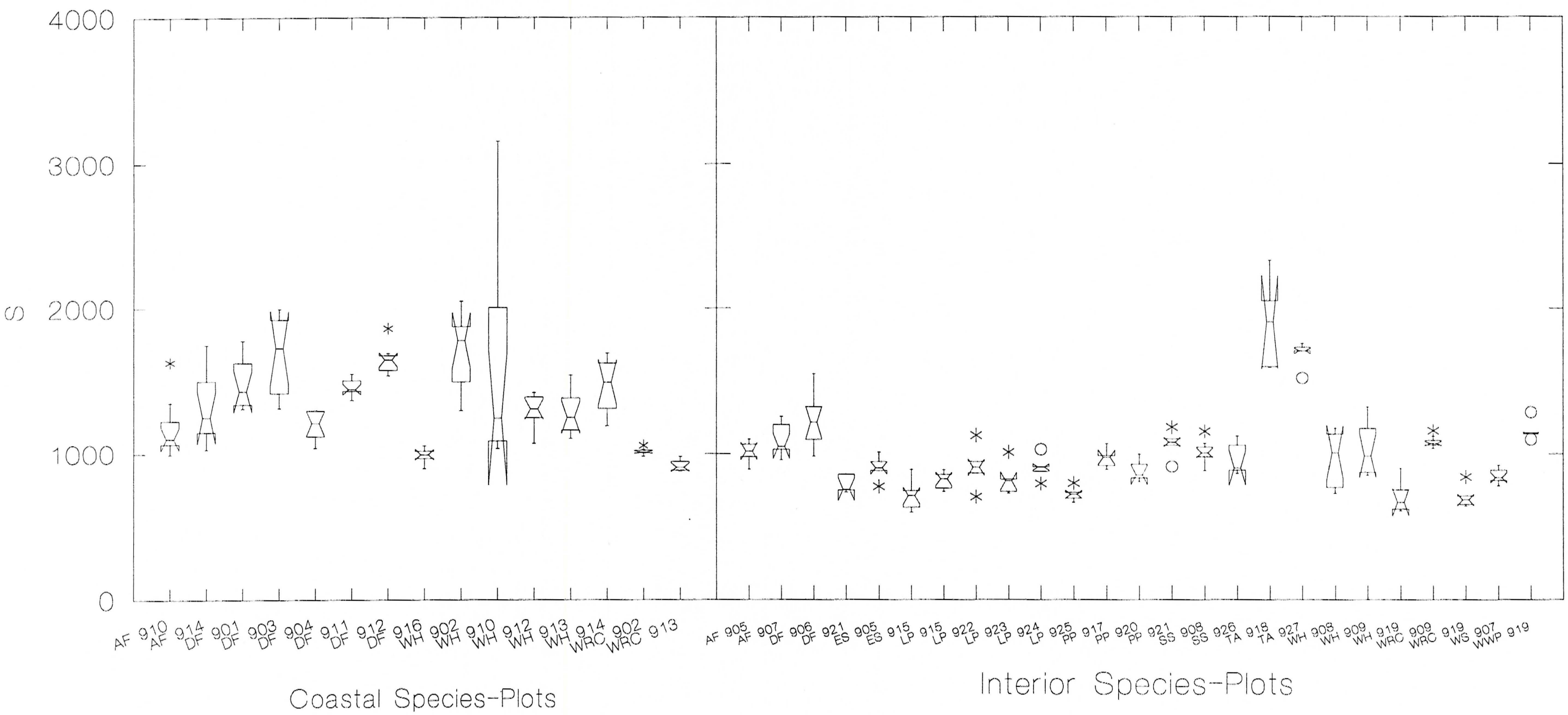

Figure 3. Sulphur in foliage from each of the Pacific and Yukon Regional ARNEWS Biomonitoring plots; note the artificial grouping of coastal versus interior plots.

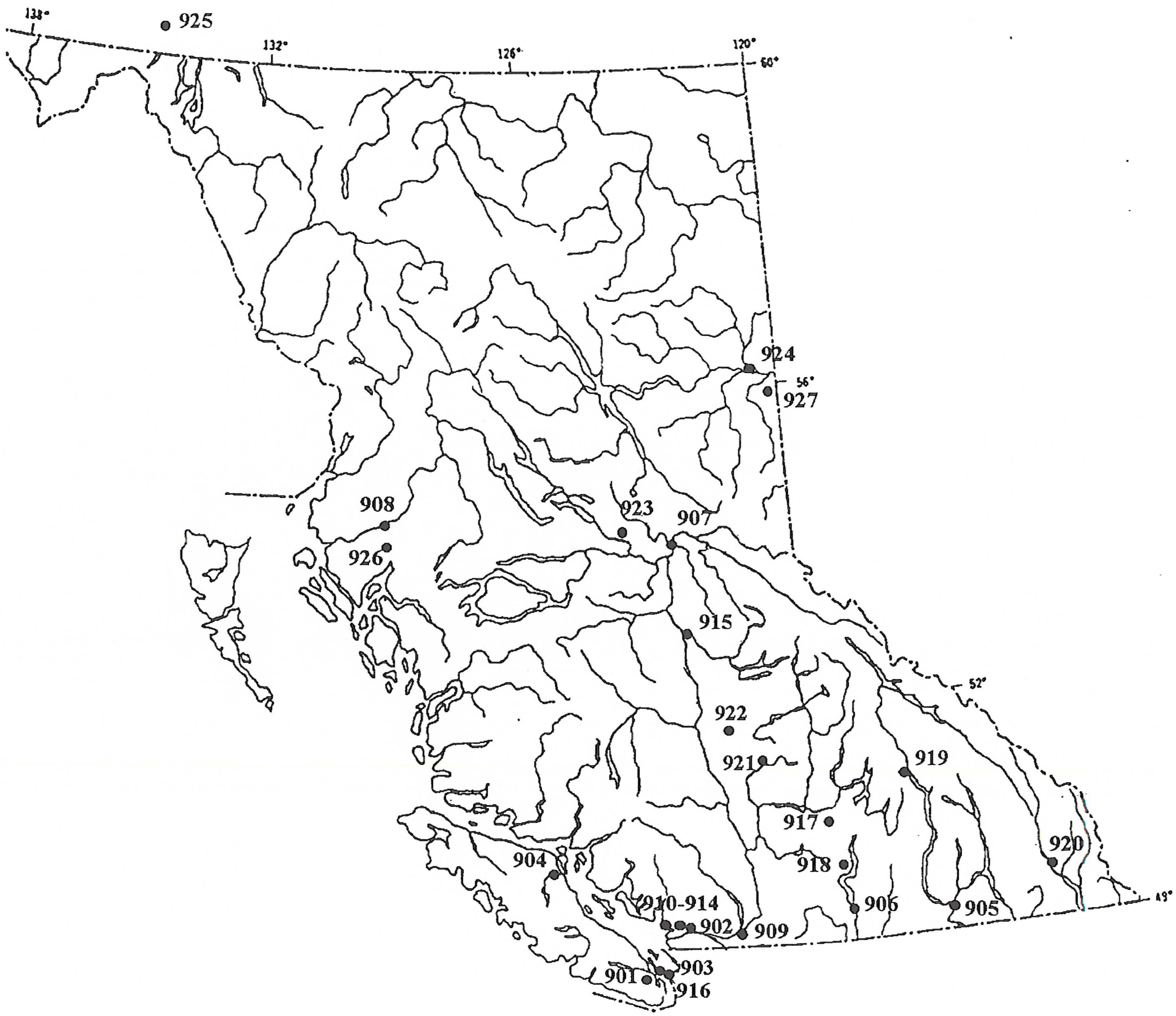

Figure 4. Location of the Pacific and Yukon Regional ARNEWS /Biomonitoring plots.

4.1 Discussion of foliage sampling results

Figures 1 - 3 are displayed in a boxplot format. Along with the display of data distributions for a given set of samples, boxplots indicate a statistically significant difference between medians in each set of samples (Tukey 1977, Velleman and Hoaglin 1981). 95% Confidence intervals are placed on the median of in a boxplot (McGill et al. 1978), such that if the notched interval between two different boxplot medians does not overlap, you can be confident around the 95% level that the two populations medians are significantly different. Of particular interest to biomonitoring objectives, boxplots are useful for indicating the data distribution within a sample interval, eg. sulphur values for a group of samples of Douglas-fir from a given ARNEWS / Biomonitoring plot. If there is a high variance in sulphur, for example, it will show up as a long, narrow bee-waist for all of the samples in a box. Outliers (very high or low samples) appear as stars and circles outside the interquartile range of the median group of data. If a box is folded over on itself, as it often is, this signifies that the larger proportion of the dataset values reside in the folded (ie. crushed) portion of the box.

Figure 1 shows foliar S contents from species of trees sampled in ARNEWS plots 916 - 927. There are patterns in foliar content of minerals that appear evident for species and for locations. In order to illustrate these trends, boxplots for a given tree species are arranged together. Most notable is the consistently high values and wide H spread (high variance) for trembling aspen in the Bear Creek (west side of Okanagan Lake) and Fort St. John ARNEWS / Biomonitoring plots. The relatively high values for Sulphur in trembling aspen is notable for other elements in trembling aspen foliage, as well. It is surprising then that S and other elements should be enhanced in the Bear Creek plot, because there is no obvious source of S in the valley. However, plot 906 at Penticton also has relatively high S values for Douglas-fir leading one to suspect either deposition, natural enhancement or intrinsic accumulation by trembling aspen has occurred. It is not known if the genus *Populus* has a wide variance in past sampling studies, but trembling aspen sampled at in the Goldenbear Lake area of northwestern B.C. was noted to have a greater variance than conifers or lichens from the same study area, but not more than surficial organic material (Davis and Enns 1991, Enns 1990a, 1990b). By using *Peltigera canina* or *aphthosa,* as an additional baseline at Bear Creek, more robust statistical comparisons could be made. These are two equally national species with a much higher central tendency, this sampling is planned for 1994- 95.

Figures 1 and 2 indicate Phosporous, Pottasium, Magnesium and Calcium have are high in trembling aspen at the Bear Creek plot as well. Although the Bear Creek site has the highest values for some minerals, trembling aspen in Plot 927 near Dawson Creek also has relatively high mineral contents in comparison to other species/plots. Because no other species was sampled in plot 918 it is difficult to tell if enhancement of mineral contents is due to intrinsic accumulation by trembling aspen or to enhancement. Figures 1 and 2 indicate a trend in higher foliar contents of most elements for samples taken from Ponderosa pine and western white pine, as well.

Figures 1 and 2 illustrate P, Mg, Al, K, Mn, Fe and Ca foliar contents for all sampled species. These data are an indication of background influences on tree nutrition and may be useful in the event of any changes in the baseline due to LRT or other influences.

Just as Sulphur contents are similar within species, there is a tendency for foliage to show consistent foliar nutrient characteristics with respect to species. Phosphorous shows the same spiking pattern in Sitka Spruce in plot 926 as in plot 908 (Enns 1991). Magnesium is fairly uniform in all the plots with the exception of the Bear Creek trembling aspen samples. Aluminum is relatively high in the Willow

River, east of Prince George and in the Revelstoke ARNEWS/ Biomonitoring plots. Calcium and Manganese are also high in the Revelstoke plots. Iron is high in the Chasm plot, near Clinton, B.C. Red pyrite (ie. iron enriched rock) was noted in the rock cliffs near this plot during the cryptogamic reconnaissance.

The interior and Saturna Island plot data are displayed in Figures 1 and 2. To obtain an understanding of Regional dry and wet sulphur deposition, the entire set of foliar ash analysis for Sulphur from the ARNEWS dataset is shown in Figure 3. These data indicate a higher variance in S and higher H-spread for values in the coastal plots. There is a tendency for coastal samples to have higher sulphur values than interior samples, even within species. The sampling in the coastal plots occurred three to five years earlier than the interior plots, however. Some of the coastal plots may now have different S values to reflect changes in air quality on the coast. Also, interpretations of Figure 3 should be tempered by the inherent differences between tree species as observed in Figures 1 and 2.

As mentioned above, Figure 3 indicates that some ARNEWS plots have relatively high S values and a wide H-spread of the sulphur data within a given sample set for an ARNEWS plot. Outliers in the distribution of sulphur values appear to be more common in the coastal plots than in the interior. The Capilano, Shawnigan, Salt Spring Island, U.B.C. Research Forest and the two Coquitlam plots have obvious outlying datapoints in Sulphur distribution. These data indicate that further attention be paid to the pathological condition of trees and of cryptogams in these plots. For example, Amabilis fir in the Capilano and Coquitlam North plot has shown some mortality that may only be partially explained by *Armillaria* and barkbeetle infestation. This shade tolerant conifer is reported to be sensitive to SO_x and metals accumulation (Mattson et al. 1990). Also, predisposition to disease is a symptom of air pollution stress (Malhotra and Hocking 1976). Although air pollution stress may not be causing the die back and pathogen attack in these plots, because of the symptomologies and the relatively high sulphur levels in foliage, some extra work in the coastal plots is warranted. Paired sampling of lichen with foliage with a larger sample size than five per plot should be used to cut down on within variance. More details of the recommended sampling regime are discussed below.

Figure 3 also indicated that there are also some relatively high S plots in the interior of the Region as well; notably Castlegar, Prince George, Dawson Creek as well as Kelowna and Penticton. Where Castlegar, Prince George and Dawson Creek plots may have high sulphur due to substantial LRT sources, Kelowna and Penticton are not at high risk for LRT.

In order to determine if there are any ARNEWS plots that stand out with significantly higher S concentrations in foliage than the mean S foliage value for the dataset, analysis of variance and Tukeys HSD tests were used. These tests are presented in Appendix 2. The analysis of variance results are summarized as follows;

- There are significant differences between all plot-species combinations for all elements.

- Tukey's HSD Multiple comparison tests indicate that the Bear Creek, Whitehorse, Dawson Creek and Saturna Island plots have a significant probability of having higher concentrations of sulphur than the other recently sampled plots.

4.2 Discussion of lichen and moss sampling results

No lichen ash analysis results are available at this time, with the exception of one case study, presented below. Ash sampling and analysis is planned for the next phase of this study. Rather, plant species lists (including vascular plants) and field examination of air quality bioindication via lichen and moss species presence/absence, pathological condition and ecological influences on species/pathology has been completed for most of the Pacific and Yukon ARNEWS / Biomonitoring plots. These data are summarized in Appendix 3. In general, cryptogamic (lichen and moss) biomonitoring status in the Pacific and Yukon plots can be summarized in the following list of points;

- Coastal ARNEWS / Biomonitoring plots (Coquitlam, Capilano and Seymour) have a relatively low lichen and moss biomonitoring capability due to two factors;

  - intrinsic low lichen diversity in the very wet, low elevation coastal forest

  - low understory diversity and biomass due to high litter accumulation and low light intensity

  The depauperate understory characteristics of these plots presents a problem in that any tree decline or loss of canopy cover, whether attributable to LRT or other causes, is likely to result in an increase in understory plant diversity and biomass. At present, canopy openings in some of the coastal plots have higher cover of understory plants than areas of the plots where there is closed canopies and a thick accumulation of leaf litter. This response to ecological conditions rather than to air quality conditions may seriously confound the purpose of understory biomonitoring in the ARNEWS / Biomonitoring plots. Some canopies, such as in Capilano appear to have experienced a decline in leaf litter accumulation, with only relatively small amounts of leaf litter arriving on the forest floor in comparison to past inputs of litter. No analysis of vegetation subplots (Government of Canada *unpublished data* 1994) has been done, but informal observation of some of the subplots in the field indicates that leaf litter accumulation has the greatest influence on biodiversity and may be of greater importance than air quality.

- Lichen substrate in the coastal plots (Capilano, Seymour and Coquitlam) and in the upper Fraser Valley plots (Chilliwack and U.B.C. Research plot) is most abundant on snags, and snags occur sporadically throughout these stands. Fragments of *Platismatia glauca, Hypogymnia physodes* and *Hypogymnia bitteri* from snags and declining upper crown branches have been observed in all except the Chilliwack plot (which has not been sampled yet for cryptogams). These lichens may show some evidence of damage from SO_2 and/or wet sulphate/ acid precipitation. Lichens show a distinct patterns of visible injury in response to air quality (Herzig *et al.* 1990, Manning and Feder 1980, Clarke (ed.) 1986, Stolte *et al.* 1993). Reddening and chlorosis of *Platismatia glauca* tissue was most evident in the Capilano ARNEWS plot. Thalli of this species from the Coquitlam upper watershed had similar reddening. It is difficult to ascertain if these symptoms are completely due to a decline in air quality over the life of the plants (estimated at 10 years). Mineral ash analysis from these plots will help to complete the picture in these plots. Due to the insufficiencies of material (low lichen diversity and a low abundance of material for re-sampling), no clear evidence of air quality changes may be available for some of the coastal plots.

- It is not known if the absence of some typical species (eg. *Bryoria* spp. and *Alectoria sarmentosa*) from the U.B.C. Research Forest, Capilano, Seymour and Coquitlam plots is due to air quality or not. The plots are located within the known geographic range and ecological tolerance of these species (Brodo and Hawksworth 1977).

- Toxitolerant species such as *Parmelia sulcata* and *Cladonia furcata* were relatively common at the U.B.C. Research plot, and relatively uncommon except in sheltered, well-drained and dry areas in Capilano and upper Seymour. These species were not present in the lower Seymour or lower Coquitlam plots. A much longer species list of lichens, mosses and liverworts was compiled for the Saturna Island plot, including a range of tolerant to relatively sensitive species.

- The Vancouver Island, Gulf Island, eastern Fraser Valley and most of the interior plots (916 - 927) have indicator species present in adjacent forested stands or openings that will support a long term and appropriately responsive lichen and moss biomonitoring system. Intrinsic diversity of lichen and moss species is high enough that any changes will be noticeable. The presence of these plants indicate relatively low levels of wet sulphates, metals or other air contaminants over the long-term. Short-term changes may be more evident in sulphur and metals contents from mineral ash analysis, however, and changes in air quality will always have to be comparative over time, plot-wise.

4.3 Past and present trends in ash analysis results

A review of both the foliage and lichen data from past sampling may be useful to put the air quality questions on the coast into perspective, as well as provide some indications for what the sampling needs for the interior will be.

A review of the foliar data indicates a number of points, as follows;

- Review of sulphur in foliage from all the plots indicates that the Capilano, Shawnigan, Salt Spring Island, U.B.C. Research Forest and Coquitlam plots have obvious outlying (ie. high) datapoints.

- Trembling aspen also has high S in the two interior plots (Kelowna and Dawson Creek).

- Within-species foliar data is the most useful for indicating geographic trends in S accumulation. The data indicates that Coquitlam, and the Vancouver area generally, has a higher S accumulation. When S is considered for Western Hemlock, Scheffe's test results indicate that the order of S levels in foliage (from lowest to highest) is as follows (from Enns 1991);

  Terrace < Capilano < Jones Lake, Chilliwack < Lower Seymour < Coquitlam Upper Watershed < Coquitlam Lower Watershed.

  For Douglas-fir;

  Campbell River < Seymour Upper Watershed < Seymour Lower Watershed <

Penticton

- An explanation for high sulphur in the Okanagan plots cannot be obtained without further sampling, using lichens preferably.

- Comparisons to the literature are useful to put the ARNEWS data in perspective; Western Hemlock samples in an area with obvious short range S deposition at Port Alice had an average S content of 2,300 ppm (van Barneveld et al. 1989), a maximum of 11,400 ppm and a minimum of 800 ppm. The latter samples were collected > 25 km from sources. In comparison to this Capilano had one Western Hemlock sample with > 3000 ppm, the rest range from 2200 ppm to < 1000 ppm. An indication of change in foliar sample data over time is not yet available.

A review of the lichen data indicates a number of points, as follows;

- There is a tendency for coastal samples of lichen species to have higher Sulphur contents than interior samples, on average. However, there are selected interior plots that have relatively high Sulphur contents in lichen tissue.

  - A Saanichton transplant donor site used in the Shawnigan Arnews plot in 1990 and the two Coquitlam plots had Sulphur values ranging from 1400 to 2350 ppm in comparison to a number of samples from Revelstoke, Willow River, One Island Lake Road, Felker Lake and Onion Lake Road which ranged from 500 to 1100 ppm. Industrial values are reported to range from 980 - 3000 ppm (compiled in Rhoades 1988).

- In 1988, the Salt Spring plot had Peltigera samples with Sulphur contents ranging from 505 to 1154 ppm (n = 3).

- An increase in Sulphur occurred in lichens in the U.B.C. Research Forest ARNEWS/ Biomonitoring plot over time between 1988 and 1990, while the Shawnigan Lake S contents were maintained over time.

- The majority of the interior values for Sulphur in lichen are more in keeping with expected background, un-enhanced lichen mineral contents while some of the coastal values are more in keeping with some enhancement and deposition of Sulphur (Rhoades 1988).

4.4 Case study; Bulldog Creek versus the lower Arrow Lakes - Castlegar Valley samples

In addition to the above data, a comparative study was made between the mineral ash analysis data from an ARNEWS plot in the interior at Castlegar (Bulldog Creek, Plot 905) and a grabsample network to show both SRT and LRT from Cominco and Celgar Pulp Company (Enns 1994). The Bulldog Creek plot is approximately 30 km from Trail and 25 km from Celgar. In this comparison, lichen tissue from the Bulldog Creek site and the larger dataset from the lower valley system was compared. Five samples of *Peltigera rufescens* from Bulldog Creek were compared to 10 plots each with ten samples of *Peltigera canina*. Although some of the differences in S content could be attributed to intra-specific variation in S absorption, the variation in S absorption of *Peltigera* as a group is fairly low in comparison to different species of conifers, for example. Bulldog samples had a median S content of 1100 ppm with a range between 950 and 1400 ppm S. Sulphur for the valley ranged from 1200 to 3500 ppm at distances of greater than 56 km northwest of Trail with the highest value occurring 25 km from Trail and 10 km from Celgar at Robson Station northeast of Castlegar. Samples of *Peltigera canina* taken from a biomonitoring plot approximately ten kilometres northeast of Nelson had values between 1600 and 2400 ppm.

These data indicate that wind patterns in the valley may cause dispersion of SO_2 and wet sulphates within the Trail - Castlegar and Arrow Lake valleys at low elevation. The majority of LRT may not disperse over the mountains to the Bulldog Creek plot. This example indicates that damage to forested stands from LRT may occur at long distances from source (eg. as far as 56 km) but at a low elevation. It is feasible that impacts may occur in lower elevation stands before they would occur at the Bulldog Creek plot, and perhaps after any remedial action could be taken. No forest pathology symptoms have yet been correlated with LRT of SO_2 from either of these sources however, although there has been considerable short range transport (SRT) damage assessment (Abbey pers.comm. 1994). Further, all industrial sources in this area are reporting reduced SO_2 emissions and they are expecting a recovery of vegetation from both LRT and SRT. This does not imply that vigilance is not necessary in this area where industrial sources of SO_2 are some of the highest in the province (B.H. Levelton and Associates, 1992). The efficacy of the ARNEWS / Biomonitoring plots may be enhanced by some informal and cost-effective background sampling at variable distances from selected plots. Although supplemental sampling is not strictly required in the Canadian ARNEWS / Biomonitoring system, owing to the complexity of terrain in B.C., this extra sampling is warranted. Industrial development is expected to continue in coastal and northeastern environments.

4.5 Trends in recent air quality monitoring

In the Pacific and Yukon Region, biomonitoring has increased over the past decade with several groups using this economical and accurate technique to show ambient sulphur and metals. There are currently several biomonitoring projects operating in the Pacific Northwest. Some of these include;

- Alcan; western hemlock foliar chemistry to indicate fluoride and sulphur distribution, using perchloric acid leachate and X-ray florescence analysis
- Westcoast Energy with Concord Environmental and the University of Calgary: lichen, soils and conifer $^{\sigma 32}S:^{\sigma 34}S$ isotope ratios
- Greater Vancouver Regional District with Acres International Limited, Pherotech and others: soils, forest ecology and pest sampling program displayed in a GIS environment
- Waste Management Branch (M.of E.L.,P.) (in-house); SO_2 symptoms in vegetation
- B.C. Ministry of Highways with Soilcon and Larkspur; province-wide sodium chloride monitoring project using foliage and soils ash analysis as well as plant pathology measurement. Recently narrowed in scope to Loon Lake, near Cache Creek.
- B.C. Ministry of Environment, Lands and Parks with Soilcon; Background sulphur and metals in B.C. soils
- Celgar Pulp Company with Larkspur; lichen ash analysis, SO_2 symptoms in vegetation
- Cominco with Larkspur; reconnaissance for lichen biomonitoring feasibility
- Environmental Protection Agency; lichen floristics mapping program in GIS

There are also several projects in progress that have not been active recently, such as the Goldenbear Mine's mercury and arsenic biomonitoring project using lichen, conifer and surficial LFH metals analysis near Meziadin, B.C., as well as a metals biomonitoring project near the Afton Mine at Kamloops, B.C.. The future of biomonitoring in the Pacific and Yukon Region may be effected by recent policy initiatives to build biomonitoring or some component of biomonitoring into resource use regulation. This is likely to have an effect on the type and quality of supplemental data available to the ARNEWS/Biomonitoring system. The environmental assessment and permit process for oil and gas exploration is currently being drafted in the Province. This has particular relevance to the northeastern portion of the Pacific and Yukon Region as well as the Northwest Region because of the expected increase in emissions from sour gas processing. Biomonitoring in some format will likely be included in policy. Communication with provincial and industrial users of biomonitoring systems should be planned for, enhanced and maintained so that the ARNEWS system can benefit from these initiatives.

5.0 FUTURE NEEDS FOR BIOMONITORING IN THE PACIFIC AND YUKON REGION

The ARNEWS system uses biological data to indicate LRT in areas where mechanical monitoring is either impractical or unlikely to be sufficient, for various reasons. The Pacific and Yukon Region has arguably the nations most complex combination of climatic and geomorphological gradients (Holland 1984). Such varied environmental influences on airborne pollutants, especially with respect to compounds of dry and aqueous sulphur, has long been known to create enormous uncertainty with respect to the predictive capability of environmental models or on anticipated long range transport (LRT) effects (Baldwin 1985). Therefore, biological monitoring is a critical addition to physical and chemical data for both short and long range transport concerns. The panboreal distribution of many species of lichens and mosses adds a relevance to this system in that the sample size and comparability between regions becomes all the more robust when plots from Newfoundland can be compared to plots in central B.C.

Lichen and moss biomonitoring should not be considered as a stand-alone biomonitoring system. An integrated approach to biomonitoring where cryptogams, vegetation condition, soils, foliage ash analysis, forest pathology, environmental and growth and yield data is being increasingly used to build an understanding of how air pollution is influencing forest health and how those forests may respond in the future (Sloof and Wolterbeek 1991, Herzig et al. 1990).

5.1 Biomonitoring guidelines and their relevance to the ARNEWS system

Jackson (et.al. 1993) have developed some recent guidelines for how to maintain a viable biomonitoring program. They suggest the following steps;

1. Define the sample population in time and space

2. Understand the ecological and environmental setting of the sample population.

3. Define the samples to be collected and the field measurements to be made.

4. Develop a program for sample collection, chemical analysis, data analysis and define the objectives (ie. qualitative and qualitative statements regarding levels of variability or uncertainty in collection and analysis of samples).

5. Review literature and/or perform preliminary sampling to determine quantifiable element

concentrations and estimate potential scales of variability or spacial trends. Preliminary sampling should be done using the same collection and analysis techniques as the primary monitoring program to produce valid conclusions.

6. Develop a statistically based field sampling plan and define statistical tests to be performed on chemical analysis results. Re-evaluate data quality objectives based on preliminary sampling results and sampling and statistical analysis schemes.

7. Execute the study according to written protocols.

8. Evaluate the chemical analysis results and determine relevant temporal and spatial trends.

9. Determine if the study objectives have been met.

Jackson (et.al. 1993)'s suggestions raises some questions for the ARNEWS/ Biomonitoring plan. Items 1 and 2 (from above) are of interest and are discussed below a format where three main questions are posed followed by some discussion with respect to the ARNEWS system. The 2nd and 3rd questions are repeated above the discussion, respectively;

Question 1. The spatial distribution of the ARNEWS plots may indicate LRT but have the locations of the ARNEWS plots been tested; do all the ARNEWS plots cover potential LRT effects or are some possible effects being missed?

Question 2. The ARNEWS system is intended to determine if depositional S and other pollutants are influencing ecosystem health, primarily as indicated by coniferous tree species health, as well as changes in vascular and non-vascular plant species health and diversity over time. In what ways can we be certain that the system is effectively achieving this? Are we prepared in advance for distinguishing between "ordinary" disease, "background" metals or S enhancement and disease/enhancement that is exacerbated by LRT?

Question 3. Understanding the environmental setting includes a fundamental knowledge of the LRT sources and what the deposition patterns are in the sample population. What is the complete distribution of aqueous and dry depositional S and other pollutants in relation to LRT sources and excluding naturally enhanced sources?

In answer to the concerns identified in Question 1 above, the Bulldog Creek example (Section 4.4) is a test of ARNEWS efficacy in an extreme case. Presumably, if LRT was serious enough to effect forest resources, most of the ARNEWS plots would show signs of decline. Some additional early-warning satellite sampling is suggested for further testing the system. The rationale for this is;

- for ARNEWS plots in a receiving position, a system of satellite sampling from close to source to beyond the ARNEWS plots would define deposition patterns and zones of severity of impact at much greater resolution then at present.

- Satellite sampling would determine where the ARNEWS plots lie within the range of LRT effects. At present it is assumed they represent some median value of LRT for a sample population. It may be that some plots lie within a relatively high impaction zone that is irrelevant to the majority of the forest resource, or that they may be located in a zone that does not reflect where impaction is actually occurring.

- Satellite sampling may allow for some ARNEWS plots to be used only as long-term references, and indicate where new sampling is most likely to be needed in the future, as the character of LRT is expected to change with the changing location of industry and change in climate.

Satellite sample planning may be complemented by an increase in interest in biomonitoring (described above). Specifically, joint ventures between industry, provincial and federal users of biomonitoring systems should be pursued, for obvious economic and scientific reasons. It makes sense to use large sample sizes, to coordinate sampling effort and to standardize the analysis of results.

Satellite sampling does not have to be encumbered by rigorous plot establishment protocols or plot maintenance. Simple mapping using repeated grab-sampling and analysis in a grid pattern may be sufficient.

Question 2 (repeated). The ARNEWS system is intended to show influences on ecosystem health. In what ways can we be certain that the system is effectively achieving this?

The ARNEWS/ Biomonitoring system has a multidisciplinary approach, but it has not completed the the analysis of all the data that has been collected. Sulphur and metal contents of foliage, lichens and mosses has been useful in providing early warnings of impingement in comparison to the literature (Rhoades 1988, Crete et al. 1992) but the relationship between lichen and foliar sulphur and forest health is not completely examined. Lichens, mosses and foliage sampling adds to efficacy by decreasing *beta* error in sampling. *Beta* error in this instance is the failure to detect a difference in LRT even though a significantly higher deposition pattern has occurred. The ARNEWS / Biomonitoring system measures differences in S over time plotwise, and compares this with differences in disease over time plotwise. The best way to avoid an incorrect rejection of a null hypothesis of no effect is to use frequent sampling of lichen tissue and intermittent sampling of forest health. The ARNEWS system is achieving this in the Pacific and Yukon Region.

Using bioindication to predict impending changes in forest health is made complex by multiple influences. The largest sources of uncertainly include ecological, physiological and meteorological variation, to the extent that we may only have a rational explanation for change in forest health after a decline has occurred. Lichen tissue ash analysis can provide an early warning of accumulation but the levels of toxicants in tissues have to be fully explained through adequate sampling, they must be gauged against background levels and compared with ambient air and forest health data in a timely fashion. Knowing precisely when high tissue levels will precipitate a decline is a major problem.

There are numerous studies that link forest decline with pollutants, but few that define the threshold of pollution levels prior to the need for abatement (Korsch and Jager 1993, Lenz and Schall 1991). Maynard et al (in press 1994) has shown a definite linkage between high S (some S sources may have been SO_2) and lower conifer productivity. They found a measurable impact on the understory in areas effected by > 5000 mg kg^{-1} of elemental sulphur together with a greater probability of dead lodgepole pine trees, and significant declines in volume growth of mature lodgepole pine. Of note is the parallel relationship between low S in foliage and percentage of healthy trees. Further, there are other robust similarities such as high correlations between Cadmium and Lead in lichen tissue samples from a number of sites (Morosini et al. 1993). A high correlation is found between the levels of metals and Sulphur in foliage and the levels in lichen taken from paired field samples (Aamlid and Venn 1993).

There are at least three steps in perfecting the link between bioindication using lichens and foliage and accurate prediction of a reversible trend toward decline in forest health.

- The first step in the refinement of the ARNEWS/Biomonitoring system is to make sure the sampling is efficient.

- The second step is to accurately track changes in forest health and to recognize LRT-influenced forest pathology.

- The third and possibly concurrent step is to try to better understand localized meteorological behaviour of LRT in the Region.

These are some suggestions for achieving the first step;

- The plotwize sample sizes for lichen material should be large enough to indicate homogeneous variance. Sample sizes can be determined by plotting residuals from the ANOV's can assist in determining if additional sampling is needed;

- plants that indicate discreet changes in S or other LRT pollutants between sampling intervals should be used. These include species with a relatively rapid growth rate (eg. members of Peltigeraceae, Pinaceae).

- plant species with a high central tendency should be used (eg. low variance in values for a given set of samples from a given location). Some examples are the genus *Peltigera*, lodgepole pine, western red-cedar and red alder.

- the conifer sampling with the lichen sampling should be paired (done at the same time), so that they reflect the same ambient conditions. The relationship between the two groups (lichens versus foliage) can be used to judge if there is any change in the relationship between foliar S (and/or halides, metals, etc.) and lichen S (etc.).

The second and third steps should not be considered as beyond the interest of managers of the ARNEWS / Biomonitoring system. Lichen and foliar sampling has to be kept relative to the fields of conifer pathology and meteorology of LRT. Also, lichen and foliage sampling systems can be refined somewhat from the present system, efficiency in foliar and lichen sampling cannot take the place of standard plant pathological and ecological techniques for detecting a change in forest health, such as classical symptoms of toxicity (modified from Horsman 1976, Malhotra and Blauel 1980, Malhotra and Hocking 1976, Smith 1990), species shifts, cover changes, and other symptoms unexplained by ordinary stand dynamics.

Question 3(repeated). What is our understanding of LRT and depositional patterns?

The ARNEWS/Biomonitoring system is designed to reflect the effects of LRT from point sources but it can't do so efficiently without evaluating the behaviour and characteristics of LRT. Large-area (ie. small-scale) meteorological models have not always been particularly helpful, in this regard, due to complexity of terrain and subsequent complexity in weather patterns (Sakiyama pers.comm. 1994). With respect to sources of LRT, the contributors to airborne pollutants are only partly documented in various forms, including a draft report by B.H. Levelton and Associates (1992) for the B.C. Ministry of Environment, Concord Environmental Corporation (1992) and a current list of sources effecting the Saturna CAPMoN station (Environment Canada 1994).

Surprisingly, there has not been a great deal of recent documentation on point sources in B.C. or the Yukon (Thompson pers.comm. 1994, Wakelin, pers.comm. 1994). Point source identification is currently being compiled by Wakelin (pers.comm. 1994) but these data were not available for this paper. Parfett (1994) has mapped pulp and paper industry sources for B.C., but she hasn't included smelting or sour gas processing sources which have a considerable influence on emissions. For example in the Castlegar - Trail area, two main sources of depositional S include Celgar Pulp Company which produces approximately 1 tonne of SO_2 per day and Cominco which produces approximately 50 tonnes of SO_2 per day (McLaren 1994, Abbey pers.comm. 1994).

Coastal data from past studies and more recently from the Saturna Island station have indicated that there is a prominent trend in higher SO_x, NO_x and particulate matter in the areas near the Greater Vancouver District than previously suspected (Thompson pers. comm. 1994). These data are being summarized by Environment Canada and will be made available in the next phase of the project.

Not surprisingly, and in general, high values for foliar and lichen S match the vicinity of some of the larger emitters of SO_x, NO_x CO, particulate matter, and volatile organic compounds from B.H. Levelton and Associates (1992, Appendix 4)). This pattern is also noted in Parfett (1994). The data from B.H. Levelton should be interpreted with caution as it is likely that the number of contributors has expanded significantly, especially in the northeastern part of British Columbia. Further steps and information needs include;

- Future work in GIS should include a more complete map of LRT contributors. If satellite grid sampling to test and calibrate the current ARNEWS/Biomonitoring system is possible, then forest health mapping could be overlayed to test for significant correlations and covariance between coincident outbreak or symptom polygons and S isolines.

- The spatial arrangement of ARNEWS/Biomonitoring plots should be mapped in relation to ALL sources, classed by emission type and quantity.

- Parfett (1994) has examined a small number of spatial relationships between data types. Statistical relationships in mapped data should be tested for as well; for example, a test for significant correlations between mapped lichen S contents and mapped incidence of disease could be attempted. Aside from a paucity of data in a grid pattern, one anticipated difficulty would be in generating compatible surfaces, however. If paired samples are available and mapping is not possible because of poor geographic distribution of sample points, then simple correlation coefficients for relationships between S and disease could be calculated.

It is possible to draw some conclusions about the influence of LRT on forest health based on data from the ARNEWS/Biomonitoring system in the Pacific and Yukon Region. Parfett's (1994) data summaries indicate that emission-related effects are occurring in southwestern B.C. Her summaries, are based on old data in some cases (13 year old SO_x data from CANSAP, for example), but recent data is not likely to show any decreasing trend (Thompson pers.comm. 1994), as there has been no abatement in this portion of the Region.

Finally, In some ecosystems, biomonitoring is being used very effectively to show recovery from previous damage by air pollution (Seaward and Letrouit-Galinou 1991, Gilbert 1992, Van Dobben and De Bakker 1990, Keinonen 1992, Boreham 1993). Can we adequately detect "red-line" bioindication results and subsequent early symptoms of forest decline in coastal or northeastern areas of the Pacific and Yukon? Where is the critical point where action will have to be taken to effect abatement of LRT? At present, forest managers in the Pacific Northwest do not have a complete model that links bioindication with forest decline. Examples in the literature that trace the changes in bioindication, ambient air quality and forest health should be examined so that a realistic model for the Pacific and Yukon Region can be constructed and calibrated with ARNEWS/biomonitoring data. Examples to build on include Maynard (*et al. in press* 1994), Beg et al. (1990). Rhoades's (1988) compendium of ash analysis data for lichens from pristine, background enhanced, impacted and heavy industrial areas should be expanded upon. As mentioned previously, a similar table for P&Y conifers is being compiled (Addendum #1).

Eventually, biomonitoring has usefulness in tracing quantities of sulphur to sources and distinguishing between proportions of source contribution in studies where ratios of the two more common sulphur isotopes in lichen (^{34}S: ^{32}S) are compared to emissions and to background lichen, surficial materials etc., (Takala et al. 1991, Case and Krouse 1980, Krouse and Case 1981, Case 1978). Where lichens have either been removed from the environment by long term sulphur and metal deposition, or naturally do not occur, transplants have been successfully used in the P&Y and are increasingly used throughout the world (Bartok et al. 1992). They may be effectively used again in some of the southwestern ARNEWS/Biomonitoring plots.

5.2 What direction should the P&Y ARNEWS/Biomonitoring system take?

With respect to the lichen and foliar part of the ARNEWS program, the next phase should therefore achieve the following goals.

- Although there are many influences on SO_2 uptake, due to ecological gradients it is recommended that *time-wize* paired ash analysis of single species or groups of species, soils and foliage be used to indicate emission-related LRT effects, and that community analysis be used secondarily as part of the environmental health sector of the monitoring program.

- Photometrics were used in an early paper (Palmer 1989) and should be re-evaluated (ie. test and refine methods) in a select number of coastal plots. For example, digitized photographs of *Peltigera canina* from Salt Spring Island should be compared to determine if any measurable change in health has occurred. Symptoms such as chlorosis, necrosis, die-back and loss of apothecia are likely to occur in S-damaged plants.

- An analysis of the vascular plant vegetation subplots where there are > two sets of measures is needed, as well as an evaluation of how frequently we need to sample these plots.

- An economical grab sampling program should be designed and implemented in riparian red alder in areas upslope from the coastal plots, as a supplement to the current ARNEWS plots.

- Soils sampling has not been examined in this paper but relative to cryptogamic bioindication, paired sampling in the lichen - LFH layer with 5 - 10 grab samples per plot is advised.

Since the program may be maintained by different investigators over the years, it is necessary that great care go into program maintenance. Changes in personnel performing the field work may not be avoidable and the program must be spelled out so that any competent biomonitoring specialist can resume operation of the program. This includes;

- In order to relate the foliar and cryptogamic data with the rest of the ARNEWS dataset, records such as photographs, raw data, FIDS data and plot location mapping require better cataloguing than they have at present.

- The same sites have to be sampled repeatedly. It is possible to sample different trees in openings outside plots as long the sample trees are from the same species, same age class, height, condition, etc. over time.

- Identical field and laboratory procedures must be maintained through time. It is not clear what earlier sample preparation procedures were followed. This should be avoided in future.

- Sample collection and analysis must be simple, well documented and reliable.

- Sampling should be done at the same time of the year and under similar weather conditions each time it is repeated. For conifers, Davis (pers.comm. 1993) recommends mid-winter when plants are dormant and are not likely to be accumulating elements in excess of ambient emissions.

6.0 SUMMARY POINTS

The following trends appear evident;

- Lichen sulphur contents range from below that of industrial sulphur deposition to above industrial levels, provincially.

- The foliar data indicate that long range transport of sulphur may have occurred in some coastal and a minor number of interior locations, but the extent of S transport and the implications are not known.

- Additional sampling is required in coastal and selected interior plots.

- Trembling aspen in the Okanagan and Yukon plots show abnormal levels of sulphur that is anomalous.

- Some ARNEWS plots may require supplemental sampling with additional, off-site grab-sampling.

- There are distinct between-species differences in foliar contents of S

Specific Recommendations for the 1995 ARNEWS sampling are as follows;

- Correlate ARNEWS data with ambient air data and develop an LRT model. Identify and map sources of LRT in as much detail as possible, including *all* sources

- Photometric surveys should be conducted in selected coastal, interior and cost-island ARNEWS / Biomonitoring plots

The ARNEWS / Biomonitoring program has been the first to identify a significant front range coastal S deposition pattern in the Pacific and Yukon Region. It is the purpose of the program to provide an early warning and to follow up with appropriate investigation.

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APPENDICES

Appendix 1. ARNEWS Plot numbers and locations

Plot #	Location	Region
901	Shawnigan Lake	Vancouver Island
902	Haney; U.B.C. Research Forest	Vancouver
903	Salt Spring Island	Vancouver Island
904	John Hart Lake, Campbell River	Vancouver Island
905	Bulldog Creek, Rossland - Castlegar	Nelson
906	Penticton	Kamloops
907	Prince George	Prince George
908	Terrace	Prince Rupert
909	Jones Lake, Chilliwack	Vancouver
910	Capilano, Vancouver	Vancouver
911	Seymour Upper Watershed	Vancouver
912	Seymour Lower Watershed,	Vancouver
913	Coquitlam Upper Watershed	Vancouver
914	Coquitlam Lower Watershed	Vancouver
915	Cottonwood, Quesnel	Cariboo
916	Saturna Island	Vancouver
917	Monte Creek, Kamloops	Kamloops
918	Bear Creek, Kelowna	Kamloops
919	Revelstoke	Nelson
920	Wasa Lake, Cranbrook	Nelson
921	Bonaparte River, Clinton - 70 Mile	Kamloops
922	Felker Lake, Williams Lake	Cariboo
923	Willow River, Prince George	Prince George
924	Fort St. John	Prince George
925	Whitehorse, Yukon	Yukon
926	Onion Lake, Terrace	Prince Rupert
927	One Island Lake Road, Dawson Creek	Prince George

Appendix 2.

The following one factor analyses of variance were run on foliar data from the newest Pacific and Yukon Region ANREWS/Biomonitoring plots. The variable being tested in each analysis was created from the combined ARNEWS plot and species for each sample. Tukey's HSD pairwise comparisons tests were used to determine where the differences, if any, lie. Probability values (where > .05 is signficant) are reported and then significant differences between categories are recorded in the matrices below. Refer to the list of value numbers for the plot species combination to determine for example if Saturna Island Douglas-fir is significantly higher in sulphur than any other plot-species combination. (It is higher than all plots except those near Prince George and Revelstoke).

ANALYSIS OF P IN SELECETED ARNEWS PLOTS

DEP VAR: P N: 75 MULTIPLE R: 0.935 SQUARED MULTIPLE R: 0.873

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	.178240E+08	14	1273141.924	29.578	0.000
ERROR	2582632.483	60	43043.875		

COL/ ROW	PLOT_SP$
1	dF 916
2	dF 921
3	lP 922
4	lP 923
5	lP 924
6	lP 925
7	pP 917
8	pP 920
9	pP 921
10	sS 926
11	tA 918
12	tA 927
13	wH 919
14	wrC 919
15	wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF P
USING MODEL MSE OF 43043.875 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	-7.536	0.000							
3	-300.920	-293.384	0.000						
4	-410.368	-402.832	-109.448	0.000					
5	-344.604	-337.068	-43.684	65.764	0.000				
6	-389.210	-381.674	-88.290	21.158	-44.606	0.000			
7	-70.218	-62.682	230.702	340.150	274.386	318.992	0.000		
8	-154.108	-146.572	146.812	256.260	190.496	235.102	-83.890	0.000	
9	66.156	73.692	367.076	476.524	410.760	455.366	136.374	220.264	0.000
10	593.168	600.704	894.088	1003.536	937.772	982.378	663.386	747.276	527.012
11	1199.546	1207.082	1500.466	1609.914	1544.150	1588.756	1269.764	1353.654	1133.390
12	933.816	941.352	1234.736	1344.184	1278.420	1323.026	1004.034	1087.924	867.660
13	-255.162	-247.626	45.758	155.206	89.442	134.048	-184.944	-101.054	-321.318
14	-522.346	-514.810	-221.426	-111.978	-177.742	-133.136	-452.128	-368.238	-588.502
15	-79.038	-71.502	221.882	331.330	265.566	310.172	-8.820	75.070	-145.194

	10	11	12	13	14	15
10	0.000					
11	606.378	0.000				
12	340.648	-265.730	0.000			
13	-848.330	-1454.708	-1188.978	0.000		
14	-1115.514	-1721.892	-1456.162	-267.184	0.000	
15	-672.206	-1278.584	-1012.854	176.124	443.308	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	1.000	1.000							
3	0.599	0.639	1.000						
4	0.139	0.158	1.000	1.000					
5	0.374	0.411	1.000	1.000	1.000				
6	0.197	0.222	1.000	1.000	1.000	1.000			
7	1.000	1.000	0.905	0.396	0.735	0.503	1.000		
8	0.997	0.998	0.998	0.816	0.978	0.892	1.000	1.000	
9	1.000	1.000	0.276	0.039	0.138	0.060	0.999	0.931	1.000
10	0.003	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.013
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.821	0.850	1.000	0.997	1.000	0.999	0.983	1.000	0.491
14	0.014	0.017	0.929	1.000	0.988	0.999	0.064	0.272	0.003
15	1.000	1.000	0.928	0.439	0.776	0.550	1.000	1.000	0.998

	10	11	12	13	14	15
10	1.000					
11	0.002	1.000				
12	0.393	0.776	1.000			
13	0.000	0.000	0.000	1.000		
14	0.000	0.000	0.000	0.769	1.000	
15	0.000	0.000	0.000	0.989	0.076	1.000

ANALYSIS OF S IN SELECTED ARNEWS PLOTS

DEP VAR: S N: 75 MULTIPLE R: 0.951 SQUARED MULTIPLE R: 0.904

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	8360769.168	14	597197.798	40.296	0.000
ERROR	889214.449	60	14820.241		

COL/ ROW	PLOT_SP$
1	dF 916
2	dF 921
3	lP 922
4	lP 923
5	lP 924
6	lP 925
7	pP 917
8	pP 920
9	pP 921
10	sS 926
11	tA 918
12	tA 927
13	wH 919
14	wrC 919
15	wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF S

USING MODEL MSE OF 14820.241 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	-198.760	0.000							
3	-79.348	119.412	0.000						
4	-166.492	32.268	-87.144	0.000					
5	-82.598	116.162	-3.250	83.894	0.000				
6	-268.106	-69.346	-188.758	-101.614	-185.508	0.000			
7	-18.954	179.806	60.394	147.538	63.644	249.152	0.000		
8	-103.810	94.950	-24.462	62.682	-21.212	164.296	-84.856	0.000	
9	80.568	279.328	159.916	247.060	163.166	348.674	99.522	184.378	0.000
10	-21.342	177.418	58.006	145.150	61.256	246.764	-2.388	82.468	-101.910
11	909.724	1108.484	989.072	1076.216	992.322	1177.830	928.678	1013.534	829.156
12	700.842	899.602	780.190	867.334	783.440	968.948	719.796	804.652	620.274
13	-281.786	-83.026	-202.438	-115.294	-199.188	-13.680	-262.832	-177.976	-362.354
14	-285.680	-86.920	-206.332	-119.188	-203.082	-17.574	-266.726	-181.870	-366.248
15	175.108	373.868	254.456	341.600	257.706	443.214	194.062	278.918	94.540

	10	11	12	13	14	15
10	0.000					
11	931.066	0.000				
12	722.184	-208.882	0.000			
13	-260.444	-1191.510	-982.628	0.000		
14	-264.338	-1195.404	-986.522	-3.894	0.000	
15	196.450	-734.616	-525.734	456.894	460.788	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	0.403	1.000							
3	0.999	0.963	1.000						
4	0.689	1.000	0.998	1.000					
5	0.999	0.970	1.000	0.999	1.000				
6	0.058	1.000	0.489	0.991	0.518	1.000			
7	1.000	0.570	1.000	0.836	1.000	0.108	1.000		
8	0.989	0.995	1.000	1.000	1.000	0.708	0.999	1.000	
9	0.999	0.039	0.744	0.115	0.717	0.003	0.992	0.528	1.000
10	1.000	0.591	1.000	0.851	1.000	0.116	1.000	0.999	0.991
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.036	0.999	0.372	0.972	0.399	1.000	0.069	0.586	0.001
14	0.031	0.998	0.342	0.963	0.367	1.000	0.061	0.551	0.001
15	0.612	0.001	0.091	0.003	0.082	0.000	0.442	0.040	0.995

	10	11	12	13	14	15
10	1.000					
11	0.000	1.000				
12	0.000	0.323	1.000			
13	0.075	0.000	0.000	1.000		
14	0.066	0.000	0.000	1.000	1.000	
15	0.422	0.000	0.000	0.000	0.000	1.000

ANALYSIS OF MG IN SELECTED ARNEWS PLOTS

DEP VAR: MG N: 75 MULTIPLE R: 0.954 SQUARED MULTIPLE R: 0.910

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	.303894E+08	14	2170673.610	43.204	0.000
ERROR	3014523.736	60	50242.062		

COL/ ROW	PLOT_SP$
1	dF 916
2	dF 921
3	lP 922
4	lP 923
5	lP 924
6	lP 925
7	pP 917
8	pP 920
9	pP 921
10	sS 926
11	tA 918
12	tA 927
13	wH 919
14	wrC 919
15	wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF MG

USING MODEL MSE OF 50242.062 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	-16.282	0.000							
3	215.400	231.682	0.000						
4	-331.124	-314.842	-546.524	0.000					
5	-253.794	-237.512	-469.194	77.330	0.000				
6	-174.378	-158.096	-389.778	156.746	79.416	0.000			
7	-246.312	-230.030	-461.712	84.812	7.482	-71.934	0.000		
8	-443.768	-427.486	-659.168	-112.644	-189.974	-269.390	-197.456	0.000	
9	-94.640	-78.358	-310.040	236.484	159.154	79.738	151.672	349.128	0.000
10	-264.218	-247.936	-479.618	66.906	-10.424	-89.840	-17.906	179.550	-169.578
11	2226.906	2243.188	2011.506	2558.030	2480.700	2401.284	2473.218	2670.674	2321.546
12	509.142	525.424	293.742	840.266	762.936	683.520	755.454	952.910	603.782
13	129.750	146.032	-85.650	460.874	383.544	304.128	376.062	573.518	224.390
14	-539.704	-523.422	-755.104	-208.580	-285.910	-365.326	-293.392	-95.936	-445.064
15	77.828	94.110	-137.572	408.952	331.622	252.206	324.140	521.596	172.468

	10	11	12	13	14	15
10	0.000					
11	2491.124	0.000				
12	773.360	-1717.764	0.000			
13	393.968	-2097.156	-379.392	0.000		
14	-275.486	-2766.610	-1048.846	-669.454	0.000	
15	342.046	-2149.078	-431.314	-51.922	617.532	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	1.000	1.000							
3	0.968	0.944	1.000						
4	0.569	0.649	0.020	1.000					
5	0.893	0.932	0.090	1.000	1.000				
6	0.995	0.998	0.302	0.998	1.000	1.000			
7	0.912	0.947	0.102	1.000	1.000	1.000	1.000		
8	0.138	0.178	0.002	1.000	0.989	0.844	0.985	1.000	
9	1.000	1.000	0.672	0.934	0.998	1.000	0.999	0.481	1.000
10	0.861	0.908	0.075	1.000	1.000	1.000	1.000	0.994	0.996
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.043	0.031	0.747	0.000	0.000	0.001	0.000	0.000	0.006
13	1.000	0.999	1.000	0.104	0.327	0.700	0.358	0.012	0.956
14	0.024	0.033	0.000	0.976	0.780	0.405	0.749	1.000	0.135
15	1.000	1.000	1.000	0.233	0.567	0.897	0.604	0.034	0.996

	10	11	12	13	14	15
10	1.000					
11	0.000	1.000				
12	0.000	0.000	1.000			
13	0.286	0.000	0.344	1.000		
14	0.822	0.000	0.000	0.001	1.000	
15	0.516	0.000	0.168	1.000	0.004	1.000

ANALYSIS OF AL IN SELECTED ARNEWS PLOTS

DEP VAR: AL N: 75 MULTIPLE R: 0.985 SQUARED MULTIPLE R: 0.971

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	4194577.964	14	299612.712	144.472	0.000
ERROR	124430.936	60	2073.849		

COL/
ROW PLOT_SP$
1 dF 916
2 dF 921
3 lP 922
4 lP 923
5 lP 924
6 lP 925
7 pP 917
8 pP 920
9 pP 921
10 sS 926
11 tA 918
12 tA 927
13 wH 919
14 wrC 919
15 wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF AL

USING MODEL MSE OF 2073.849 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	81.678	0.000							
3	19.766	-61.912	0.000						
4	346.630	264.952	326.864	0.000					
5	442.596	360.918	422.830	95.966	0.000				
6	164.056	82.378	144.290	-182.574	-278.540	0.000			
7	37.980	-43.698	18.214	-308.650	-404.616	-126.076	0.000		
8	33.786	-47.892	14.020	-312.844	-408.810	-130.270	-4.194	0.000	
9	22.554	-59.124	2.788	-324.076	-420.042	-141.502	-15.426	-11.232	0.000
10	30.658	-51.020	10.892	-315.972	-411.938	-133.398	-7.322	-3.128	8.104
11	-45.508	-127.186	-65.274	-392.138	-488.104	-209.564	-83.488	-79.294	-68.062
12	-47.872	-129.550	-67.638	-394.502	-490.468	-211.928	-85.852	-81.658	-70.426
13	726.636	644.958	706.870	380.006	284.040	562.580	688.656	692.850	704.082
14	-33.330	-115.008	-53.096	-379.960	-475.926	-197.386	-71.310	-67.116	-55.884
15	563.346	481.668	543.580	216.716	120.750	399.290	525.366	529.560	540.792

	10	11	12	13	14	15
10	0.000					
11	-76.166	0.000				
12	-78.530	-2.364	0.000			
13	695.978	772.144	774.508	0.000		
14	-63.988	12.178	14.542	-759.966	0.000	
15	532.688	608.854	611.218	-163.290	596.676	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	0.257	1.000							
3	1.000	0.697	1.000						
4	0.000	0.000	0.000	1.000					
5	0.000	0.000	0.000	0.085	1.000				
6	0.000	0.245	0.001	0.000	0.000	1.000			
7	0.991	0.969	1.000	0.000	0.000	0.004	1.000		
8	0.997	0.936	1.000	0.000	0.000	0.003	1.000	1.000	
9	1.000	0.759	1.000	0.000	0.000	0.001	1.000	1.000	1.000
10	0.999	0.900	1.000	0.000	0.000	0.002	1.000	1.000	1.000
11	0.957	0.004	0.618	0.000	0.000	0.000	0.227	0.300	0.550
12	0.936	0.003	0.561	0.000	0.000	0.000	0.191	0.257	0.493
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.998	0.014	0.870	0.000	0.000	0.000	0.472	0.573	0.823
15	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000

	10	11	12	13	14	15
10	1.000					
11	0.363	1.000				
12	0.315	1.000	1.000			
13	0.000	0.000	0.000	1.000		
14	0.649	1.000	1.000	0.000	1.000	
15	0.000	0.000	0.000	0.000	0.000	1.000

ANALYSIS OF K IN SELECTED ARNEWS PLOTS

DEP VAR: K N: 75 MULTIPLE R: 0.922 SQUARED MULTIPLE R: 0.850

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	.409544E+09	14	.292532E+08	24.268	0.000
ERROR	.723247E+08	60	1205411.714		

COL/ ROW	PLOT_SP$
1	dF 916
2	dF 921
3	lP 922
4	lP 923
5	lP 924
6	lP 925
7	pP 917
8	pP 920
9	pP 921
10	sS 926
11	tA 918
12	tA 927
13	wH 919
14	wrC 919
15	wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF K

USING MODEL MSE OF 1205411.714 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	1503.224	0.000							
3	125.152	-1378.072	0.000						
4	-1084.832	-2588.056	-1209.984	0.000					
5	-383.296	-1886.520	-508.448	701.536	0.000				
6	-1364.490	-2867.714	-1489.642	-279.658	-981.194	0.000			
7	770.466	-732.758	645.314	1855.298	1153.762	2134.956	0.000		
8	633.340	-869.884	508.188	1718.172	1016.636	1997.830	-137.126	0.000	
9	1809.650	306.426	1684.498	2894.482	2192.946	3174.140	1039.184	1176.310	0.000
10	2183.084	679.860	2057.932	3267.916	2566.380	3547.574	1412.618	1549.744	373.434
11	5555.790	4052.566	5430.638	6640.622	5939.086	6920.280	4785.324	4922.450	3746.140
12	7395.752	5892.528	7270.600	8480.584	7779.048	8760.242	6625.286	6762.412	5586.102
13	850.528	-652.696	725.376	1935.360	1233.824	2215.018	80.062	217.188	-959.122
14	-967.336	-2470.560	-1092.488	117.496	-584.040	397.154	-1737.802	-1600.676	-2776.986
15	235.356	-1267.868	110.204	1320.188	618.652	1599.846	-535.110	-397.984	-1574.294

	10	11	12	13	14	15
10	0.000					
11	3372.706	0.000				
12	5212.668	1839.962	0.000			
13	-1332.556	-4705.262	-6545.224	0.000		
14	-3150.420	-6523.126	-8363.088	-1817.864	0.000	
15	-1947.728	-5320.434	-7160.396	-615.172	1202.692	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	0.687	1.000							
3	1.000	0.799	1.000						
4	0.960	0.030	0.911	1.000					
5	1.000	0.320	1.000	0.999	1.000				
6	0.810	0.009	0.700	1.000	0.983	1.000			
7	0.998	0.999	1.000	0.347	0.936	0.156	1.000		
8	1.000	0.994	1.000	0.473	0.977	0.237	1.000	1.000	
9	0.387	1.000	0.507	0.008	0.129	0.002	0.972	0.927	1.000
10	0.134	1.000	0.198	0.001	0.032	0.000	0.770	0.642	1.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.996	1.000	0.999	0.282	0.898	0.120	1.000	1.000	0.986
14	0.985	0.047	0.958	1.000	1.000	1.000	0.454	0.591	0.013
15	1.000	0.878	1.000	0.843	1.000	0.592	1.000	1.000	0.617

	10	11	12	13	14	15
10	1.000					
11	0.001	1.000				
12	0.000	0.360	1.000			
13	0.834	0.000	0.000	1.000		
14	0.002	0.000	0.000	0.379	1.000	
15	0.273	0.000	0.000	1.000	0.914	1.000

ANALYSIS OF MN IN SELECTED ARNEWS PLOTS

DEP VAR: MN N: 75 MULTIPLE R: 0.957 SQUARED MULTIPLE R: 0.915

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	.257526E+08	14	1839474.925	46.168	0.000
ERROR	2390597.112	60	39843.285		

COL/ ROW	PLOT_SP$
1	dF 916
2	dF 921
3	lP 922
4	lP 923
5	lP 924
6	lP 925
7	pP 917
8	pP 920
9	pP 921
10	sS 926
11	tA 918
12	tA 927
13	wH 919
14	wrC 919
15	wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF MN

USING MODEL MSE OF 39843.285 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	-28.886	0.000							
3	19.486	48.372	0.000						
4	210.008	238.894	190.522	0.000					
5	198.606	227.492	179.120	-11.402	0.000				
6	-0.124	28.762	-19.610	-210.132	-198.730	0.000			
7	-141.574	-112.688	-161.060	-351.582	-340.180	-141.450	0.000		
8	-269.752	-240.866	-289.238	-479.760	-468.358	-269.628	-128.178	0.000	
9	-259.204	-230.318	-278.690	-469.212	-457.810	-259.080	-117.630	10.548	0.000
10	763.482	792.368	743.996	553.474	564.876	763.606	905.056	1033.234	1022.686
11	-265.910	-237.024	-285.396	-475.918	-464.516	-265.786	-124.336	3.842	-6.706
12	-266.964	-238.078	-286.450	-476.972	-465.570	-266.840	-125.390	2.788	-7.760
13	2051.306	2080.192	2031.820	1841.298	1852.700	2051.430	2192.880	2321.058	2310.510
14	509.526	538.412	490.040	299.518	310.920	509.650	651.100	779.278	768.730
15	603.020	631.906	583.534	393.012	404.414	603.144	744.594	872.772	862.224

	10	11	12	13	14	15
10	0.000					
11	-1029.392	0.000				
12	-1030.446	-1.054	0.000			
13	1287.824	2317.216	2318.270	0.000		
14	-253.956	775.436	776.490	-1541.780	0.000	
15	-160.462	868.930	869.984	-1448.286	93.494	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	1.000	1.000							
3	1.000	1.000	1.000						
4	0.936	0.848	0.970	1.000					
5	0.958	0.888	0.982	1.000	1.000				
6	1.000	1.000	1.000	0.936	0.958	1.000			
7	0.998	1.000	0.993	0.283	0.333	0.998	1.000		
8	0.706	0.840	0.601	0.024	0.031	0.706	0.999	1.000	
9	0.759	0.879	0.658	0.030	0.039	0.759	1.000	1.000	1.000
10	0.000	0.000	0.000	0.004	0.003	0.000	0.000	0.000	0.000
11	0.725	0.855	0.622	0.026	0.034	0.726	1.000	1.000	1.000
12	0.720	0.851	0.616	0.026	0.033	0.721	1.000	1.000	1.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.012	0.006	0.019	0.544	0.481	0.012	0.000	0.000	0.000
15	0.001	0.001	0.002	0.143	0.116	0.001	0.000	0.000	0.000

	10	11	12	13	14	15
10	1.000					
11	0.000	1.000				
12	0.000	1.000	1.000			
13	0.000	0.000	0.000	1.000		
14	0.784	0.000	0.000	0.000	1.000	
15	0.994	0.000	0.000	0.000	1.000	1.000

ANALYSIS OF FE IN SELECTED ARNEWS PLOTS

DEP VAR: FE N: 75 MULTIPLE R: 0.927 SQUARED MULTIPLE R: 0.860

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	218545.078	14	15610.363	26.368	0.000
ERROR	35520.541	60	592.009		

COL/ ROW	PLOT_SP$
1	dF 916
2	dF 921
3	lP 922
4	lP 923
5	lP 924
6	lP 925
7	pP 917
8	pP 920
9	pP 921
10	sS 926
11	tA 918
12	tA 927
13	wH 919
14	wrC 919
15	wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF FE

USING MODEL MSE OF 592.009 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	195.414	0.000							
3	-1.690	-197.104	0.000						
4	-26.928	-222.342	-25.238	0.000					
5	-19.714	-215.128	-18.024	7.214	0.000				
6	-9.270	-204.684	-7.580	17.658	10.444	0.000			
7	-17.366	-212.780	-15.676	9.562	2.348	-8.096	0.000		
8	-32.476	-227.890	-30.786	-5.548	-12.762	-23.206	-15.110	0.000	
9	41.614	-153.800	43.304	68.542	61.328	50.884	58.980	74.090	0.000
10	-4.326	-199.740	-2.636	22.602	15.388	4.944	13.040	28.150	-45.940
11	-3.066	-198.480	-1.376	23.862	16.648	6.204	14.300	29.410	-44.680
12	-4.152	-199.566	-2.462	22.776	15.562	5.118	13.214	28.324	-45.766
13	-23.670	-219.084	-21.980	3.258	-3.956	-14.400	-6.304	8.806	-65.284
14	-4.194	-199.608	-2.504	22.734	15.520	5.076	13.172	28.282	-45.808
15	-29.258	-224.672	-27.568	-2.330	-9.544	-19.988	-11.892	3.218	-70.872

	10	11	12	13	14	15
10	0.000					
11	1.260	0.000				
12	0.174	-1.086	0.000			
13	-19.344	-20.604	-19.518	0.000		
14	0.132	-1.128	-0.042	19.476	0.000	
15	-24.932	-26.192	-25.106	-5.588	-25.064	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	0.000	1.000							
3	1.000	0.000	1.000						
4	0.908	0.000	0.942	1.000					
5	0.993	0.000	0.997	1.000	1.000				
6	1.000	0.000	1.000	0.998	1.000	1.000			
7	0.998	0.000	0.999	1.000	1.000	1.000	1.000		
8	0.723	0.000	0.790	1.000	1.000	0.970	1.000	1.000	
9	0.328	0.000	0.268	0.003	0.014	0.091	0.022	0.001	1.000
10	1.000	0.000	1.000	0.976	0.999	1.000	1.000	0.877	0.190
11	1.000	0.000	1.000	0.963	0.999	1.000	1.000	0.838	0.225
12	1.000	0.000	1.000	0.975	0.999	1.000	1.000	0.872	0.194
13	0.965	0.000	0.981	1.000	1.000	1.000	1.000	1.000	0.006
14	1.000	0.000	1.000	0.975	0.999	1.000	1.000	0.873	0.193
15	0.843	0.000	0.892	1.000	1.000	0.992	1.000	1.000	0.002

	10	11	12	13	14	15
10	1.000					
11	1.000	1.000				
12	1.000	1.000	1.000			
13	0.994	0.990	0.994	1.000		
14	1.000	1.000	1.000	0.994	1.000	
15	0.947	0.924	0.944	1.000	0.945	1.000

ANALYSIS OF CA IN SELECTED ARNEWS PLOTS

DEP VAR: CA N: 75 MULTIPLE R: 0.977 SQUARED MULTIPLE R: 0.954

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT_SP$	.157780E+10	14	.112700E+09	88.841	0.000
ERROR	.761134E+08	60	1268556.786		

COL/ ROW	PLOT_SP$
1	dF 916
2	dF 921
3	lP 922
4	lP 923
5	lP 924
6	lP 925
7	pP 917
8	pP 920
9	pP 921
10	sS 926
11	tA 918
12	tA 927
13	wH 919
14	wrC 919
15	wwP 919

USING LEAST SQUARES MEANS.

POST HOC TEST OF CA

USING MODEL MSE OF 1268556.786 WITH 60. DF.

MATRIX OF PAIRWISE MEAN DIFFERENCES:

	1	2	3	4	5	6	7	8	9
1	0.000								
2	1196.810	0.000							
3	-1690.276	-2887.086	0.000						
4	-1698.718	-2895.528	-8.442	0.000					
5	-2397.536	-3594.346	-707.260	-698.818	0.000				
6	-2036.340	-3233.150	-346.064	-337.622	361.196	0.000			
7	-2909.920	-4106.730	-1219.644	-1211.202	-512.384	-873.580	0.000		
8	-2455.514	-3652.324	-765.238	-756.796	-57.978	-419.174	454.406	0.000	
9	-2596.894	-3793.704	-906.618	-898.176	-199.358	-560.554	313.026	-141.380	0.000
10	-879.782	-2076.592	810.494	818.936	1517.754	1156.558	2030.138	1575.732	1717.112
11	13260.502	12063.692	14950.778	14959.220	15658.038	15296.842	16170.422	15716.016	15857.396
12	4370.704	3173.894	6060.980	6069.422	6768.240	6407.044	7280.624	6826.218	6967.598
13	-18.984	-1215.794	1671.292	1679.734	2378.552	2017.356	2890.936	2436.530	2577.910
14	9520.516	8323.706	11210.792	11219.234	11918.052	11556.856	12430.436	11976.030	12117.410
15	24.696	-1172.114	1714.972	1723.414	2422.232	2061.036	2934.616	2480.210	2621.590

	10	11	12	13	14	15
10	0.000					
11	14140.284	0.000				
12	5250.486	-8889.798	0.000			
13	860.798	-13279.486	-4389.688	0.000		
14	10400.298	-3739.986	5149.812	9539.500	0.000	
15	904.478	-13235.806	-4346.008	43.680	-9495.820	0.000

TUKEY HSD MULTIPLE COMPARISONS.
MATRIX OF PAIRWISE COMPARISON PROBABILITIES:

	1	2	3	4	5	6	7	8	9
1	1.000								
2	0.931	1.000							
3	0.544	0.011	1.000						
4	0.535	0.011	1.000	1.000					
5	0.078	0.001	1.000	1.000	1.000				
6	0.246	0.002	1.000	1.000	1.000	1.000			
7	0.010	0.000	0.921	0.925	1.000	0.995	1.000		
8	0.063	0.000	0.999	0.999	1.000	1.000	1.000	1.000	
9	0.037	0.000	0.994	0.994	1.000	1.000	1.000	1.000	1.000
10	0.995	0.219	0.998	0.998	0.710	0.946	0.250	0.655	0.517
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	1.000	0.923	0.562	0.554	0.084	0.259	0.011	0.068	0.040
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	1.000	0.941	0.519	0.511	0.072	0.229	0.009	0.058	0.034

	10	11	12	13	14	15
10	1.000					
11	0.000	1.000				
12	0.000	0.000	1.000			
13	0.996	0.000	0.000	1.000		
14	0.000	0.000	0.000	0.000	1.000	
15	0.994	0.000	0.000	1.000	0.000	1.000

Table 1. Pacific and Yukon ARNEWS plots lichen biomonitoring survey data indications for Plots 901 - 916 (later plots are described in Enns 1993). Capability for biomonitoring using lichens and mosses is ranked according to abundance of known indicator material, range of sensitivities of species and absence of confounding factors (eg. closed canopy and high litterfall). Comments in cases pertain to surrounding area directly outside the ARNEWS plot.

Plot # and Location		Lichen survey data and sampling needs
901	Shawnigan Lake	Excellent capability for showing changes in coastal air quality. There are sensitive species of Alectoria and related arboreal lichens are well established with several foliar species on bark and very abundant ground lichen for repeated sampling. Baseline ash analysis complete. Transplants survived here for > than one year. Photometric plots were established here.
902	Haney; U.B.C. Research Forest	Moderate capability for showing changes in coastal air quality. Ground lichen communities occur in openings outside the plot. Baseline ash analysis complete. Mortality of transplanted lichens have occurred within one year. Photometric plots were established here.
903	Salt Spring Island	Excellent capability for showing changes in southern coast island air quality. There are moderately sensitive species of Hypogymnia and moderately abundant ground lichen for repeated sampling. Baseline ash analysis complete but sample size was low (n = 3). Photometric plots were established here.
904	John Hart Lake, Campbell River	Excellent capability for showing changes in coastal and northern island air quality. Abundant arboreal fruticose and foliose lichens including some sensitive species of Bryoria. No ash analysis, collections taken.
905	Bulldog Creek, Rossland - Castlegar	Moderate capability for showing changes in interior mountain air quality, but see discussion below for efficacy with respect to major LRT sources. Arboreal and ground lichen species are avaialble for re-sampling but are not especially abundnant.
906	Penticton	Moderate capability for showing changes in interior dry-belt air quality, of interest because of high sulphur values in trembling aspen foliage. Two species of *Peltigera* are abundant enough for repeated sampling. No ash analysis available.
907	Prince George	Moderate capability for showing changes in interior mountain air quality, at least one species of *Peltigera* is abundant enough for repeated sampling. No ash analysis available.
908	Terrace	Moderate capability for showing changes in coastal mountain air quality, at least one species of *Peltigera* is abundant enough for repeated sampling. No ash analysis available. LRT from ALCAN and other sources are of concern. Cross referencing with ALCAN's flouride and SO_2 biomonitoirng program is advised.

909	Jones Lake, Chilliwack	Unknown cryptogamic biomonitoring potential. To be sampled
910	Capilano	Moderate to poor capability for biomonitoring. Dense leaf litter with a declining rate of deposition. *Plagiothecium undulatum* and *Isothecium stolonifera* are available for ash analysis. Snags with abundant lichen occur nearby and should be used for repeated sampling. *Hypogymnia* spp. and *Platismatia* occur on the edge of the hydro line.
911	Seymour Upper Watershed	Moderate to poor capability for biomonitoring. Frequent openings in the canopy with subsequent high diversity in understory especialy species of moss. *Plagiothecium undulatum* and *Isothecium stolonifera* are available for ash analysis. A creekside cliff and an old logging road should have several species of *Peltigera* but these were not found here. Alder is available for re-sampling. Transplants may be possible.
912	Seymour Lower Watershed	Moderate to poor capability for biomonitoring. *Isothecium stolonifera* is very abundant. Very few lichens.
913	Coquitlam Upper Watershed	Moderate to low lichen and moss biomonitoring potential; lichen transplants were used in the edge of the block with an accelerated mortality in comparison to the U.B.C. Research Forest. Few species of lichens occur in the cutblock below the plot. In the older stand, deep litterfall has resulted in a poor understory development. Species suitability for biomonitoring is low; there is only sporadic presence of liverworts and hygric mosses with very little references in literature as to sensitivities or absorptivities in relation to LRT for metals or for wet/dry S compounds.
914	Coquitlam Lower Watershed	Biomonitoring potential is similar to 913. Deep litterfall, uncommon or infrequently used species. Road development and gravel pit are both nearby and all sampling must take place to the west of the plot. Kindbergia ash data available.
915	Cottonwood Quesnel	Unknown biomonitoring potential.
916	Saturna Island	Excellent biomonitoring potential; open stand on well-drained materials have resulted in diverse cryptogamic flora. Several species with a range in sensitivity to changes in air quality are available in high abundance for resampling.

Appendix 3. Summary of monthly averages, minimums and maximums of wet deposition of sulfate at Saturna Island (mg/ml/hour) (from Environment Canada 1994).

Saturna Island Sulfate

			MEAN		GMEAN		MIN		MEDIAN		MAX	
			SO4	X-SO4	SO4	X-SO4	SO4	X-SO4	SO4	X-SO4	SO4	X-SO4
SAT	1989	JUN	2.38	2.3	1.54	1.43	0.68	0.57	1.3	1.23	9.58	9.48
SAT	1989	JUL	1.7	1.57	1.38	1.29	0.44	0.42	1.22	1.19	3.85	3.62
SAT	1989	AUG	0.95	0.93	0.57	0.55	0.19	0.18	0.57	0.55	2.92	2.88
SAT	1989	SEP	2.18	1.73	2.18	1.73	2.18	1.73	2.18	1.73	2.18	1.73
SAT	1989	OCT	1.65	1.48	1.28	1.04	0.67	0.41	1.32	1.13	5.58	5.5
SAT	1989	NOV	1.27	1.08	0.95	0.73	0.25	0.2	0.97	0.61	4.63	4.58
SAT	1989	DEC	1.29	1.16	1.11	0.95	0.51	0.31	1.22	1.02	2.72	2.56
SAT	1990	JAN	1.38	0.96	0.83	0.59	0.18	0.15	0.94	0.77	3.89	3.12
SAT	1990	FEB	0.98	0.65	0.81	0.52	0.26	0.21	0.93	0.48	2.46	2.38
SAT	1990	MAR	1.43	1.17	1.26	1.07	0.52	0.5	1.41	1.21	3.01	2.31
SAT	1990	APR	1.29	1.25	1.15	1.11	0.71	0.67	0.95	0.86	3.26	3.23
SAT	1990	MAY	2.53	2.4	1.9	1.77	0.3	0.26	2.2	2.11	7.54	7.51
SAT	1990	JUN	1.38	1.29	1.09	1	0.31	0.28	1.17	1.08	3.35	3.25
SAT	1990	JUL	2.24	2.03	2.2	1.98	1.87	1.6	1.87	1.6	2.6	2.46
SAT	1990	AUG	2.31	2.26	1.21	1.17	0.21	0.19	0.98	0.96	6.21	6.12
SAT	1990	SEP	1.05	0.96	1.03	0.95	0.79	0.76	1.07	0.98	1.29	1.14
SAT	1990	OCT	1.38	0.99	1.17	0.76	0.43	0.26	1.12	0.72	3.24	3.04
SAT	1990	NOV	0.9	0.56	0.77	0.44	0.18	0.12	0.72	0.37	2.2	2
SAT	1990	DEC	1.59	1.31	1.13	0.8	0.28	0.2	0.99	0.69	7.81	7.63
SAT	1991	JAN	1.03	0.84	0.81	0.58	0.3	0.19	0.61	0.45	3.15	2.9
SAT	1991	FEB	1.56	1.22	1.1	0.75	0.5	0.29	1.06	0.68	6.91	6.84
SAT	1991	MAR	1.75	1.44	1.49	1.23	0.49	0.42	1.82	1.37	4.42	3.1
SAT	1991	APR	1.12	0.87	0.93	0.66	0.39	0.19	0.87	0.73	2.83	2.69
SAT	1991	MAY	1.03	0.97	0.85	0.77	0.32	0.24	0.85	0.82	2.83	2.73
SAT	1991	JUN	1.18	1.11	0.92	0.85	0.16	0.15	0.76	0.72	2.67	2.5
SAT	1991	JUL	0.77	0.75	0.67	0.65	0.16	0.15	0.73	0.69	1.31	1.29
SAT	1991	AUG	0.94	0.87	0.83	0.77	0.28	0.2	0.86	0.84	1.83	1.62
SAT	1991	SEP	0.81	0.8	0.81	0.8	0.81	0.8	0.81	0.8	0.81	0.8
SAT	1991	OCT	1.4	1.25	1	0.81	0.38	0.28	0.64	0.6	4.38	4.26
SAT	1991	NOV	1.37	0.97	0.98	0.63	0.2	0.16	1.06	0.51	6.89	5.85
SAT	1991	DEC	1.26	1.05	1.17	0.89	0.44	0.23	1.19	1.03	2.16	2.11

Appendix 4. Sources of LRT in the Pacific and Yukon Region. (From B.H. Levelton and Associates 1992).

TABLE 10

20 Largest Emitters of SOX
in B.C. (outside LFV) for year 1990

CODE	PERMIT	FACILITY	LOCATION	WMR	QUANTITY (tonnes)	% OF TOTAL
ALCAN	PA2552	Alcan Smelters and Chemicals Ltd.	Kitimat	06	7087.6	9.5
	PA6884		Kitimat	06		9.5
WTC02	PA1555	Westcoast Transmission Co. Ltd.	Fort Nelson	05	6158.3	8.2
TEC03	PA2691	Cominco Ltd. Metals Division (Lead	Trail	04	5688.0	7.6
BCF04	PA1902	Fletcher Challenge	Crofton	01	4286.8	5.7
WTC29	PA5151	Westcoast Transmission Co. Ltd.	Chetwynd	05	3758.4	5.0
PCA09	PA1742	Petro-Canada & Westcoast Energy	Taylor	05	3591.6	4.8
QPETR	PA5056	Quasar Petroleum Ltd.	Grizzly Valley	05	3234.7	4.3
	PA5057		Grizzly Valley	05		4.3
	PA5058		Grizzly Valley	05		4.3
BPE02	PA5365	BP Exploration Canada Ltd.	Bullmoose	05	3025.6	4.0
HUOIL	PA2065	Husky Oil	Prince George	05	2817.4	3.8
CRO07	PA3341	Fletcher Challenge, Elk Falls	Campbell River	01	2741.7	3.7
MMB06	PA3149	MacMillan Bloedel Ltd.	Powell River	02	2489.7	3.3
MMB01	PA1863	MacMillan Bloedel Ltd.	Port Alberni	01	2483.3	3.3
WPU01	PA3760	Western Pulp Limited Partnership	Port Alice	01	2295.3	3.1
BPE01	PA5364	BP Exploration Canada Ltd.	Sukunka Area	05	2253.8	3.0
MMB03	PA2708	MacMillan Bloedel Ltd.,Harmac Div.	Nanaimo	01	1849.7	2.5
PLDEN	PA2399	Placer Development Ltd., Endako Mi	Endako	06	1771.4	2.4
CIP01	PA3201	CIP Inc., Tahsis Pacific Region	Gold River	01	1689.0	2.3
SKE01	PA3547	Skeena Cellulose Inc.,Pulp Operati	Prince Rupert	05	1355.6	1.8
WPU02	PA1647	Western Pulp Limited Partnership	Squamish	02	1284.7	1.7
NPT03	PA2559	Northwood Pulp & Timber Ltd.	Prince George	05	1241.5	1.7
			TOTAL :		61096.9	81.7
		Total SOX emissions outside LFV :			74811.3	100.0

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