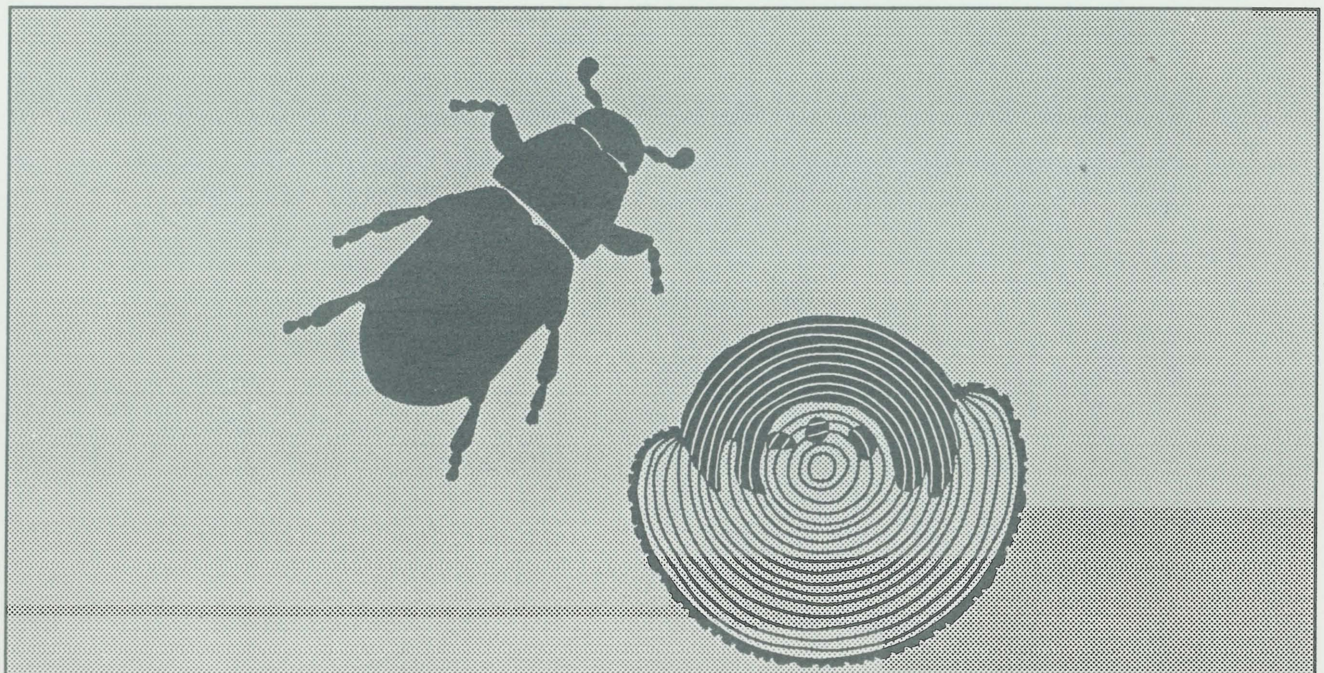
Mineral Contents of Coniferous Foliage from Forestry Canada's ARNEWS plots: Pacific and Yukon Region

(FIDS Report 91-10 — March 1991)

Pacific and Yukon Region



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Mineral Contents of Coniferous Foliage from Forestry Canada's ARNEWS plots: Pacific and Yukon Region

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Prepared For:

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Summary

Forestry Canada has 15 Acid Rain National Early Warning System monitoring plots throughout British Columbia. They were established by 1986 to provide an assessment of the impacts of acidic precipitation on the provincial forest resource. The methods of monitoring acidic precipitation have included the mineral ash analysis of coniferous foliar tissue taken from sample trees growing within the ARNEWS plots. This paper reviews the results of the baseline foliar mineral ash analysis and makes comparisons between ARNEWS foliar ash analysis and similar analysis from other, impacted and non-impacted ecosystems.

The sample trees occurring in the ARNEWS plots include coastal Douglas-fir, (*Pseudotsuga menziesii*), interior (blue) Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), western white pine, (*Pinus monticola*), shore pine (*Pinus contorta* var. *contorta*), lodgepole pine (*Pinus contorta* var. *latifolia*), amabalis fir (*Abies amabilis*), subalpine fir (*Abies lasiocarpa*), white spruce (*Picea glauca*), Sitka spruce (*Picea sitchensis*), Engelmann spruce (*Picea engelmannii*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), birch (*Betula* sp.), willow (*Salix* sp.). Douglas-fir is and western hemlock were the most common species. The element content in the foliage of subalpine fir (Fa), Engelmann spruce (Es), white spruce (Sw), Douglas fir (Fd), Western Hemlock (Hw), Western Red Cedar (Cw) Lodgepole Pine (Pl) from selected ARNEWS plots were examined. The foliar ash analysis for all species and all plots were placed in a data display format using Tukey's boxplots (Wilkinson 1988). These boxplots illustrate within sample variation for a series of replicates of a given species, the central tendency for foliar element content for a given species as well as indicating significant differences between sample medians. Element contents of foliage were expressed as parts per million (ppm) for all elements with the exception of some determinations in % dry weight (ie. nitrogen). The notched boxplots indicated that some elements had a wider within-species variance than others. The order of within-sample variance was related to the range in parts per million expressed in the sample.

This study provides a measure of variability of elemental content in individual tree species, and within ARNEWS plots. Comparisons of elemental concentrations in foliage were made between the ARNEWS plot data and sources in the literature. Comparisons were made between Port Alice foliar analysis (van Barneveld *et al.* 1989). Port Alice Western Hemlock foliar sulphur contents ranged from 800 ppm (at a distance from the mill) to 11,400 ppm. Comparisons were made between mineral contents determined in the early 1960's in the UBC research forest (Beaton *et al.* 1965) and those determined from samples from the UBC research forest ARNEWS plot. Comparisons were also made between Davis (1989), who studied mineral contents of foliage in Douglas-fir in coastal plots. A limited number of papers were also reviewed and compared to the ARNEWS plot data (Ballard and Carter 1985, Jacobsen *et al.* 1990, Gough *et al.* 1982, Joslin *et al.* 1988, Hutchison *et al.* 1986).

Manganese, Aluminum, Copper, Phosphorous and Zinc contents were highly variable, both within species and between ARNEWS plots. One of the possible sources of variation may be the difference in mineral absorptivity between species. Two species were often sampled within and ARNEWS plot. The boxplots indicated that species within an ARNEWS plot had significantly different mineral contents. Median Manganese contents of 910 Fd and Hw, 912 Fd and Hw, 913 Cw and Hw, 914 Fd and Hw were all between 400 and 1000 ppm apart. A similar relationship was

note for Aluminum and Copper, although for these elements the magnitude in differences were 100 - 500 ppm and < 10 ppm, respectively.

Nitrogen contents ranged between 9 and 25 ppm. There was no significant difference between any species or ARNEWS plot for this element. Iron contents tended to be elevated in 914 Fd and Hw, in a similar pattern as sulphur contents, but again, due to high within sample variance these contents were not significantly higher than any other ARNEWS plot.

Magnesium contents showed a high within-species variance, with some anomalously high values. Calcium, Potassium and Sodium contents also exhibited some anomalous values for single species within ARNEWS plots. For example Fd in ARNEWS plot 911 had Potassium contents considerably higher than the rest of the dataset, as did Calcium contents of Cw in ARNEWS plot 913. Both ARNEWS plot 910 species (Fa and Hw) had anomalous within sample variance for Sodium, indicating that contamination of samples has possibly occurred.

In general, ARNEWS plot data showed some anomalous values in iron measurements, but sulphur values were lower than in Beaton *et al.* (1965). The foliar contents of individual species were similar to the foliar nutrient characteristics noted in other studies, for example, western hemlock is typically noted as an accumulator of manganese and is frequently low in zinc in comparison to other species (Ballard *pers. comm.* 1991). Western redcedar had very high calcium content as well, which is apparently typical (Ballard *pers. comm.* 1991). The sulphur content of Douglas-fir and western hemlock, two of the most common species throughout the B.C and Yukon Regional study area, was examined with analysis of variance and Scheffe's tests. They indicate that western hemlock foliage from the Coquitlam watershed has a significantly greater sulphur content than those ARNEWS plots where hemlock occurred and was sampled for ash analysis. This includes some of the other ARNEWS plots within the main Fraser River watershed. Also, the ARNEWS plot 914 (Coquitlam) is significantly different (ie. higher) than 908 (Terrace), 909 (Chilliwack), 910 (Capilano) and 912 (Seymour), but is not significantly different (ie. higher) than 913 (the other Coquitlam ARNEWS plot). Further, and that ARNEWS plot 913 is significantly different from ARNEWS plots 908 and 910. Also, Douglas-fir foliage from ARNEWS plot 906 (Penticton) has a significantly lower sulphur content than any other ARNEWS plot where this species has been sampled.

A series of recommendations were made concerning future sampling for the ARNEWS system in British Columbia. Minor adjustments to the present sample system including some additional spot sampling to determine control values are recommended. Additional sampling may be warranted in the Seymour and Capilano plots.

Acknowledgements

This project was funded by Forestry Canada and supervised by Dr. A. Van Sickle, Pacific Forestry Centre, Victoria, B.C. His advice and support are gratefully acknowledged. Dr. Van Sickle, and members of his staff, also made various data from the Forestry Canada ARNEWS system available for use in this document. Dr. George Krumlick of the Ministry of Forests kindly provided his research results, as well as those papers from similar studies. Fred Rhoades, Mycena Consultants and Hubert Bunce of Reid Collins Forest Resource Consultants provided papers and advise regarding the use of foliar mineral ash analysis to indicate increases in acidic precipitation. Tony Basabe of Western Washington University searched American government literature. Philip Ross of the Smithers office of Ministry of Environment Waste Management Branch provided several references for sources of error in sampling that were most helpful. Ann Van Niekert (Pacific Forestry Centre) provided advise regarding the comparability of older sulphur determinations from the literature and current techniques. Dr. Ballard of UBC and Gerry Davis of Soilcon Laboratories are gratefully acknowledged for their contributions to this paper, in the form of comments of general variability in the process of foliar ash analysis, and documents.

Note: Meidinger (1987) is the authority used for species names in this report. Where other names are used in a cited publication, Meidinger's name is placed in brackets adjacent to name given in the cited publication.

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1.0 INTRODUCTION

Forestry Canada initiated a Canada-wide programme to monitor the early impacts of acidic precipitation on coniferous resources in 1983, following the procedures outlined in Magasi (1985). The system of monitoring utilizes repeated sampling in single 10 m x 40 m ARNEWS (Acid Rain National Early Warning System) plots established in immature forests. British Columbia has 15 plots. These are illustrated in Figure 1. Most of the B.C ARNEWS plots are mid-seral, representing either natural regeneration following logging, or post-fire succession. Many are placed in areas with a history of scientific research in order to supplement the ARNEWS monitoring system with background information, including studies of climate, second-growth forest productivity and other relevant programs. Examples include, (but may not be limited to), the ARNEWS plots at Shawnigan Lake, the UBC Research Forest at Haney, the Campbell River productivity study, and plots established with the cooperation of the Greater Vancouver Regional District. They are also thought to be at least partly typical of British Columbian second-growth, forested ecosystems. Although many forest types of British Columbia are not exemplified by the 15 ARNEWS plots, each of the plots represent areas where some form of sulphate deposition may occur, in comparison to other, neighbouring forests. As such, they represent the only province-wide effort to describe the potential impacts of acid precipitation impingement on forest resources.

Ash analysis of foliage has been proven to be a particularly useful tool for monitoring acidic precipitation impacts. Another symptom of damage as a result of acidic precipitation is the increased foliar leaching of potassium, magnesium and calcium (Linzon 1983). Loss of cations and the accumulation of sulphur compounds is measurable by means other than assessing the health of the plant. Leachates result in decreases in tissue concentrations, which when compared to controls, can be a useful indication of minor accumulation. This has value as an integral part of an early warning system. If adequately planned, the sampling process is not labour intensive and is more reflective of the biotic system being monitored, in comparison to precipitation monitoring. If sample contamination is avoided, and replicates are used to illustrate the range in interspecific or onsite variability, this method is acceptable as a valuable component of acidic precipitation monitoring procedures.

Mineral ash analysis has been used as one component of the early warning system, along with soils monitoring, and cryptogamic biomonitoring in selected plots (Enns 1991). Stream and rainfall chemistry has been studied in selected ARNEWS plots (Feller 1986). Data from nearby hydrological stations (Ministry of Environment 1989, Environment Canada 1989) stations have been discussed with respect to sulphur contents in the cryptogams (Enns 1989). However, although foliar ash analysis of conifer tissue was completed in 1984 - 1986, these data have never been examined or compared to current literature.

1.1 Objectives

The objectives of this report are as follows;

1. Review results of foliar mineral ash analysis of foliage samples taken from 15 ARNEWS plots.

3. Identify and discuss any elevated or anomalous values beyond the limits of sampling error.

4. Provide comments and suggestions for future data collection, analysis or modifications to increase suitability as baseline data for monitoring of acid rain and climate change effects.

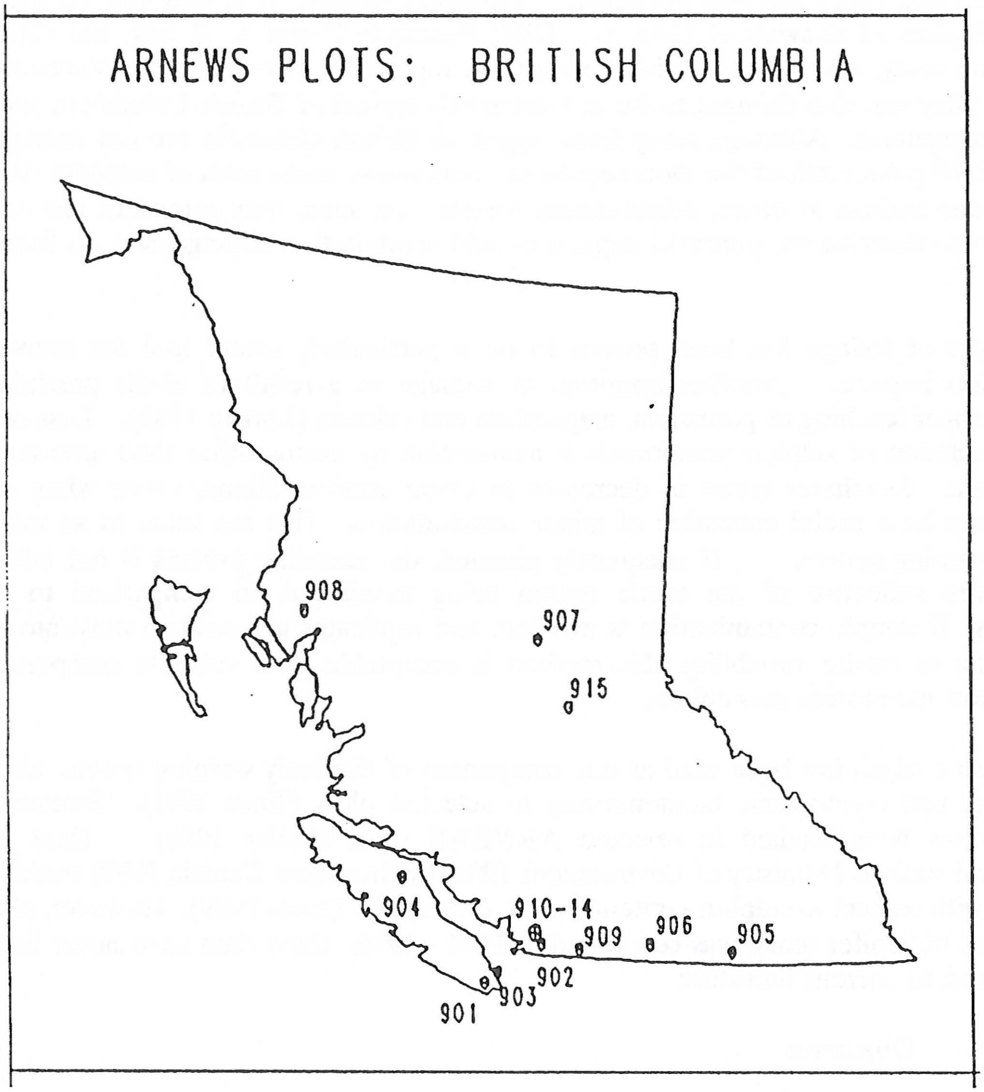

Figure 1. Forestry Canada ARNEWS plot locations. (from Van Sickle 1989)

1.2 Introduction to biomonitoring and the impacts of acidic precipitation

Biomonitoring has been used throughout the industrial world to measure the impact of sulphur dioxide, NO_x compounds, aqueous sulphur compounds (acid rain) and metal deposition. In most studies, paired sampling of soils with vegetation is done to correlate ambient pollutants with background accumulation (Addison 1980). Vascular plants are frequently used when impingement on forest resources or agricultural crops are of concern (Sarkela and Nuorteva 1987, Gough and Erdman 1977, Bargagli *et al.* 1987, Robertson and Price 1986, Folkeson and Andersson-Bringmark 1988, Westman 1974). Although pathological symptoms of chronic injury, such as chlorosis, premature needle abscission, reduced radial and volume growth (Lathe and McCallum 1939) and early death of the tree (Linzon 1983) are still the mainstay of disease survey procedures, these symptoms are not as easily quantified or attributed to single causes (Treshow 1970). The use of mineral ash analysis of tissues has allowed researchers to compare ambient sulphate (dry) deposition and acidic precipitation with elemental sulphur in soils, air and rainwater samples in an effort to eliminate such variables as pathogenesis from not-pollutant related symptomologies, ie. disease organisms, water stress, etc.. The more numeric approach has allowed comparisons between other ecosystems where acid rain impingement has occurred and been documented.

Acid rain, produced when sulphur dioxide is oxidized to sulfuric acid, is a potentially serious toxicant to plants (Gough *et al.* 1982). The main source of sulphur in acidic precipitation is SO_2, the long range transport of this compound and derivatives can extend to distances of 1000 km from the pollution source (Gough *et al.* 1982). Compounds of sulphur, whether aqueous or dry, enter the conifer principally through the leaf stomates and pass into the intercellular spaces of the mesophyll, where it contacts and is absorbed onto the cell wall (Thomas *et al.* 1950). Here it either combines with water to form sulfurous acid and sulphate or becomes slightly more diluted H_2SO_4 (Treshow 1973). The result is foliar tissue damage (Malhotra and Hocking 1976) and significant growth decreases (MacDonald and Sandhu 1975). Because the uptake of heavy metals is increased by lower than normal pH values, a synergistic effect can be expected where fallout of heavy metals and acid rain appear simultaneously (Gough *et al.* 1982). Malhotra and Khan (1984) have further described the impacts of major pollutants on conifer physiology to include membrane permeability, photosynthetic activity, photophosphorylation and carboxylation, electron transport and respiration. Peterson *et al.* (1989), Turner *et al.* (1978), Liechty and Mroz (1990) also describe reduced frost hardiness, discussed in the earlier work by Treshow (1970).

Individual species response to sulphur accumulation has been studied by a number of researchers, although comparisons between species appear to be from earlier, rather than later literature. Katz *et al.* (1939) report a discoloration and defoliation of Douglas-fir foliage, beginning at the tip of the needle and progressing toward the base. Katz (*et al.* 1939) listed the order of susceptibility of native conifers of British Columbia from most susceptible to least as western larch (*Larix occidentalis*), Douglas-fir (*Pseudotsuga menziesii*), yellow pine (*Pinus ponderosa*), Engelmann spruce (*Picea engelmannii*), (western) white-pine (*Pinus monticola*), (western) hemlock (*Tsuga heterophylla*), lodgepole pine (*Pinus contorta*), silver (amabalis) fir (*Abies amabilis*), white (subalpine) fir (*Abies lasiocarpa*) and (western) red cedar (*Thuja plicata*). Auclair *et al.* (1990) reports that, in comparison to eastern species, many of the western conifers are more susceptible to sulphur dioxide. Susceptibility is especially high for species of true firs (*Abies*), as well as western redcedar and Douglas-fir (Auclair *et al.* 1990). They state that Douglas-fir ranked second of eight conifers in sensitivity to SO_2 damage from smelting in Montana and fifth of 12 conifers in Washington State.

Scheffer and Hedgecock (1955 *cited in* Auclair *et al.* 1990) list western white pine as one of the more sensitive of the pine species. Species with highly cutinous leaves such as species of Juniper are thought to be among the most tolerant (Katz 1939).

Agreement in the literature on the impact of acidic precipitation on growth of conifers is not always clear, however. Linzon (1983) reported a 20% increase in growth of eastern white pine (*Pinus strobus*) seedlings subjected to artificial rains with pH's of 2.3 in comparison to high pH rainfall, and accredited this to increased nitrogenous content of the artificial rainfall. However, Berry (1967 *cited in* Treshow 1970) found severe injury of eastern white pine seedlings at 0.1 ppm after 8 hours of fumigation when the humidity was high and the nitrogen content of soils was low.

Some workers report an annual variation in the response of coniferous tissues to acidic precipitation which may be the reason for some of the lack of continuity in the literature. Winter damage is more apt to cause a more gradual chlorosis than summer damage. For example fumigation of coniferous tissue at 2.0 ppm for 69 hours in February failed to cause injury, whereas a 35-hour fumigation in March destroyed 75% of the foliage of the same species and stock (Treshow 1970). Because of genetic variation, symptoms may vary among species and among individuals of a single species (Treshow 1970).

1.3 Characteristics of the British Columbia ARNEWS plots

A brief description of the 15 B.C ARNEWS plots (Van Sickle 1989) is given in Appendix 1. The average stand age is 41.3 years (excepting the Castlegar ARNEWS plot (age unspecified), and the uneven-aged Quesnel ARNEWS plot where the lodgepole pine is 112 and the white spruce is 79 years of age. The youngest plot is 18 years old and the oldest is 76.

Tree species in the ARNEWS plots are dissimilar, not surprisingly, as they must reflect the impacts of early increases in acidic precipitation over a wide variation in landforms and forested zones. There are 12 biogeoclimatic zones and several variants within each of these zones (Meidinger and Pojar 1991). The ARNEWS plots are located within Coastal Douglas-fir, Sub-boreal Spruce, and Coastal Western Hemlock zones, with the latter being most commonly represented. The sample trees occurring in the ARNEWS plots include Douglas-fir, (*Pseudotsuga menziesii*), interior (blue) Douglas-fir (*Pseudotsuga menziessii* var. *glauca*), western white pine, (*Pinus monticola*), shore pine (*Pinus contorta* var. *contorta*), lodgepole pine (*Pinus contorta* var. *latifolia*), amabalis fir (*Abies amabilis*), subalpine fir (*Abies lasiocarpa*), white spruce (*Picea glauca*), Sitka spruce (*Picea sitchensis*), Engelmann spruce (*Picea engelmannii*), western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), birch (*Betula* sp.), willow (*Salix* sp.). Douglas-fir and western hemlock are the most common species for sampling.

Because of the enormous variation between forested ecosystems in British Columbia (Pojar and Meidinger 1991), the ARNEWS plots by necessity must use different species for sampling. In order for the reader to be familiar with the variation between sample locations a brief descriptions of the vascular plant vegetation is presented in Appendix 1. These data are not derived from field sampling, but from brief descriptions of presence/absence of some of the more obvious vascular plants (data provided by Van Sickle *pers. comm.* 1991).

2.0 METHODS OF ANALYSIS

Ten trees of each species per ARNEWS plot were sampled and analyzed (n=10). Ash analysis procedures followed those documented in Kalra *et al.* (1989). A microwave digestion method using HNO_3, H_2O_2 and HCl was followed by inductively coupled plasma - atomic emission spectrophotometry (ICP - AES). Samples were digested and analyzed at the Northern Forestry laboratory in Edmonton, Alberta.

Results of the analysis were tabulated and values were compared between ARNEWS plots. Comparisons between species are not recommended, because of indications of highly variability between species. Comparisons were plotted, using those data subsets with greater than 2 trees per ARNEWS plot. Due to the low sample sizes, samples taken from differing years of growth from a single tree and analyzed separately were treated as independent samples. There are no repeated samples available for comparison. Box plots were used to determine within species and within data set variability as a baseline for future comparisons. ARNEWS plots established in 1984 and some established in 1985 do not have the same array of field available for examination, that is lead contents were determined in the early samples taken from Shawnigan Lake, but this element was not analyzed in later work.

Boxplots (Wilkinson 1988) were used to illustrate the mineral contents of each species in each ARNEWS plot with a sample size > 2 samples. The boxplots illustrate 95% confidence intervals around the median of the group of within-species ARNEWS plot replicates for each element. The notch above and below the median represents 95% confidence intervals, such the observer can be 95% certain that notch boundaries aligned above neighbouring boxplot notches represent a significantly higher median value. A labelled example of a notched boxplot is given in Appendix 2. The reader should be aware that significant differences between different species median element contents are most likely a result of inherent differences between species absorptive or leachate producing capabilities, and not necessary the result of a greater or lesser response to air pollution. In order to determine if any one ARNEWS plot has greater sulphate deposition / acidic precipitation impacts, Analysis of Variance and Scheffe's multiple comparisons were used to examine the within species variability of sulphur contents of Douglas-fir and western hemlock, the most common species. Comparisons between values in the literature and values determined for the ARNEWS plots are discussed, as are a list of suggestions for improvements to the biomonitoring program is given.

3.0 RESULTS AND DISCUSSION

ARNEWS plots numbered 901 through 903 did not have sufficient data for boxplot display. These data are presented in Appendix 3. Douglas-fir was sampled in ARNEWS plots 901 and 903 (Shawnigan Lake and Saltspring Island, respectively). Western hemlock was sampled in the U.B.C. plot. The species used in the sample process in each of the ARNEWS plots are recorded on the figures, but it should be stressed that the species of trees used for sampling are not the same in each of the ARNEWS plots, mainly because of species geographic distribution. The complete dataset from ARNEWS plots 904 through 915 is graphically displayed and discussed below in section 5.1. Section 5.2 is an examination of sources of error and suggestions for future acid rain research.

3.1 Element concentrations in conifer foliage from ARNEWS plots 904 - 915

Table 1 illustrates the mean foliar nutrient content for all the samples taken from ARNEWS plots 901 - 915. Means are from replicated samples of the same species within an ARNEWS plot.

Table 1. Mean element contents for selected trees from Forestry Canada's 15 ARNEWS plots. Nitrogen values and data from Plots 901 - 903 units are expressed as percentages, the remaining are expressed as ppm.

PLOT	SPECIES	Ca	Mg	K	Mn	Al	Fe	P	S	N
901	dF	0.69	0.15	0.76	1618.50	ERR	54.50	0.35	0.19	1.09
902	wH	0.25	0.12	0.53	1072.00	ERR	136.25	0.18	0.17	1.29
903	df	0.50	0.16	0.74	558.25	ERR	69.25	0.21	0.20	1.26

PLOT	SPECIES	Ca	Mg	K	Mn	Al	Fe	P	S	N
904	df	2808.98	1216.56	6670.75	1237.73	138.71	1201.17	1813.73	972.55	1.11
905	eS	4581.64	748.68	7399.95	429.54	35.75	20.98	1636.88	597.96	1.11
905	alF	4723.45	808.37	6789.83	506.44	230.65	47.25	1575.78	798.17	1.11
906	dF	5548.60	940.19	6741.72	574.19	83.95	38.18	1257.61	703.63	1.46
907	alF	4729.60	842.92	7830.25	1221.50	47.26	45.79	1731.25	770.34	2.06
907	wS	4043.50	708.47	6103.05	443.95	5.56	40.14	1416.05	611.48	1.27
908	sS	4481.78	1114.77	8807.98	738.35	48.09	28.87	2206.93	933.05	1.64
908	wH	3534.55	1277.48	5777.00	1697.53	663.50	45.81	2144.95	936.34	1.26
909	wH	2756.43	1372.18	7173.75	596.33	559.66	72.22	1767.60	1052.84	1.87

PLOT	SPECIES	N	Ca	Mg	Na	K	P	S	Mn	Al	Fe	Cu	Zn
910	wH	14.86	5376.82	1307.44	51.56	4828.29	1035.50	1061.07	2398.33	239.17	47.45	1.13	13.17
910	alF	12.05	4678.03	1013.69	25.09	4859.75	772.57	933.38	901.52	146.24	59.08	1.04	20.85
911	dF	16.74	4024.34	1156.20	39.02	8786.32	1492.75	1105.99	418.79	143.80	53.66	3.70	15.78
912	dF	19.72	3723.57	924.68	17.34	5696.56	1151.89	1146.59	548.17	185.68	46.05	1.63	12.72
912	wH	16.18	5266.70	1402.28	12.17	6437.90	1488.70	1182.05	1801.80	446.50	56.48	1.58	8.70
913	wH	13.37	4945.57	1460.13	25.86	5694.18	932.35	1327.75	1607.30	356.55	71.68	2.44	3.78
913	wC	13.68	15399.79	1459.78	35.66	4461.06	1338.92	903.17	215.89	69.52	73.69	5.43	6.92
914	wH	9.79	5654.64	1776.88	12.66	5704.70	847.68	1481.20	1801.79	275.79	100.90	4.82	5.14
914	alF	10.27	5629.08	1300.00	4.97	4525.26	787.13	1285.07	811.02	158.44	101.02	4.10	15.59
915	lP	14.41	3829.59	1296.07	9.49	4806.12	1323.26	854.17	973.83	532.13	69.85	2.14	37.15
915	wS	10.74	8431.71	1033.43	5.80	5872.54	1779.71	670.03	1346.63	66.33	61.42	1.92	36.88

Figures 1 through 21 (below) illustrate baseline foliar ash analysis data for a variety of species from each of the 15 ARNEWS plots in British Columbia. They illustrate the high between-species variability in foliar mineral contents between species. The above dataset represents one of the first trans-provincial efforts to evaluate the potential impact of long range transport of sulphates and metals on conifer foliar nutrient status. Earlier work includes the threshold values for nutritional status applied to Pinaceae (Ballard and Carter 1985) and the multispecies comparisons of Beaton *et al.* (1965). Beaton *et al.* (1965) can be used as a benchmark comparison; they reported extensively on the mineral contents of conifer foliage in various locations throughout British Columbia, some of which are comparable to the ARNEWS plots. They analyzed the mineral contents of subalpine fir, amabilis fir, western red cedar, Douglas-fir, western hemlock, lodgepole pine, Engelmann spruce and Sitka spruce at Trail, Kelowna, Gold River, Terrace, Powers Creek, Haney Research Forest, Cowichan Lake, Port Alberni, and a variety of other locations. Presumably, this paper may be considered a background analysis for mineral nutrient contents as data were collected in the early 60's prior to current levels of sulphate loading and acidic precipitation. Appendix 3 includes tables of data from this paper. There are also numerous nutrient status studies with limited comparability to the ARNEWS data presented above (ie. Davis 1989, Krumlick 1974, 1979, Kabzems 1986, Ritcher 1983). Comparisons of the ARNEWS data from the above figures with other values in the literature are constrained by various factors. A brief discussion of some of the restrictions imposed when trying to make comparisons between different datasets is included in the discussion of elemental concentrations, and in section 5.2 below.

3.1.1 Elemental Concentrations in Foliage: Nitrogen and Sulphur

Nitrogen and sulphur are discussed separately from the other elements. Figures 1 through 4 illustrate the nitrogen and sulphur contents (respectively) of foliage samples taken from ARNEWS plots 904 - 915.

Figure 1 and 2 illustrate Nitrogen contents of various ARNEWS species. (Note that Figure 1 is illustrating N content as a percentage of dry matter, whereas Figure 2 is expressed as g/kg; conversions between percentages and ppm have not been made but an example is that 0.18% = 1800 ppm). Notable is the indication that Sitka spruce has a high variance in Nitrogen content. There does not appear to be a significant difference in N contents within species.

Kimmins and Krumlik (1976) present data for foliar nutrient contents in four sites in British Columbia. These sites are the UBC Research Forest, two sites near Prince George, and a site near Squamish. Foliar nitrogen is listed as 40.0% in foliage and twigs at Haney and 30.4% (expressed as a percentage of an above ground total) at Squamish. Krumlick (1979) sampled mountain hemlock and amabilis fir at Squamish, 0.85 percent was determined for mountain hemlock. Unfortunately these species were not sampled in the Seymour or Capilano ARNEWS plots. Douglas-fir and western hemlock were sampled, and probably being younger, more rapidly growing trees the high nitrogen contents of these samples are not surprising.

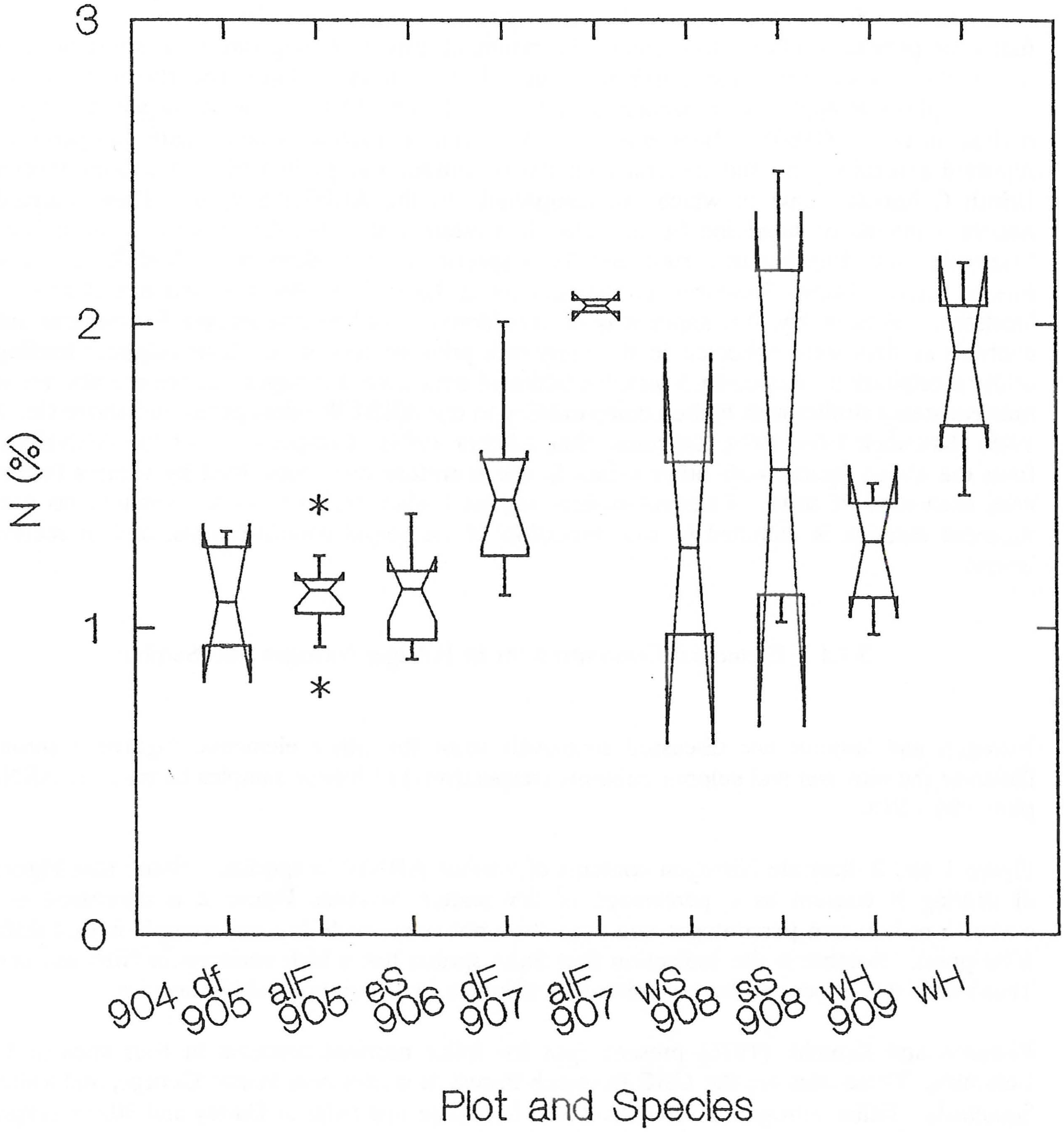

Figure 1. Nitrogen contents of foliar samples (expressed as a percent of dry weight) for ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

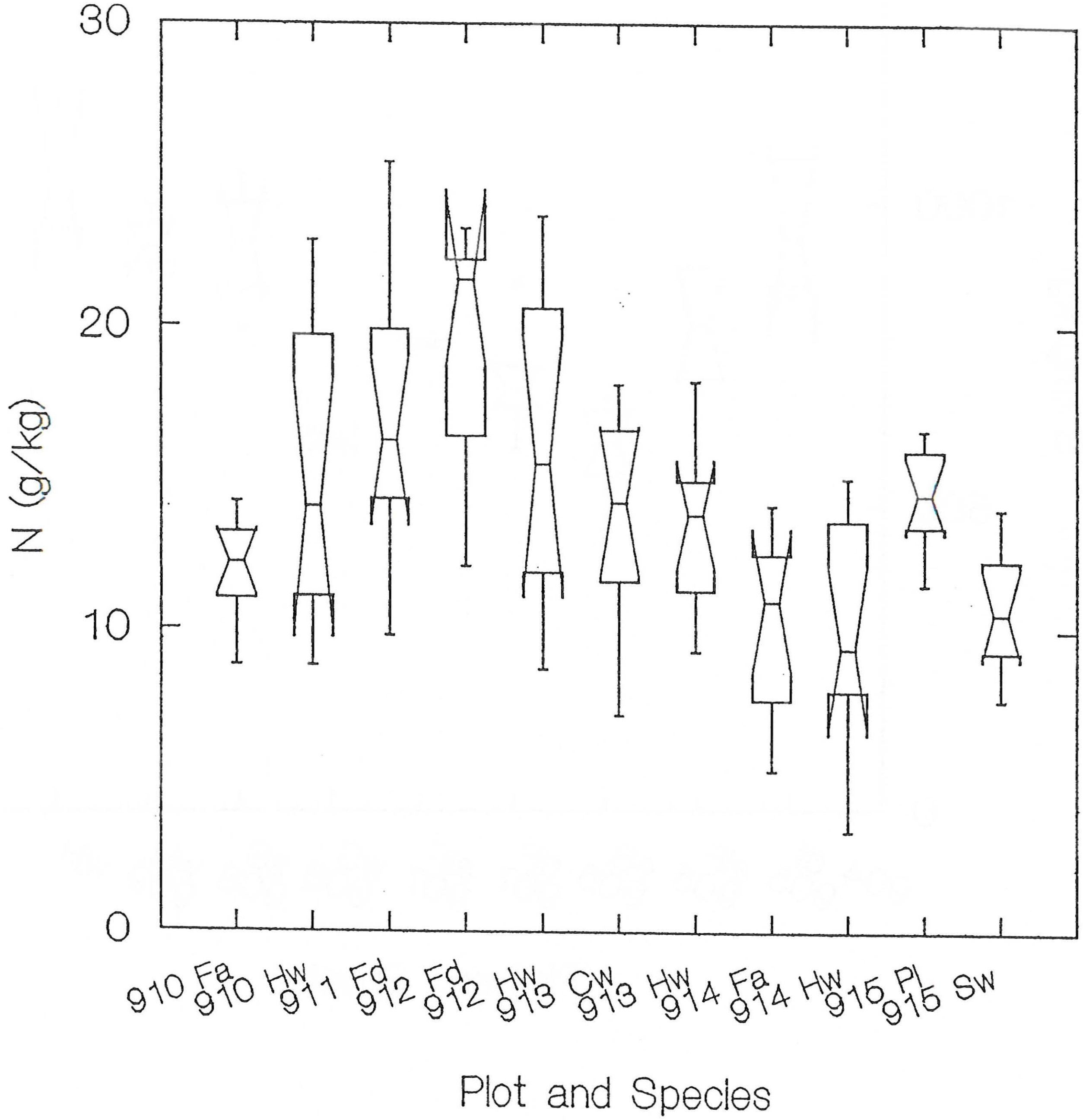

Figure 2. Nitrogen contents of foliar samples (expressed as g/kg) for ARNEWS plots 910 through 915. alf = subalpine fir, Hw = western hemlock, Fd = Douglas-fir, Cw = western redcedar, Pl = lodgepole pine, Sw = white spruce.

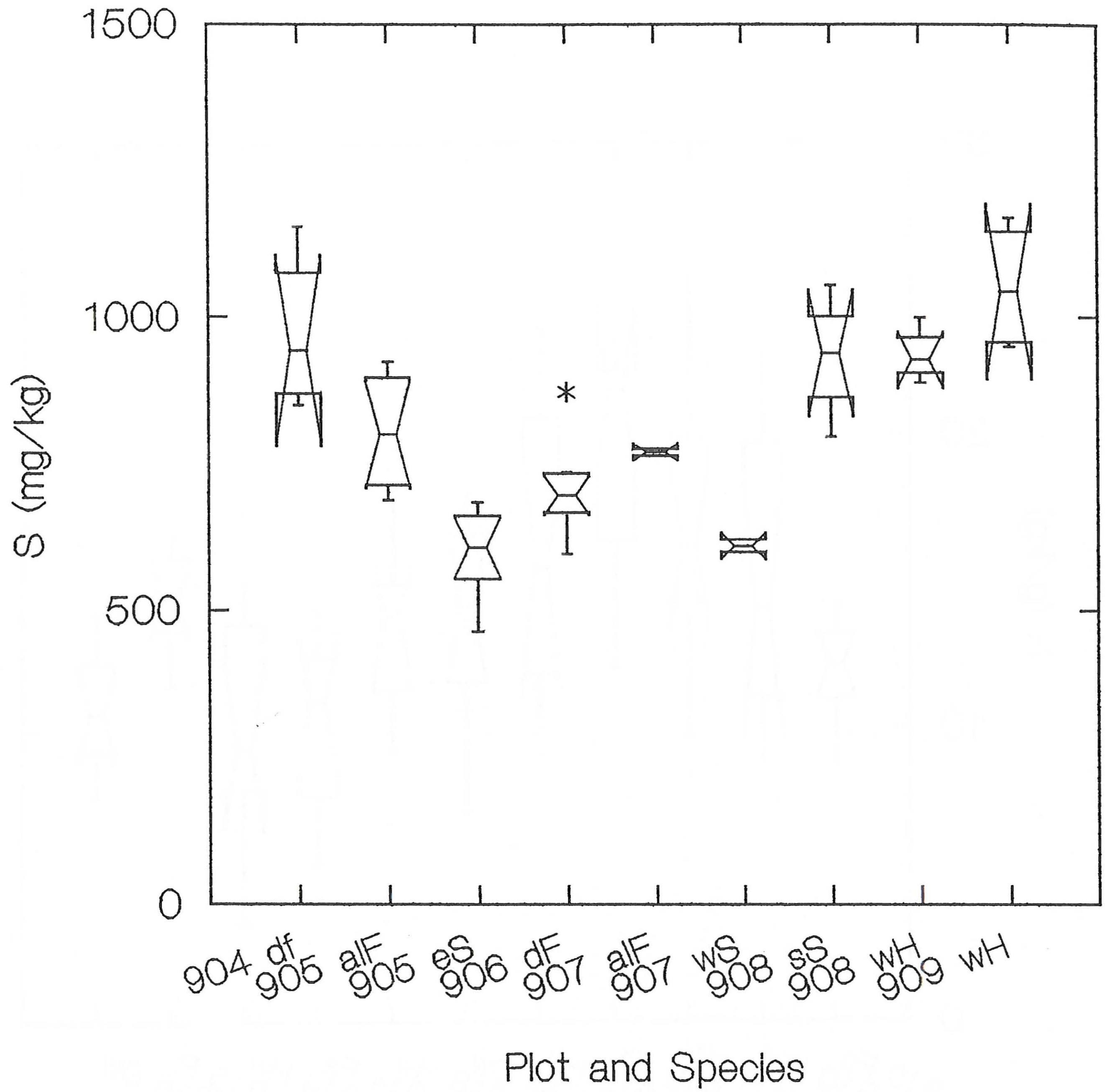

Figure 3. Sulphur contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

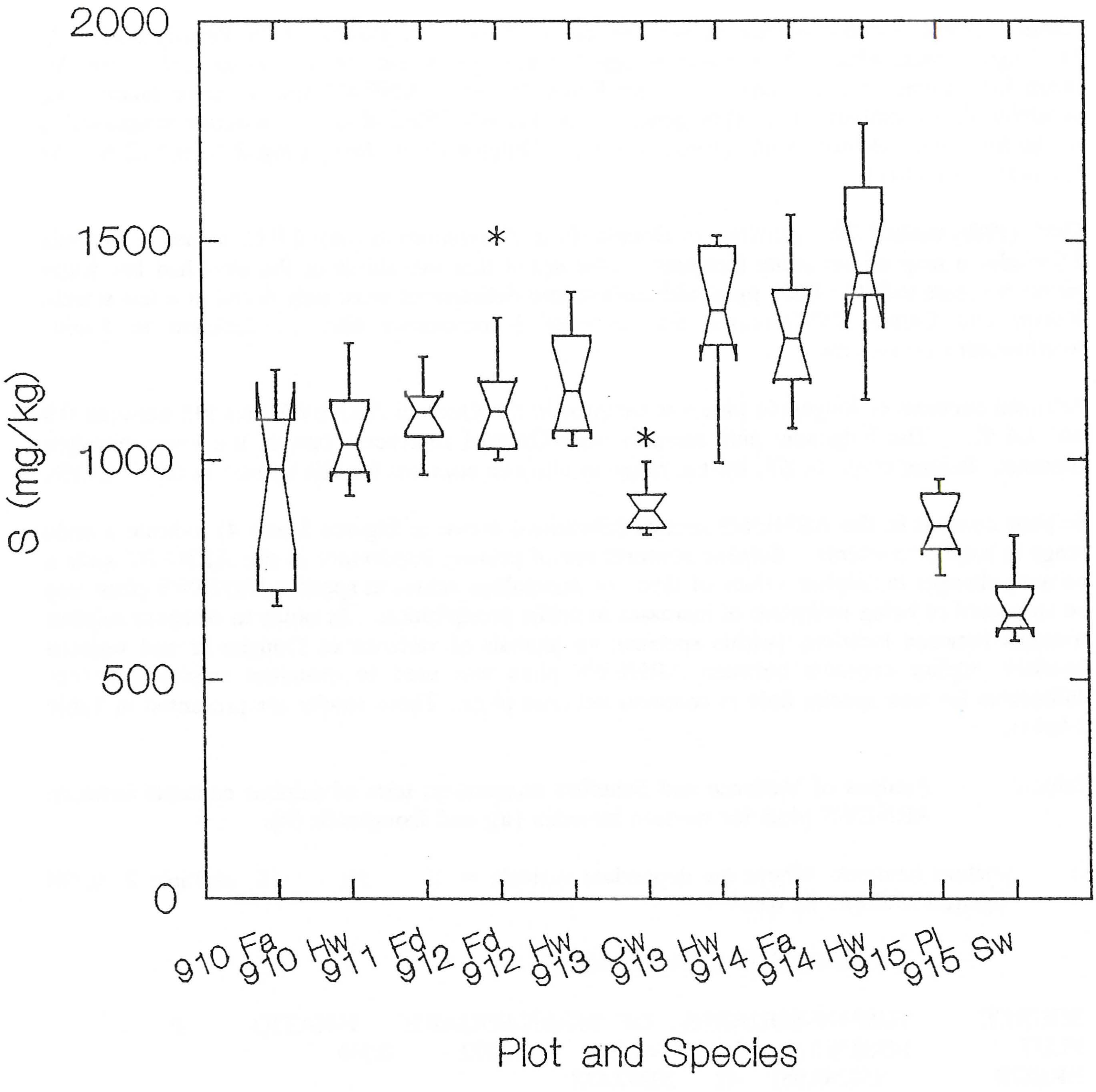

Figure 4. Sulphur contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. Fa = subalpine fir, Hw = western hemlock, Fd = Douglas-fir, Cw = western redcedar, Pl = lodgepole pine, Sw = white spruce.

Kimmins (1984) found that nitrogen contents ranged from 0.82 - 0.94% at the Parsnip River. At McGregor Creek, white spruce foliar nitrogen percentages ranged from 0.90 to 1.07 in samples taken from lower to upper crowns. The Prince George ARNEWS samples were taken from subalpine fir, so comparisons must be general. Coastal ARNEWS plots have a better comparability to the literature. Beaton *et al.* (1965) values for Douglas-fir at Haney ranged from 1.22 to 1.37 (percent dry matter).

Davis (1989) studied foliar nutrition of Douglas-fir in 27 locations in coastal B.C. stands. Appendix 1 includes a map of her study locations. She noted that two thirds of the sites had low foliar nitrogen values (0.930 - 1.551 ppm) although severe deficiencies were only noted in a few stands. Ballard and Carter (1985) stated that nitrogen is commonly cited as deficient in Pacific Northwestern ecosystems.

Nitrogen contents of lodgepole pine was sampled in the Quesnel ARNEWS plot 915 between 0.9 and 1.4 %. The lodgepole pine samples from Quesnel represents one of the lower nitrogen contents; Beaton *et al.* (1965) list the range in nitrogen contents for this species as 0.97 - 1.12%.

Sulphur content in the ARNEWS species (illustrated above in Figures 3 and 4) indicate a wide range in sulphur contents. Sulphur contents are of primary importance in the ARNEWS system because changes in sulphur values of time or anomalous values in specific ARNEWS plots may be suspected of being indicative of increases in acidic precipitation. In order to compare sulphur contents between locations (within species), an analysis of variance of Douglas-fir and western hemlock sulphur contents between ARNEWS plots was used to examines sulphate content differences for tree species held in common between plots. These results are presented in Table 2 below.

Table 2. Analysis of Variance and Scheffe's comparison tests of sulphur contents between ARNEWS plots for western hemlock (a), and Douglas-fir (b).

a) western hemlock; Where the dependant variable = S N: 48 Multiple R: 0.798 Squared Multiple R: 0.637

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT	1498836.874	5	299767.375	14.772	0.000
ERROR	852289.951	42	20292.618		

Scheffe's test:

ROW	PLOT	
1	908.000	A
3	910.000	A
2	909.000	AB
4	912.000	AB
5	913.000	BC
6	914.000	C

Table 2. (cont.) Analysis of Variance and Scheffe's comparison tests of sulphur contents between ARNEWS plots for western hemlock (a), and Douglas-fir (b).

b) Douglas-fir; Where the dependant variable is S, N: 34 Multiple R: 0.870 Squared multiple R: 0.756

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
PLOT	1199740.527	3	399913.509	30.994	0.000
ERROR	387091.314	30	12903.044		

Scheffe's test:

ROW	PLOT	
1	904.000	A
3	911.000	A
4	912.000	A
2	906.000	B

The results of these analysis indicate that western hemlock foliage from the Coquitlam watershed has a significantly greater sulphur content than all other ARNEWS plots where hemlock occurred and was sampled for ash analysis. This includes some of the other ARNEWS plots within the main Fraser River watershed and other areas of the province. The analysis of variance and Scheffe's tests (Appendix 3) indicate that western hemlock foliage in ARNEWS plot 914 (Coquitlam) is significantly different (ie. higher) than 908 (Terrace), 909 (Chilliwack), 910 (Capilano) and 912 (Seymour), but is not significantly different (ie. higher) than 913 (the other Coquitlam ARNEWS plot). Further, ARNEWS plot 913 is significantly different from ARNEWS plots 908 and 910. Also, Douglas-fir foliage from ARNEWS plot 906 (Penticton) has a significantly lower sulphur content than any other ARNEWS plot where this species has been sampled.

Beaton *et al.* (1965) describe the foliar sulphur contents of western hemlock and Douglas-fir in coastal areas of B.C.. Sulphur contents for these species ranged between 1400 to 2500 ppm in Douglas-fir and 1000 and 1500 ppm in western hemlock. Their values for Douglas-fir samples taken from current foliage at Haney, Cowichan Lake, Courtenay, Duncan and the San Juan River range from 1400 to 3000 ppm (converted from percent dry matter). Douglas-fir samples taken from the ARNEWS plots may have lower sulphur concentrations due to differences in techniques from thirty years ago, however. Ballard and Carter (1985) describe foliar sulphur levels as a function of nutrition; percentages of 0.00 to 0.12% could indicate a possible deficiency in Pinaceae, whereas 0.16% (1600 ppm) are considered to be non-deficient. Beaton *et al.* (1965) found that balsam fir contents ranged between 0 .12% and 016%. ARNEWS sulphur contents for this species were considerably lower than this in the Prince George ARNEWS plot, but these analysis were based on a small sample size. Enns (1990) found the sulphur content for subalpine fir in a northwestern, remote study area 500 km NW of Telegraph Creek ranged from 1070 - 1930 ppm (N = 40).

Point source impact studies can be used as a comparison to long range transport. Most of the so-called "biomonitoring network" studies using lichens, or rarely, a combinations of soils, lichens and/or trees (Baker 1977, Addison 1980, Muir and McCune 1988, Enns 1990, Case *et al.* 1985, Case 1984, Frenzel *et al.* 1985, Kral *et al.* 1989, Bargagli *et al.* 1987) were established in an effort to describe the extent of impact over long distances. Sulphur values from impacted systems may possibly be used as a comparison to ARNEWS data and interpreted as a spiked field sample (Keith 1990), to give an indication of the level of sulphur in conifer tissue to be expected in the event of long-range impacts. In a point source study of pulp mill environmental impacts near Port Alice, van Barneveld (*et al.* 1989) listed the sulphur contents of western hemlock, white pine, amabilis fir, Sitka spruce, western redcedar and Douglas-fir at variable distances from the source. Most sample sizes were > 5, except where indicated (data are presented in Appendix 3). Sulphur contents of western hemlock foliage range from to 0.08 to 1.14%. The average contents were 0.23% and were higher than the range of contents of sulphur from those ARNEWS plots with Western Hemlock. Sulphur contents of white pine foliage range from 0.12 to 0.13% (N = 2). Sulphur contents of amabilis fir foliage range from to 0.06 to 0.09%. Sulphur contents of Sitka spruce foliage range from to 0.07 to 0.47%. Sulphur contents of western redcedar foliage range from to 0.11 to 0.17% (N = 3). Sulphur contents of Douglas-fir foliage range from to 0.11 to 0.64%. Figure 3 (above) indicates that western hemlock from ARNEWS plot 909 (Chilliwack), Douglas-fir from ARNEWS plot 904 (Campbell River), Sitka Spruce from ARNEWS plot 908 (Terrace) and many of the species from ARNEWS plots 910 through 914 (Figure 4; Capilano, Seymour and Coquitlam, respectively), all have sulphur levels in foliage comparable to values from van Barneveld (*et al.* 1989). The Coquitlam ARNEWS plots especially have somewhat higher sulphur values than may be expected for a non-impacted, long range transport monitoring plot. However, because true non-impacted controls have not been sampled, it is difficult to say for certain that any foliage samples from the B.C and Yukon ARNEWS plots have accumulated sulphur.

Davis (1989) provides an analysis of the geographic distribution of sulphur contents in Douglas-fir foliage in her southwestern B.C. study sites, many of which coincide with the ARNEWS locations, notably Haney (U.B.C. Research Forest), Squamish, Shawnigan Lake Forest and others (see Appendix 1), and many locations distant from pollution point sources. She found a significant relationship between pH of forest floor layers and proximity Vancouver. Further, she found a significant relationship between higher foliar sulphur in Douglas-fir and low pH of forest floor materials, concurrent with the geographic centre of low pH and proximity to Vancouver. She found that Douglas-fir foliar sulphur contents in low pH sites ranged from 0.149 - 0.203%, whereas in high pH sites, foliar sulphur ranged from 0.091 to 0.139% (smallest n = 10 per site, 27 sites).

Davis (1989) noted that Douglas-fir foliar S concentrations of 0.15 to 0.20% were within the range reported by other researchers where atmospheric sulphur measured in wet deposition ranged from 0.12 to 0.22% (Turner *et al.* 1980, Stednick 1982). Other indications of acidic precipitation or sulphate loading in southwestern B.C. are noted in the literature (Feller 1977, Duncan 1985). The rainfall pH data to support this is presented by Barrie and Sirois (1982); the rainfall acidity in the Vancouver area over the five year period from 1977 - 1981 averaged a pH of 4.75. A normal pH of rainfall is 5.7 (Kramer 1978). These values may not reflect long range transport, however. Rennie (1986) states that 7 million hectares of land in the west (loosely defined to include B.C.) have been significantly exposed to acid rain. From a continental perspective, Auclair *et al.* (1991) estimate that deposition of acidic compounds over the Pacific Northwest is about four times lower than in the northeastern U.S., concluding that the northwest could act as a "control" for comparisons to northeastern impingement. Although pH values are extensively reported, the most recent summary of pH values indicates that the Squamish mountain region northwest of Vancouver is the only area in B.C. currently receiving rain/mist with pH levels low enough to warrant concern (Province of B.C. Ministry of Environment 1990). This may be a function of limited sampling, however.

Sulphur contents of the foliage samples from the 1985-1986 sampling process are of interest for establishing a baseline dataset, but also for examining any pre-sample impacts of long-range transport of sulphate compounds (dry or aqueous) on forest resources. In particular, the concentration of sulphur in second-growth forests are of concern. The impacts of sulphate loading on plantations were examined Winner and Bewley (1978). They document an inhibition of white spruce establishment in areas with sulphate loading. Further, sublethal sulphur dioxide (and subsequent acidic precipitation) are widely related to depression of conifer growth rates (Dochinger and Seuskar 1970, Westman 1974). Reams *et al.* (1990) found that winter injury as a result of acidic precipitation (in the form of acid fog) contributed to reduced radial growth and deteriorating crown conditions in *Picea rubra* but that so far no direct mortality had occurred in this species after several years of study. The threshold sulphur levels for Douglas-fir seedlings are noted as 812 micrograms/meter^3 (290 ppb) after 44 hours (Gough *et al.* 1982).

3.1.2 Elemental Concentrations in Foliage: Phosphorous through Sodium

There are two physiological consequences of acidic precipitation in conifers; hydrogen ion loading and throughfall enrichment by leached cations. Although presented secondarily, here, to sulphur and nitrogen foliar concentrations as indications of potential acidic precipitation through long-range transport, cation loss and metals imbalances are also symptoms of acid rain. Abrahamsen (1980) reported a higher production of foliar calcium and magnesium leachate in conifers exposed to low pH rainfall in his artificial acid precipitation studies. This is borne out in more recent work; Jacobsen (*et al. in press and cited in:* Mattson *et al.* 1990), monitored decreased foliar K, Ca, Mg in Douglas-fir exposed to low pH rainfall where pH's equalled 4.2, 3.4 and 2.6 for 6 - 19 weeks. Presumably, foliar element contents could be used to indicate reduction in rainfall pH and provide a warning of subsequent reductions in radial growth. However, Mattson *et al.*(1990) state that some EPA studies of foliar contents have shown increased nutrient levels, some show decreased nutrient levels in response to pH differences, and some show no effect at all. However, the use of elemental concentrations (other than sulphur and nitrogen/sulphur ratios) to indicate imbalances in environmental sulphur are perhaps secondary to sulphur determinations, but are no less interesting to forest pathologists because they complete the nutritional profile for the evaluation of coniferous forest health. Figures 5 through 21 illustrate the concentration of elements in the foliage of coniferous species from ARNEWS plots 904 through 915.

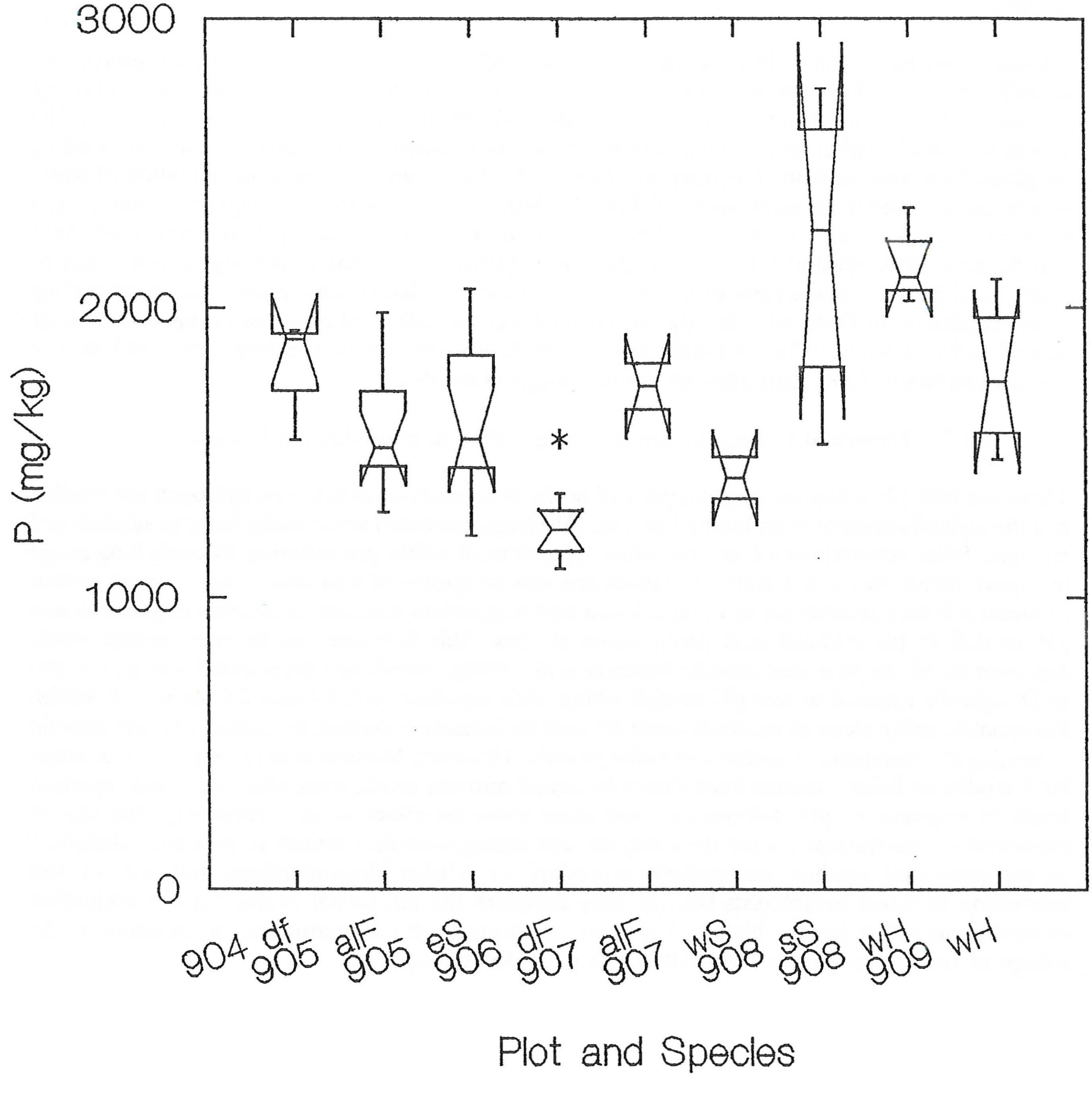

Figure 5. Phosphorous contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

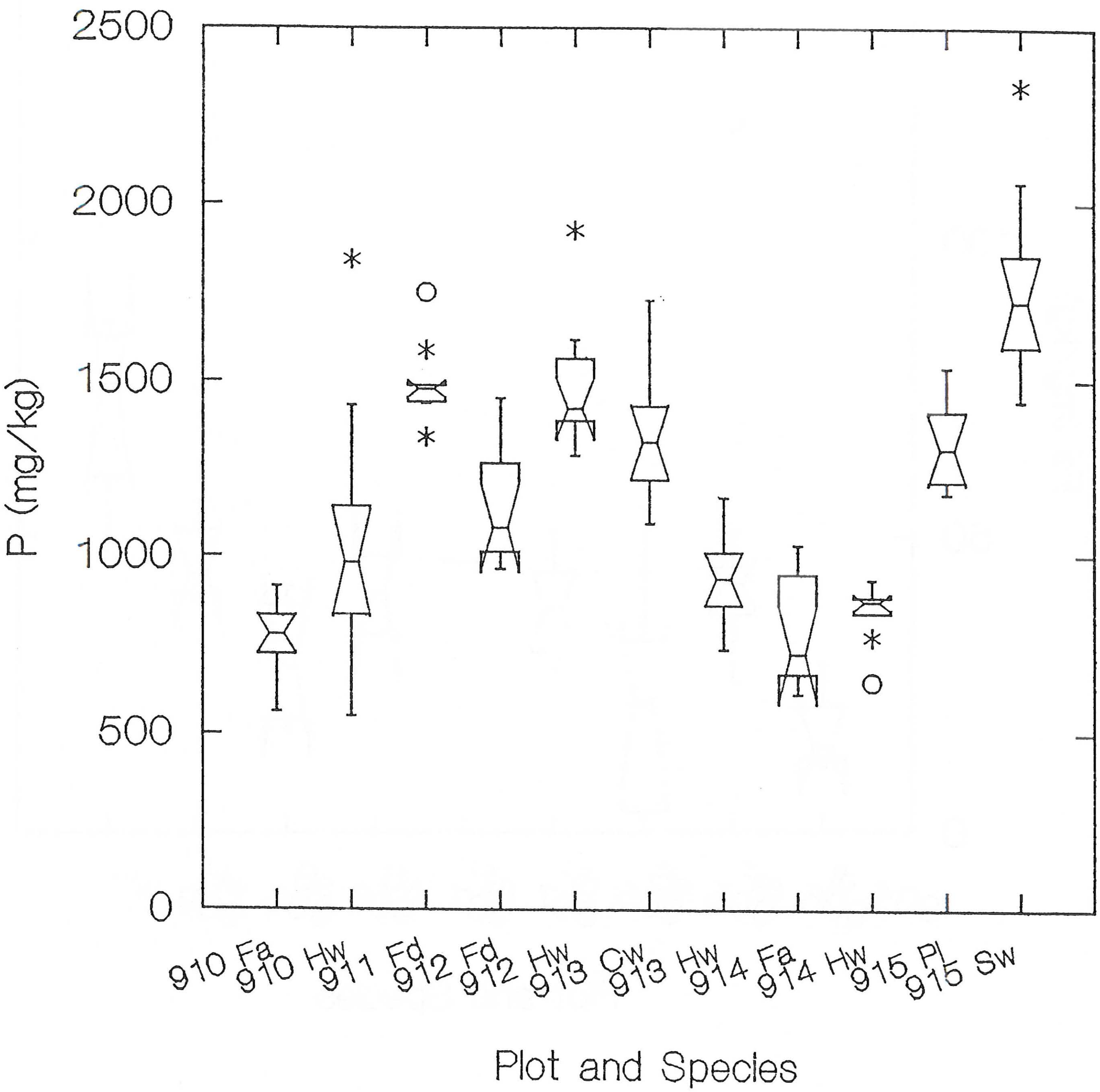

Figure 6. Phosphorous contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. Fa = subalpine fir, Hw = western hemlock, Fd = Douglas-fir, Cw = western redcedar, Pl = lodgepole pine, Sw = white spruce.

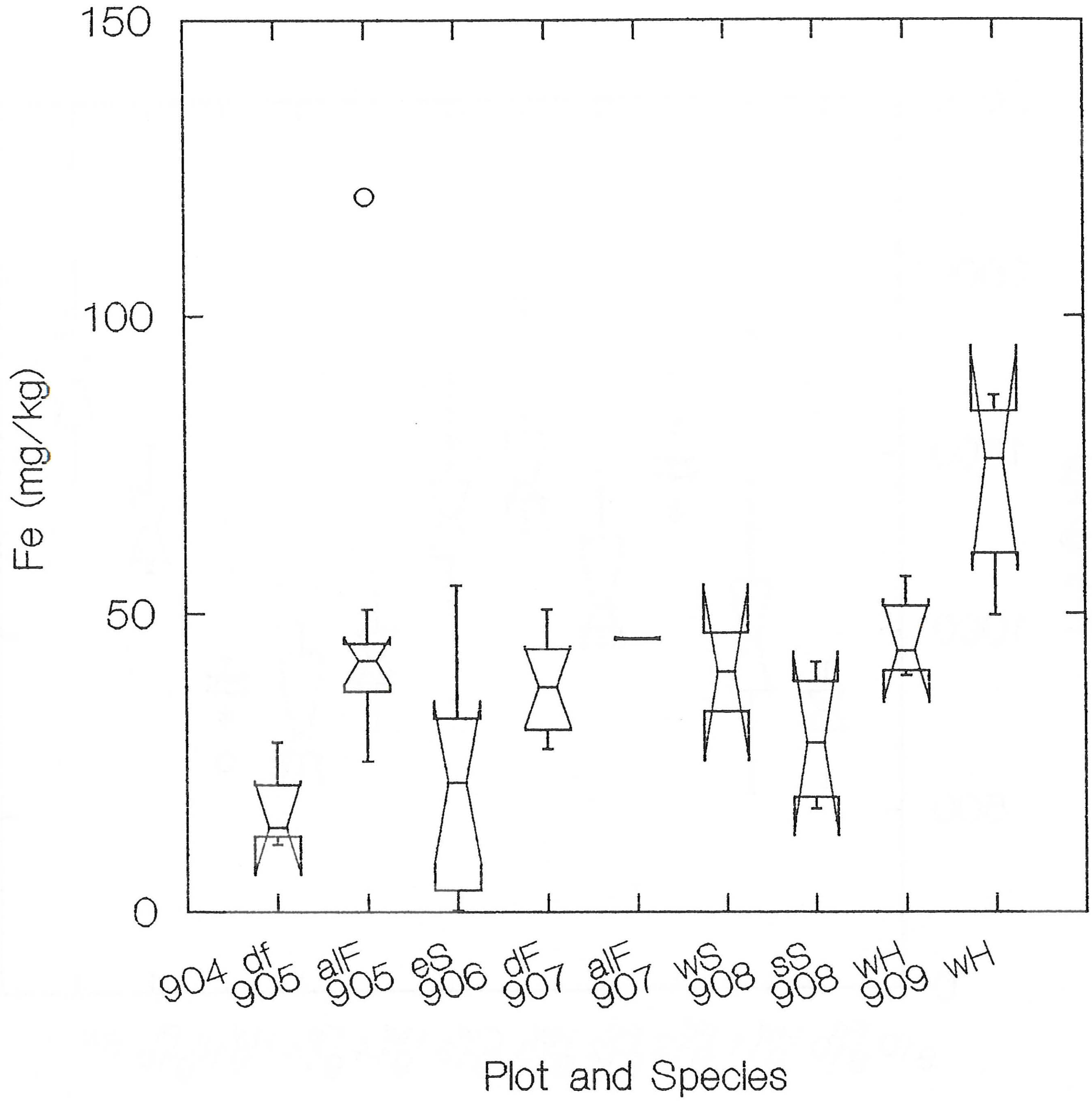

Figure 7. Iron contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock. Note: One anomalous value was removed from the data set; a Douglas-fir sample from ARNEWS plot 904 had an iron content of 4,750.8 ppm (see text).

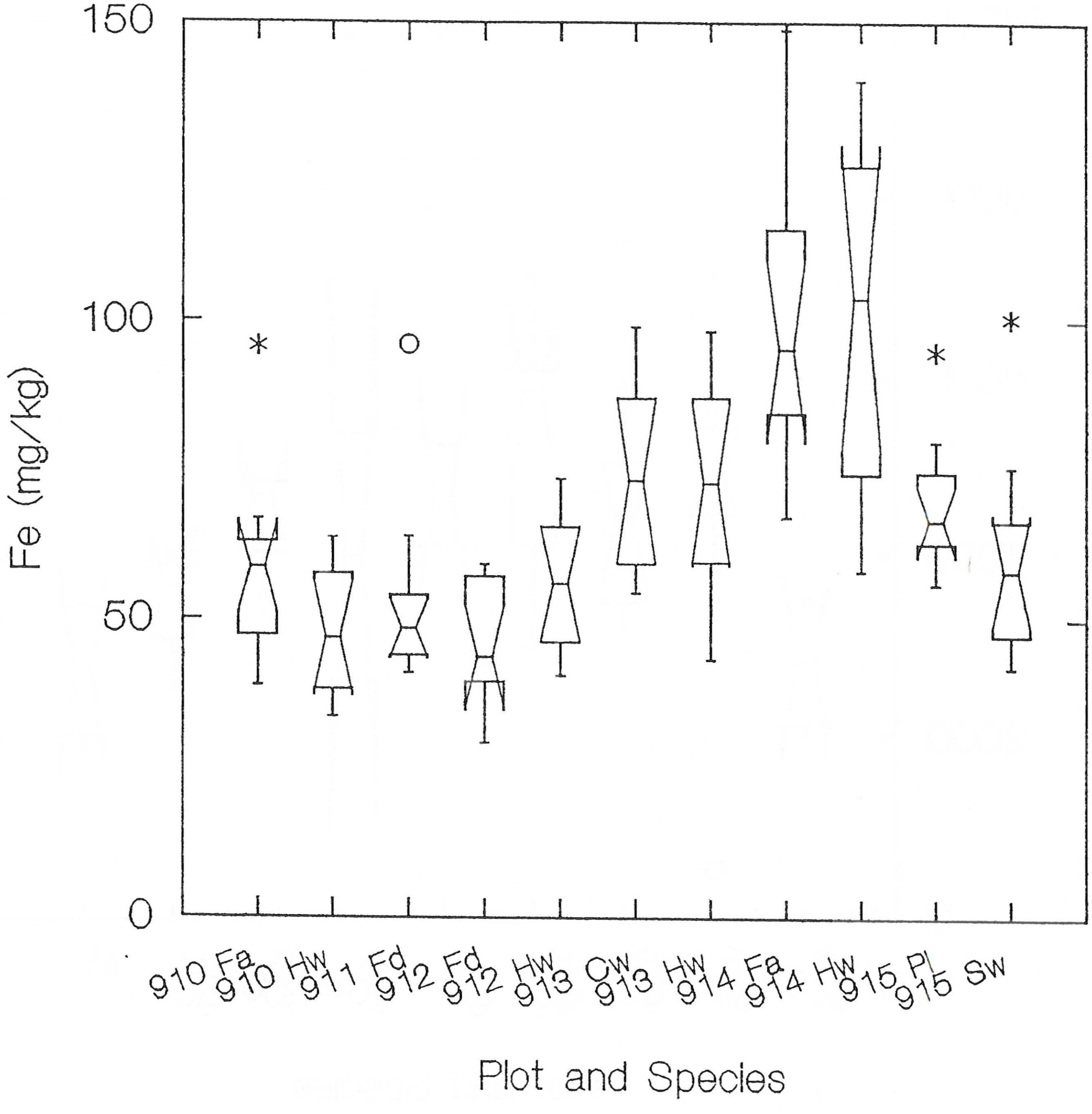

Figure 8. Iron contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. Fa = subalpine fir, Hw = western hemlock, Fd = Douglas-fir, Cw = western redcedar, Pl = lodgepole pine, Sw = white spruce.

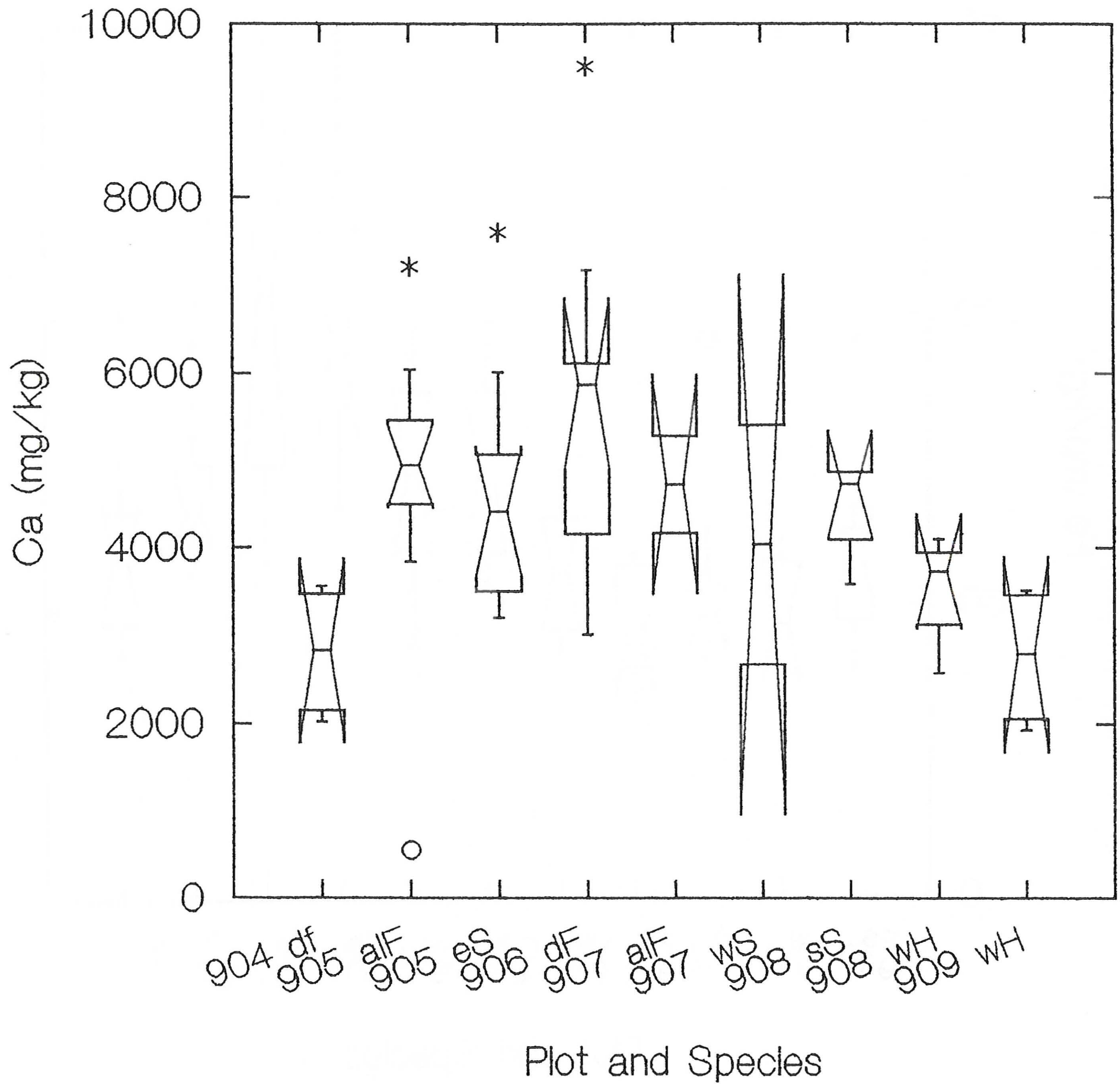

Figure 9. Calcium contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

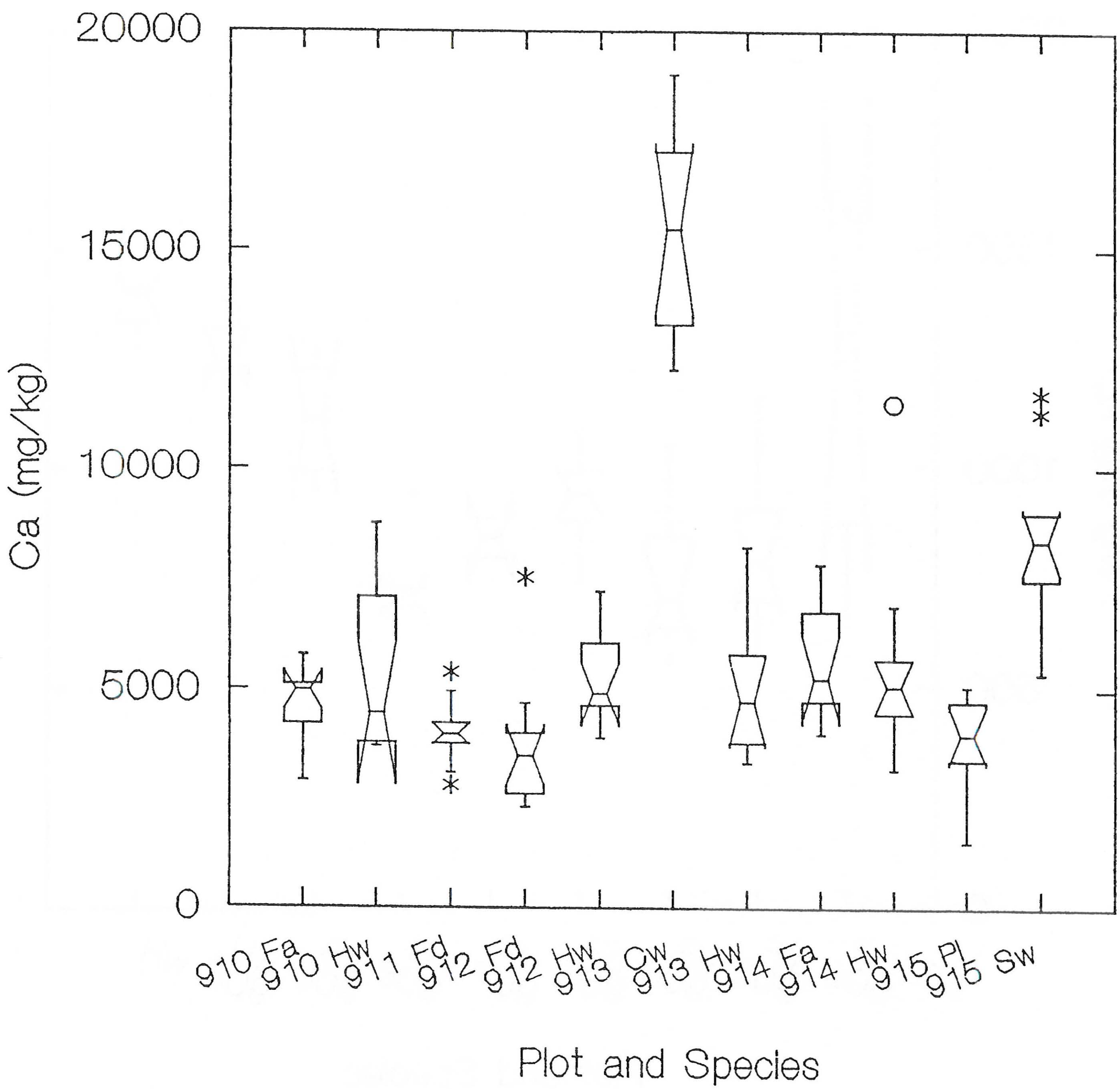

Figure 10. Calcium contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. Fa = subalpine fir, Hw = western hemlock, Fd = Douglas-fir, Cw = western redcedar, Pl = lodgepole pine, Sw = white spruce.

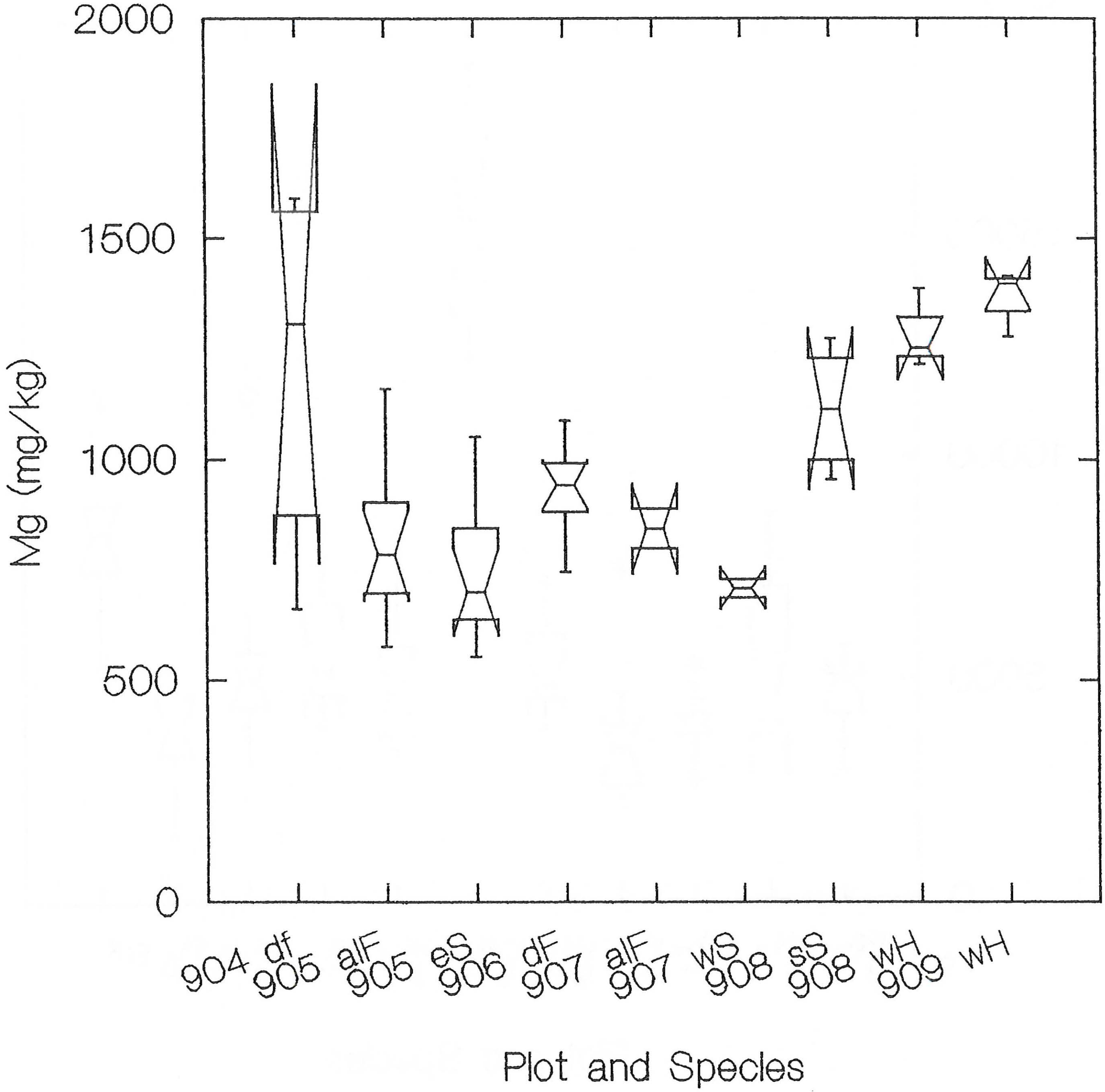

Figure 11. Magnesium contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

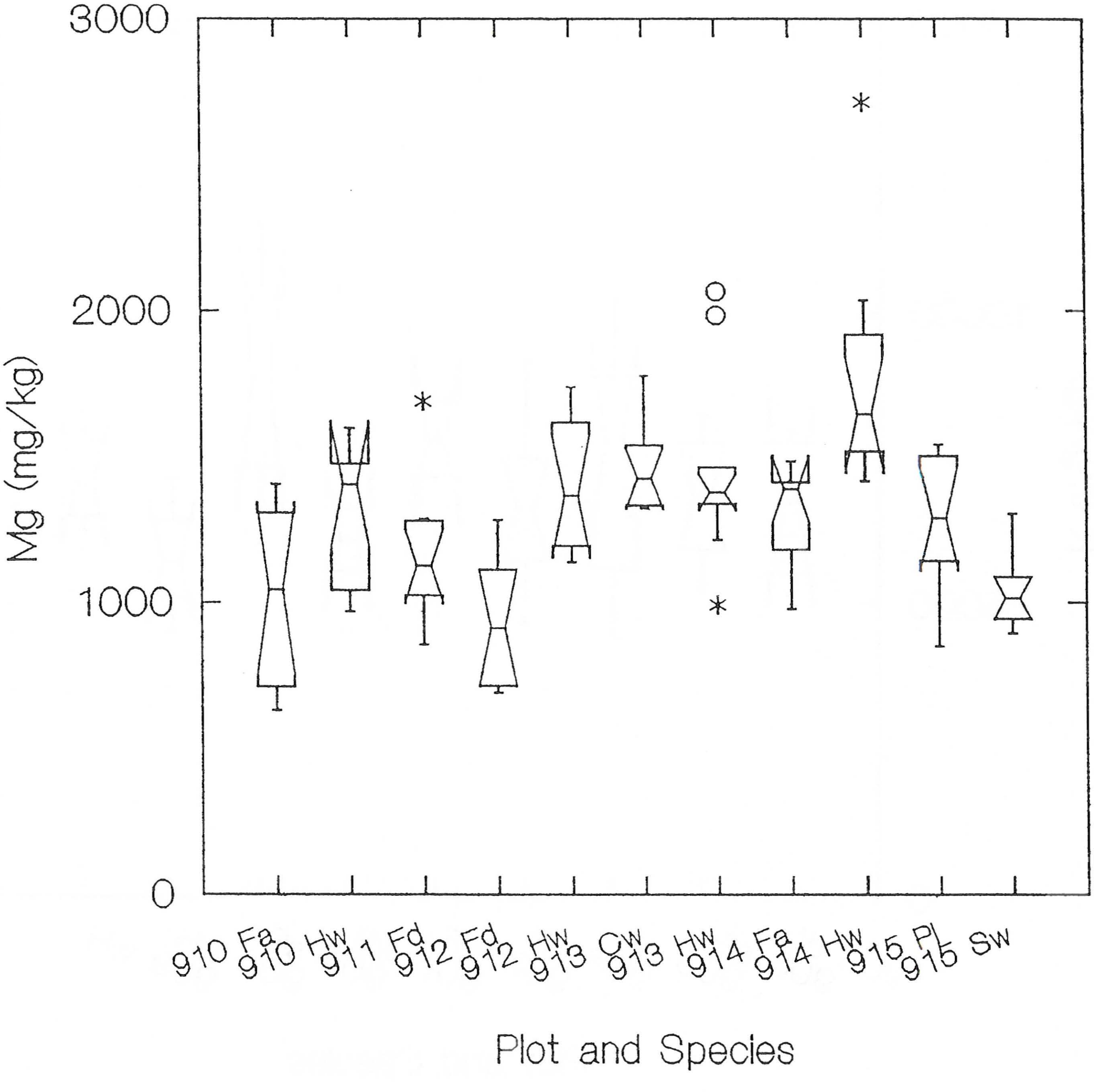

Figure 12. Magnesium contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

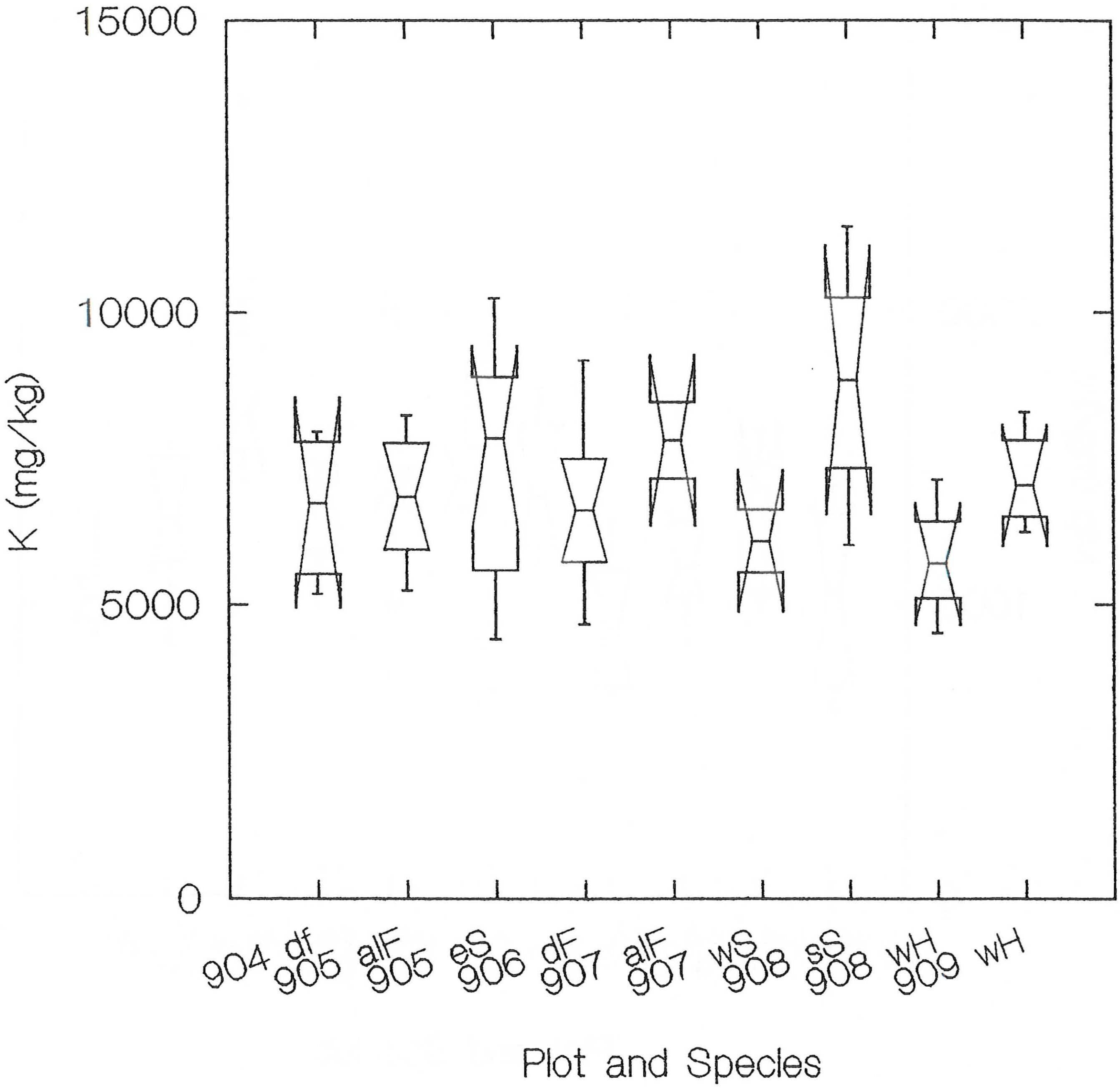

Figure 13. Potassium contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

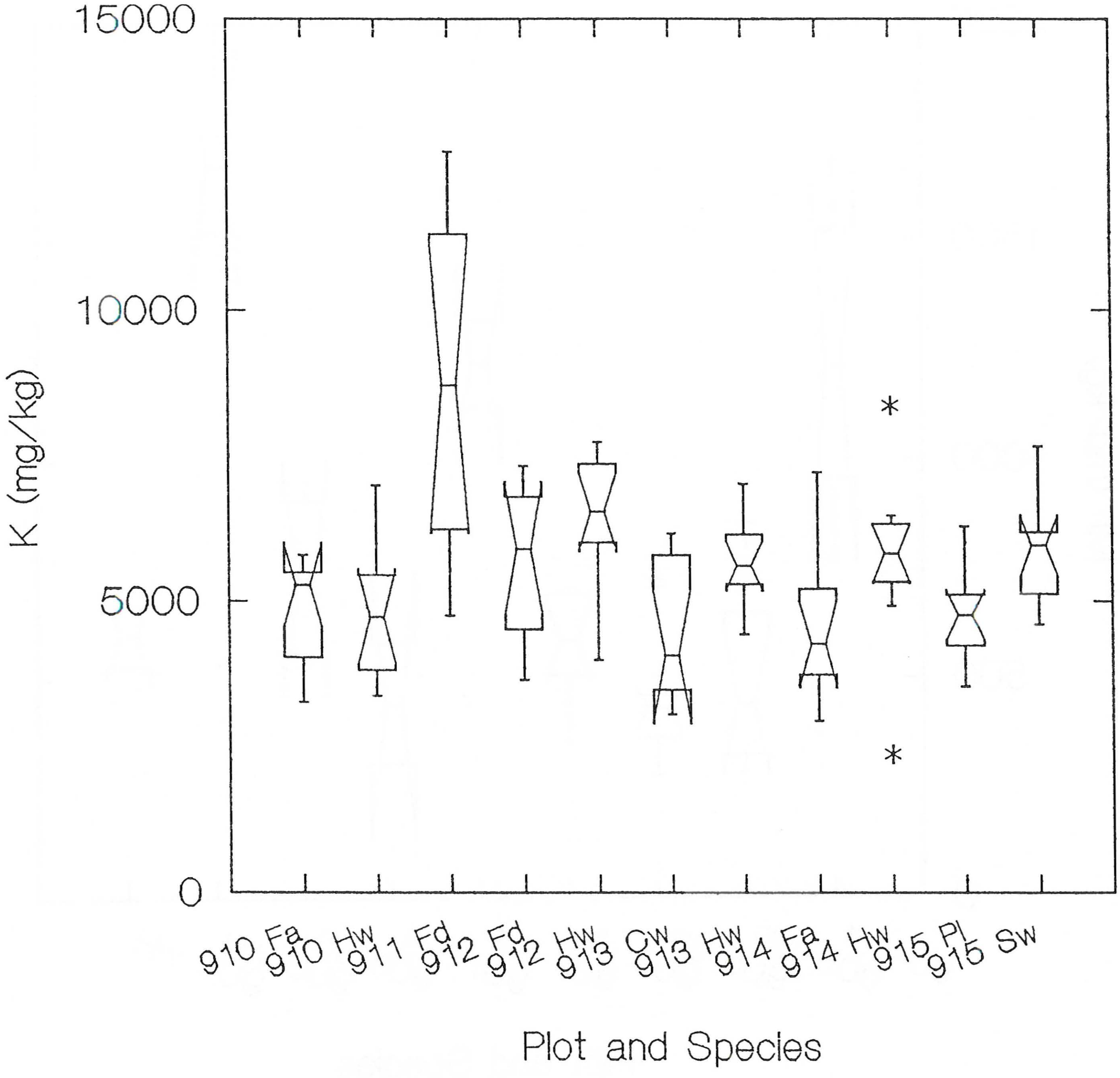

Figure 14. Potassium contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

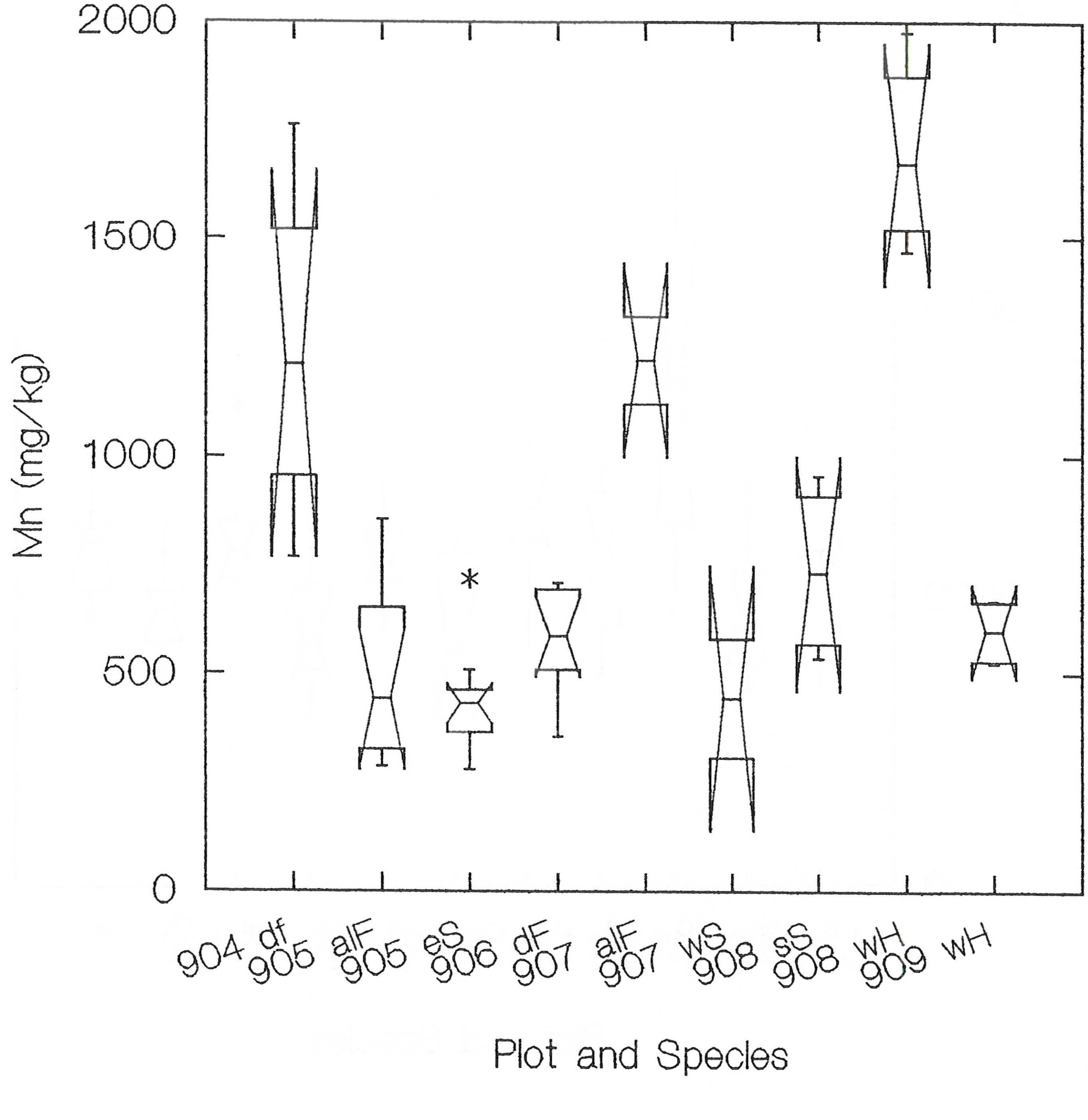

Figure 15. Manganese contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

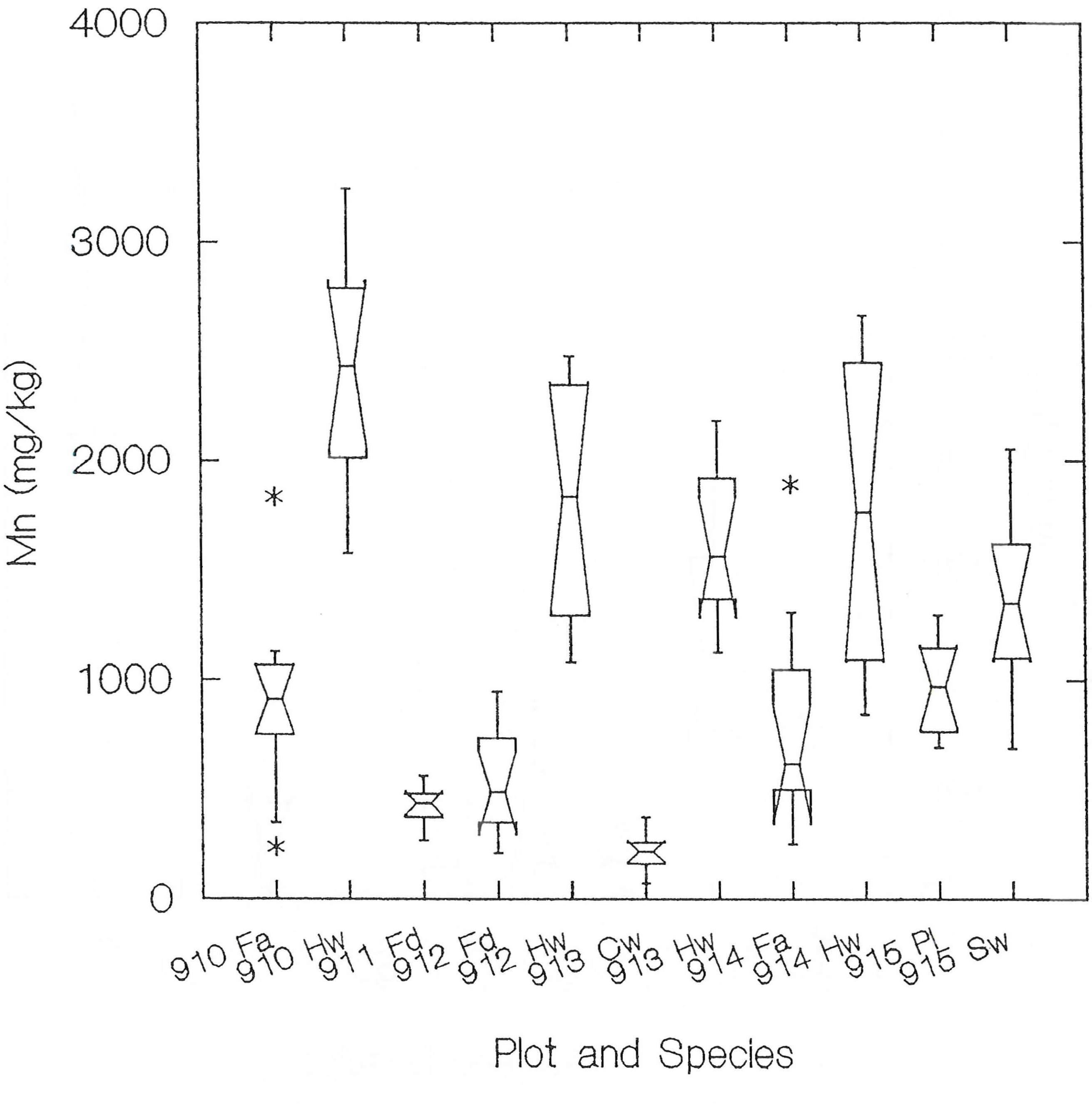

Figure 16. Manganese contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

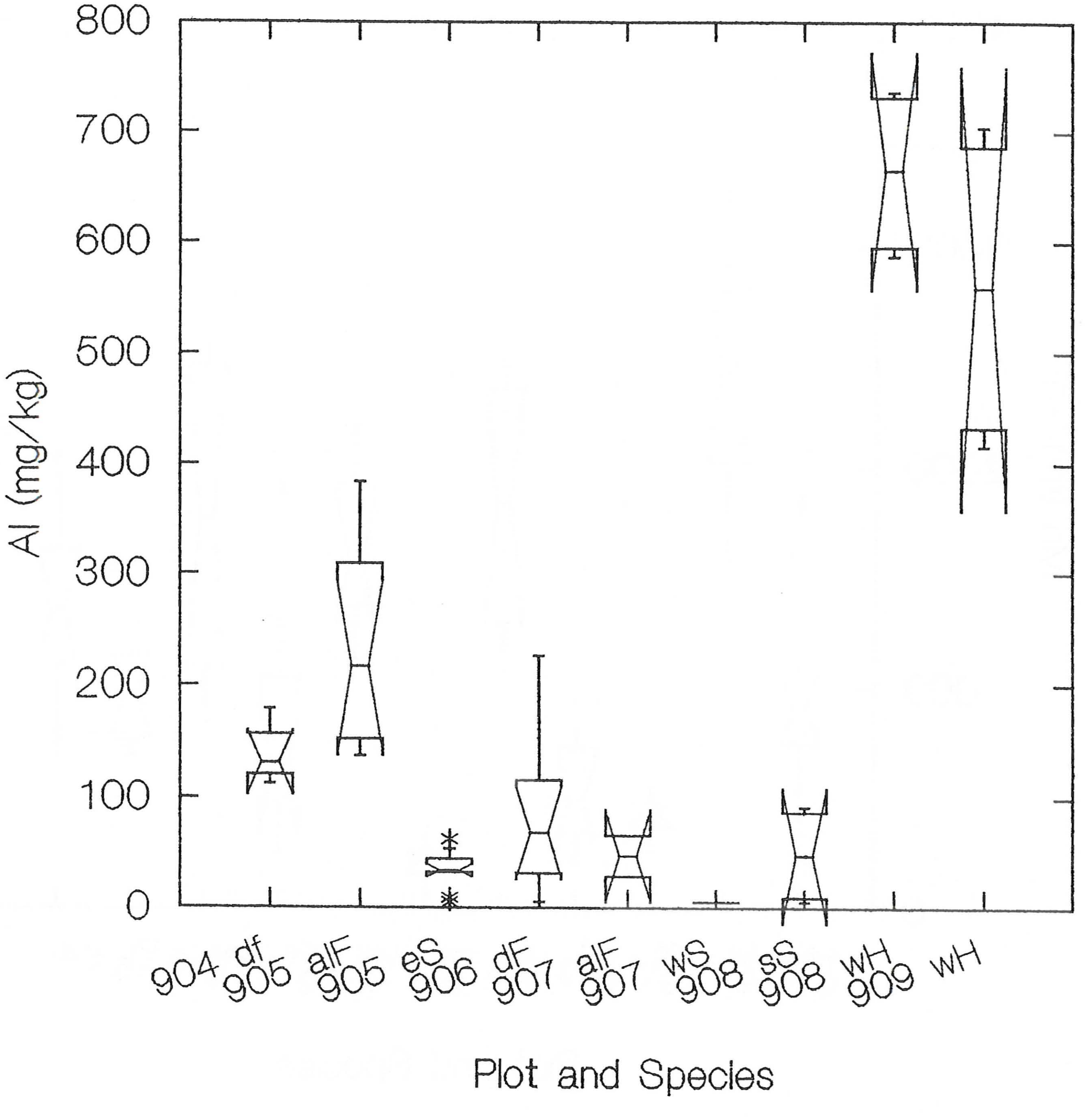

Figure 17. Aluminum contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 904 through 909. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

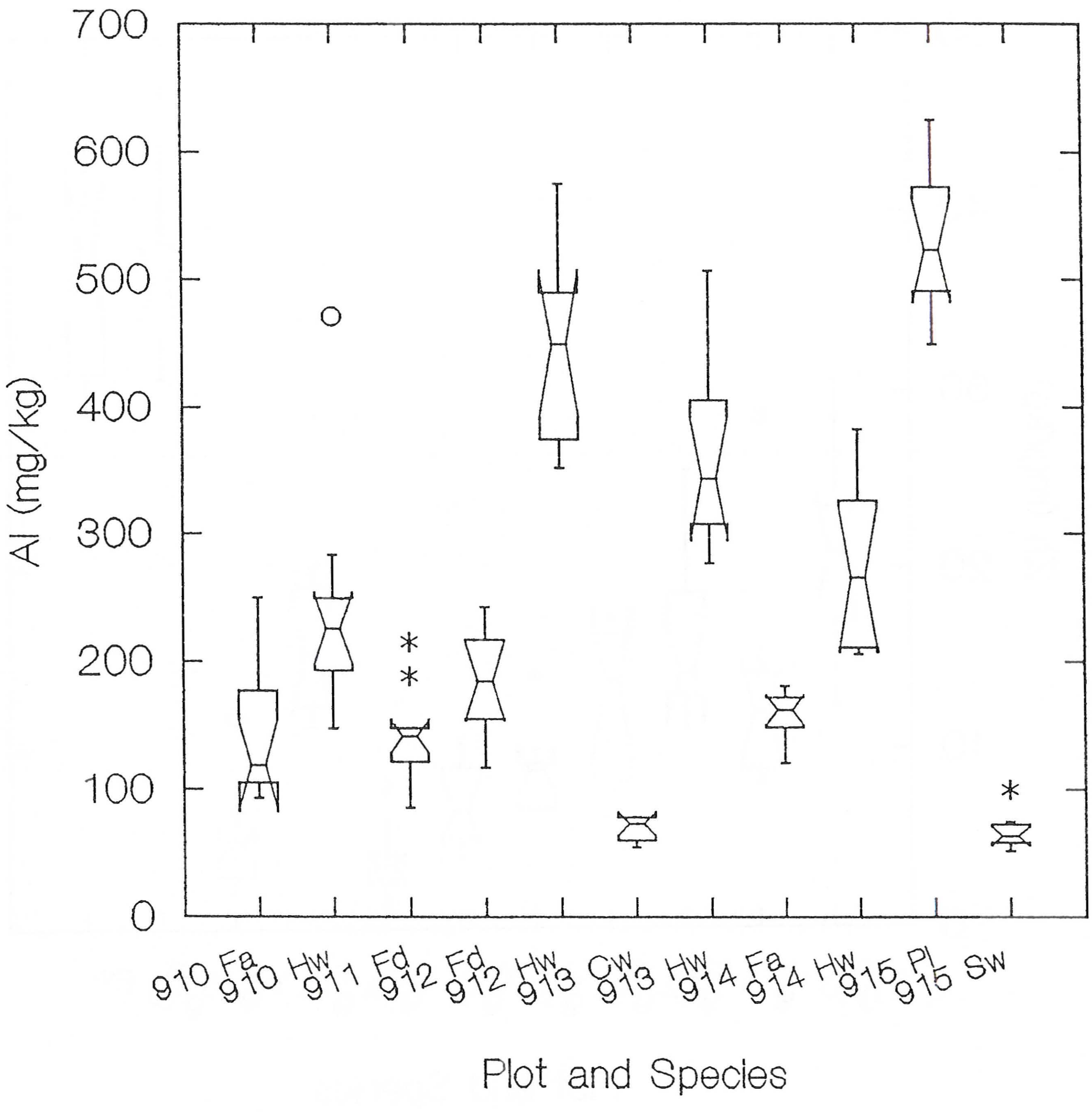

Figure 18. Aluminum contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

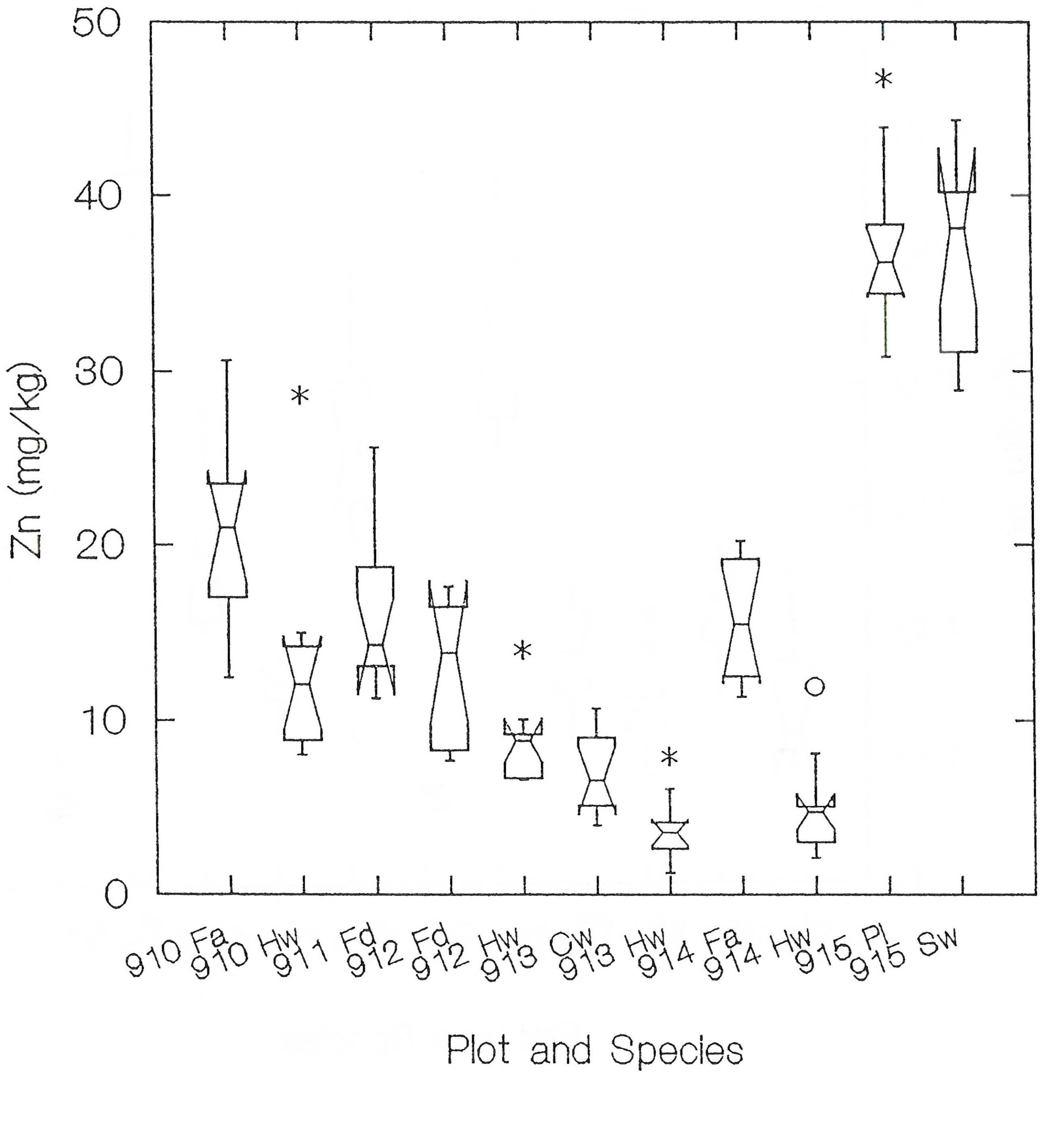

Figure 19. Zinc contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

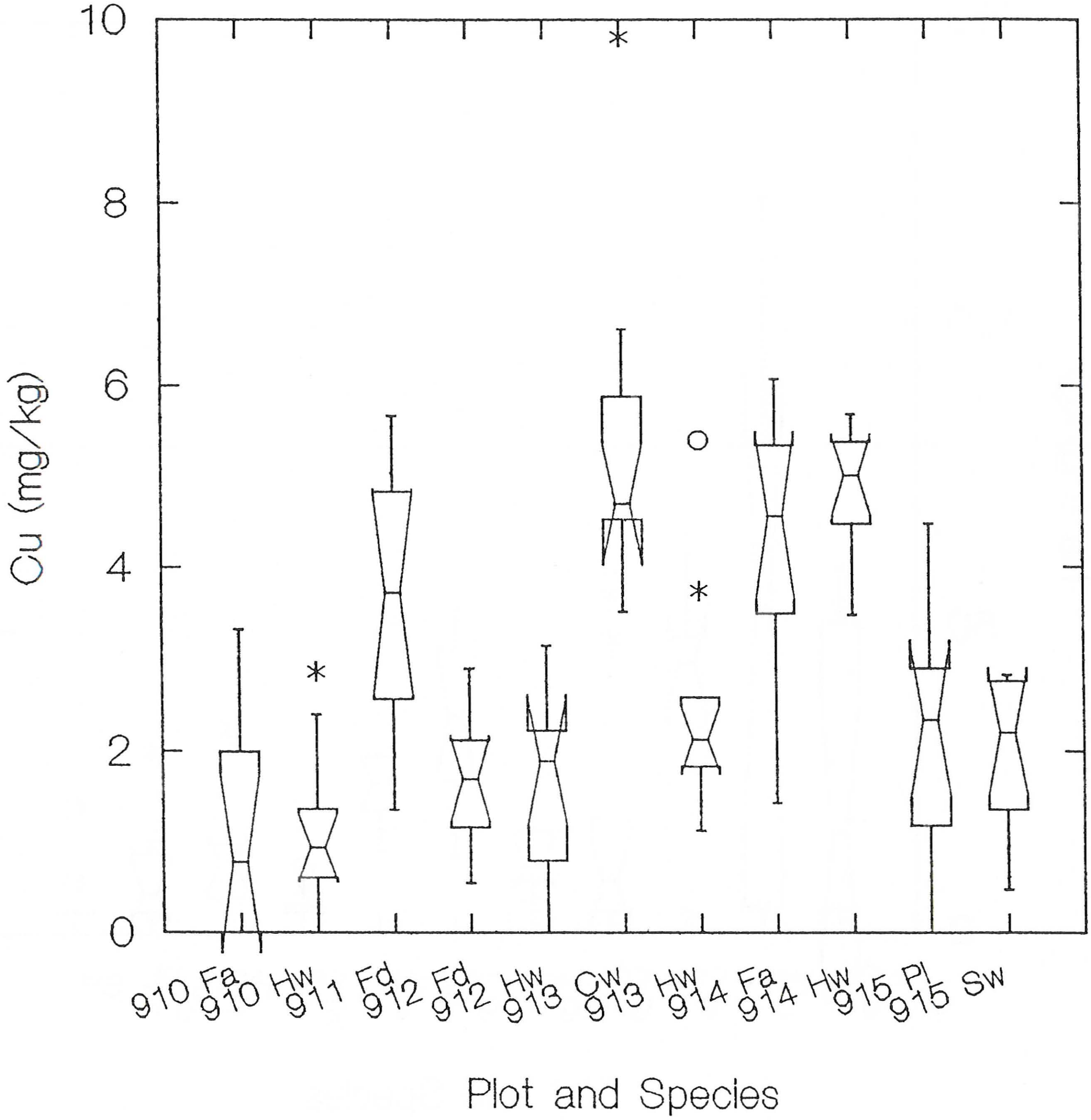

Figure 20. Copper contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

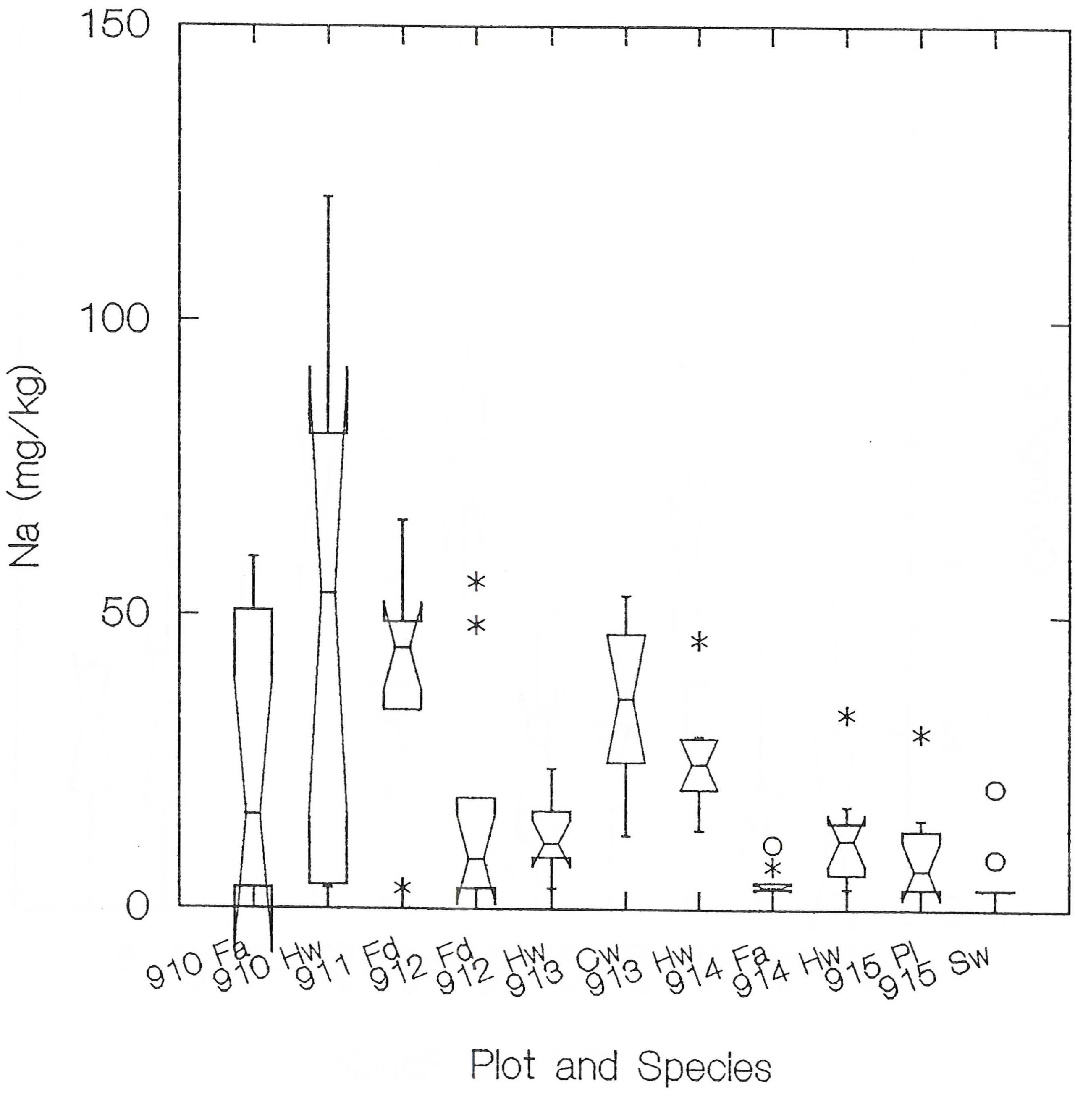

Figure 21. Sodium contents of foliar samples (expressed as a parts per million) for coniferous foliar samples from ARNEWS plots 910 through 915. df = Douglas-fir, alf = subapline fir, eS = Engelmann spruce, wS = white spruce, ss = Sitka spruce, wH = western hemlock.

Figures 5 and 6 display the data distribution for Phosphorous in tree species from ARNEWS plots 904 - 915. Sitka spruce has a fairly wide range of Phosphorous contents. Further, phosphorous contents appear to be highly variable throughout the ARNEWS dataset. Davis (1989) reported phosphorous contents in Douglas-fir foliage from her southwestern B.C. sites. Phosphorous contents ranged from 0.1430 to 0.255 %, with an average of 0.189%. Most of the ARNEWS samples of Douglas-fir had somewhat lower average phosphorous values, with the exception of the Campbell River plot and most of the coastal plots. Seymour and Capilano phosphorous contents in Douglas-fir were also low in relation to the Davis (1989) dataset. Beaton *et al.* (1965) had an average foliar phosphorous content of .21%, which is also high in comparison with the ARNEWS data set. Kimmins and Krumlick (1976) reported a foliar phosphorous content for samples taken in a Hemlock - fir stand in Squamish as 0.23 %.

Figure 7 and 8 illustrate the data distribution for Iron in tree species from the ARNEWS plots 904 - 914. Values range from 0 to approximately 150 ppm. One anomalous value was removed from the data set for the generation of Figure 7; a single Douglas-fir sample from ARNEWS plot 904 had an iron content of 4,750.8 ppm, possibly a result of iron flakes from the pole pruners. Other anomalous iron values occur in the dataset. Subalpine fir samples from ARNEWS plot 905 (Castlegar) has one anomalous value, possibly also a result of contamination. Central tendency of iron is also various. For example, within sample variance can be both high and low for western Hemlock, for example. Such heteroscedasticity indicates that sample reliance is low. However, allowances should be made for natural variation in metal contents. Enns (1990) found similar variance in several metal contents of subapline fir from the Goldenbear Mine north of Telegraph Creek; forty samples ranged in iron content from 102 to 931 ppm. The samples were taken from a metals-rich environment and probably reflected a high natural background fluctuation in iron. Beaton *et al.* (1965) did not determine Fe contents. Douglas-fir foliar iron contents in the Davis (1989) study ranged from 18.50 ppm to 102.5 ppm (mean = 36.312 ppm)

Figure 9 and 10 illustrate the Calcium content of coniferous foliage from ARNEWS plots 904 - 915. Calcium ranges from near 200 parts per million to 1000 parts per million. Increases in rates of foliar Ca^{2+} and Mg^{2+} losses with increasing acidity were observed in red spruce (Joslin *et al.* 1988). However, equating throughfall contents with foliar ash contents, concurrent with increases in acidity of precipitation, is not common in the literature. Jacobsen *et al.* (1990) found that acidic mists increased foliar calcium, potassium and magnesium by 20 to 30% in red spruce. The ARNEWS plots have not had extensive study of throughfall chemistry. The baseline dataset illustrated above can be used for comparisons to later analysis. Most notable are the contents of calcium in western redcedar from Coquitlam plot 913. This species was also shown by Beaton *et al.* (1965) to have twice as much foliar calcium as other conifer species. Kimmins and Krumlick (1976) reported a foliar calcium content for samples taken in a Hemlock - fir stand in Squamish as 13.8%. Ballard and Carter (1985) report that a calcium content of 0.10% is deficient, whereas a content of 0.25 % is non-deficient for Douglas-fir. Comparisons with any other dateset may not be relevant in this case, however, except from a nutritional standpoint. To date, the most common method of determining changes in cation leachate and subsequent pathological symptoms has been throughfall studies.

Figure 11 and 12 illustrate Magnesium contents of tree species in the ARNEWS plots 904 - 915. The same arguments presented for calcium above, apply generally to magnesium as well. Douglas-fir samples taken from Campbell River had a high variance in magnesium contents in comparison to the other ARNEWS plots. Western hemlock from Coquitlam plot 914 also had a single high outlying magnesium value.

Figure 13 and 14 illustrate the Potassium contents of tree species in the ARNEWS plots 904 - 915. Data points describing the central tendency of Potassium contents in foliage are fairly closely aligned to the median values, as compared to other elements. One notable exception is Douglas-fir samples from ARNEWS plot 911 at Seymour Mountain. These values are seen to range outside the other values, from 5000 to 13000 ppm. Kimmins and Krumlick (1976) reported a foliar potassium content for samples taken in a Hemlock - fir stand in Squamish as 19.1 % . Beaton *et al.* (1965) reported an average potassium content for Douglas-fir as .54%. Ballard and Carter (1985) report that a potassium content of 0.08% is deficient, whereas a content of 0.15 % is non-deficient for Douglas-fir. Davis (1989) found a range of 0.638 to 0.904% foliar potassium in a minimum of ten replicates of Douglas-fir foliage from 27 southwestern B.C. sites.

Figure 15 and 16 illustrate the Manganese contents of foliar samples from ARNEWS plots 904 - 915. Foliar contents of this metal are variable throughout the ARNEWS plots and within ARNEWS plots, as well. Ballard and Carter (1985) report that a manganese content of 0 ppm is deficient, whereas a content of 25 ppm indicates no deficiency for Douglas-fir. Western hemlock appears to accumulate this metal at higher concentrations than other species within the same plots. Western hemlock was noted by Ballard (*pers. comm.* 1991) as a manganese accumulator. Further, ARNEWS plot 904 (Campbell River) has a comparatively wide ranging Manganese content in Douglas-fir. Davis (1989) noted than Mn concentrations in Douglas-fir from southwestern coastal B.C. were an order of magnitude greater than the recommended critical level. She found a range of 0.194.2 to 1410.5 ppm foliar manganese in a minimum of ten replicates of Douglas-fir foliage from 27 southwestern B.C. sites. Douglas-fir is also noted by Turner *et al.* (1978) as an accumulator of manganese. Enns (1991) found high manganese contents (ranges of 257 to 2920 ppm) in subalpine fir in the mineral rich Goldenbear mine study area. It is possible that future ARNEWS sampling may indicate that unanticipated accumulation of manganese or other elements may occur in different species from the same ARNEWS plot.

Figures 17 and 18 illustrate the aluminum content of foliar samples from ARNEWS plots 904 through 915. Concentrations of this element are of concern to managers of the ARNEWS program because of the impact that acidic precipitation has on aluminum availability in soils (Hoyt and Nyborg 1971). Acidic precipitation can result in aluminum toxicity, particularly in seedlings, even in podzolize soils where aluminum toxicity was not anticipated to occur, until recently (Hutchinson *et al.* 1986). Baker (1977) found that tissues of lodgepole pine from sulphur exposed sites contained greater amounts of sulphur and aluminum, but less calcium, magnesium and phosphorous than control samples.

Variability of aluminum contents between the species sampled in the ARNEWS plots is high; western hemlock appears to accumulate aluminum to a greater extent than other species from the ARNEWS plots. One notable exception is the Capilano ARNEWS plot which has significantly lower western hemlock foliar aluminum than the other western hemlock samples. Davis (1989) found a range of 99 to 289 ppm foliar aluminum in a minimum of ten replicates of Douglas-fir foliage from 27 southwestern B.C. sites. Aluminum as a nutritional entity is not discussed by Ballard and Carter (1985). The ratio of phosphorous to aluminum is of greater nutritional and phytotoxic significance, as they both occur as a co-precipitate in acidic soils (Hutchinson *et al.* 1986). In an artificial acid rain experiment on red, black and white spruce, and jack pine, Hutchison (*et al.* 1986) found a linear relationship between foliar aluminum and concentrations of aluminum in soils. White spruce foliar concentrations ranged from 41 ppp (@ 0 mg/L Al in soils) to 237 ppm (@ 160 mg/L Al in soils). Seedlings were seen to be growth-inhibited at 20 mg/L Al and upward, and were Phosporous deficient as well.

Figure 19 illustrates the foliar zinc content of coniferous tissue from ARNEWS plots 910 through 915. ARNEWS plots 904-909 were not sampled for zinc. These boxplots illustrate a somewhat higher zinc concentration in foliage from the Quesnel ARNEWS plot, but this may be due to between species differences in accumulation. Davis (1989) found a range of 17.5 ppm to 36.6 pmm (mean = 23.54 ppm) foliar zinc in a minimum of ten replicates of Douglas-fir foliage from 27 southwestern B.C. sites. The two ARNEWS plots where this species was sampled had somewhat lower minimums than this. These were plots 911 and 912, both on Seymour Mountain. Hogan and Wotton (1984) studied zinc accumulation in the foliage of jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) growing near Cu-Zn smelters in Manitoba. Foliar zinc content of jack pine were highest closest to the smelter; contents ranged from 75 ppm to 506 ppm. Black spruce ranged from 62 to 455 ppm. Folkeson and Andersson-Bringmark (1987) found foliar contents of 95 - 140 ppm for Zinc in pine foliage from an area with vegetation impoverished by a smelter operation on the Baltic coast.

Figure 20 illustrates the foliar copper content of coniferous tissue from ARNEWS plots 910 through 915. (904-909 were not sampled for copper). Elevation of copper and nickel in soils has been the cause of some damage to forests near copper smelters (Lozano and Morrison 1981), resulting in the impoverishment of exchangeable bases (Ca and Mg). Copper contents in the ARNEWS samples do not range any higher than 7 ppm. Davis (1989) found a range of 1.3 ppm to 7.73 pmm (mean = 3.6 ppm) foliar copper in a minimum of ten replicates of Douglas-fir foliage from 27 southwestern B.C. sites. The two ARNEWS plots where this species were sampled had similar values (plots 911 and 912, both on Seymour Mountain). Hogan and Wotton (1984) report foliar copper content of jack pine as 3 to 33 ppm and black spruce from 2 to 18 ppm in an impacted ecosystem. They also noted that metal levels in soils had effected foliar nutrient levels in jack pine and black spruce. Folkeson and Andersson-Bringmark (1987) found foliar contents of 11 - 15 ppm for copper in pine foliage from an area with vegetation impoverished by a smelter operation on the Baltic coast.

Figure 21 illustrates the foliar sodium content of coniferous tissue from ARNEWS plots 910 through 915. ARNEWS plots 904-909 were not sampled for sodium. Foliar sodium contents show a broad range in ARNEWS plot 910 (Capilano), but central tendency is relatively high in the rest of the ARNEWS samples. There appears to be a relatively high frequency of outlying points in most of the samples, however. Davis (1989) did not sample for sodium, nor did Beaton *et al.* (1965). This element is not discussed in Ballard and Carter (1985), nor Gough (*et al.* 1982). Enns (1990) reports a range of 83.1 to 105.0 ppm (mean = 95.66 ppm) sodium in the foliage of subalpine fir from northwestern B.C.

3.2 Constraints placed in comparisons between ARNEWS and other datasets

There are a number of constraints based on the interpretation of foliar ash analysis as an indication of long range transport of sulphur compounds. Further there are constraints placed on the comparison of ARNEWS data with data from the literature.

3.2.1 Variability Error

Constraints placed on interpretation of foliar ash analysis data include such factors as introduction of elevated or depressed levels of individual elements as a result of environmental effects. Davis (1989) discusses the sources of variation in foliar element concentration within species. Differences in parent material and geochemical processes can be an obvious source of mineral enrichment not evident from above ground vegetation characteristics. Differences in soil microfloral activity, frequently correlated with moisture, can influence the rate at which elements are taken up, due to differences in availability. An example of this is the effect that increased densities of soil fungi have on iron nutrition. By similar mechanisms, soil structure and moisture-holding capacities will influence foliar concentrations. Krumlik (1974) discusses the degree of variability in foliar nutrient concentrations as a result of differing levels of utilization. The concentrations in foliage for any element may vary, for example, by where in the crown the sample has been taken, and by what percentage of the sample is fine versus small branches. He states that concentration of elements vary such that nutrient concentrations in big branches < small branches < stem bark < twigs. This was true for most macronutrients, with the exception of calcium where he found that stems > twigs and that stems = foliage in western hemlock.

Different ages of foliage are widely recognized as having different concentrations of nutrients. This has been linked recently with forest pathology as a source of variability in foliar element concentration. Santerre (*et al.* 1990) classified element concentrations from several replicates of diseased and non-diseased *Picea* (no species indicated) according to element concentration and needle age. They observed, over a three year period, that nutrients such as Al, Ba, Ca, Sr, Mn and Fe increase with needle age. Mg, K and Cu levels decreased with needle age, and Zn levels increase in healthy trees and decrease in diseased trees. Further, they found that Ba and Sr were higher in diseased trees and Mg was lower. They found that Al, Ca and Mn accumulated more rapidly in diseased trees than in healthy trees. The implications of this to the ARNEWS system is that the use of mineral analysis of foliage may not be sufficient in specific cases where acidic precipitation is only one possible reason for forest decline. Precipitation monitoring, comparisons to controls or manipulated (field spiked) samples may be necessary.

Sample locations on the tree can also introduce variability. Morrison (1985) found that concentrations of K, Ca, Mg, Fe, Z and Na were significantly higher in lower crowns of *Betula alleghaniensis*, in comparison to other crown positions.

Differing weather conditions between sample years introduce variation in element concentrations (Ballard *pers. comm.* 1991). Ammonium uptake, iron and manganese levels may be altered as a result of moisture variability. If the two sample years differ in weather conditions such that one year is extraordinarily wet, root respiration can be impaired and uptake is further retarded.

Sample contamination and sample processing differences can result in different concentrations for split samples. This is particularly true for older techniques, such as calorimetry. In a study involving the cooperation of 46 laboratories, Hume (1973) found standard deviations of 19 to 43% in calorimetric determinations of elements in similar water samples. Samples with adequate replication, repeated over time using the same techniques should be a marked improvement on sample processing from the early 1970's, however. Contamination of field samples is probably more likely than lab-induced variance. ARNEWS sample processing takes place in a comparatively standardized setting using microwave digestions and ICP spectrophotometry which are the error margins are reduced considerably from previous methods (Munter *et al.* 1984). Avoidance of contamination is discussed in detail by Kieth (1990).

The sources of sample variability discussed above are not insignificant. However, the impact of sulphur loading in any of the ARNEWS will most likely result in increases in sulphur content, with variability taken into account. Some suggestions for including the recognition of sample variability into further ARNEWS sampling are as follows;

> Samples should be taken with as many replicates as possible. The variance exhibited in the above figures indicates that >10 samples would be required. Morrison (1985) recommends 30 trees (by species) per stand and 40 to 70 trees if trace elements are to be sampled, but this may be too cost-prohibitive to be realistic. Davis (1989) determined minimal sample for precision in foliar nutrient analysis, her samples were mostly between 10 and 15 trees per site.
>
> Standardized collection materials and techniques should be used. Contamination is suspected to have occurred in some of the samples; perhaps stainless steel clippers could be used. Ballard and Carter (1985) have written an extensive protocol for foliage sampling. This protocol should be followed.
>
> Mid crown samples should be taken and only from current years growth. Sample processing should be done in a closed, isolated room at below room temperature. If mercury is being analyzed (see below), cool room air drying and cool handling is mandatory, as mercury volatilizes at room temperature.
>
> Presumably, soils information for the ARNEWS plots can explain any variance introduced as a result of differences in parent materials.

3.2.2 Interpretation Error

With some notable exceptions, the majority of the British Columbian literature that includes coniferous foliage ash analysis results occurs in the fields of mineral nutrition and nutrient cycling. These studies have different objectives and fall short of expectations for establishing baseline toxicity levels for comparison to ARNEWS data. Comparisons between nitrogen contents are probably one of the most tenuous to make between studies. The units for expression of Nitrogen contents in many papers are frequently in relation to an area (kg/ha see Yarie 1987 p.76, Johnson and Lindberg 1991), or stand type (Kimmins and Krumlick 1979).

Sampling objectives and the sample processing for mineral nutrition studies are expected to be somewhat different, perhaps contributing to some uncertainty about the comparability of results. For example, samples collected for mineral nutrition evaluation are routinely washed (Davis *pers. comm.* 1991, Ballard and Carter 1985, Case *pers. comm.* 1991). This process eliminates road dusts and short range or immediate contamination, as uptake from soils are the main issue for examination. Unfortunately washing also removes the long range deposition of sulphates and metals from the sample.

Nutrition papers are frequently the only datasets with which comparisons can be made and these do not describe elevated levels of elements. For example Ballard and Carter (1985) describe those levels of an element in a given conifer species which constitute very severely deficient to adequate levels of nutrients. These values are useful for evaluating non-long-range transport impacts, but they do not assist in the formulation of toxic levels for British Columbian conifers. Although papers such as Beaton *et al.* (1965) are of obvious interest because they provide a baseline dataset from the early 1960's and a useful comparison to more recent determinations for sulphur in some locations similar to the ARNEWS sites (ie. Haney, Terrace, Okanagan Valley, Cowichan Valley, Quadra Island), methodologies have changed from somewhat roughhewn colorimetric methods to ICP and microwave digestions used in the ARNEWS system (Kalra *et al.* 1989).

Further, tree species are often different for those studies, such as those done by the U.S. Environmental Protection Agency, where toxicity determination is an objective. Studies that evaluate long range transport of sulphates and metals using mineral ash analysis are generally from eastern United States and are concerned with tree species other than those common in British Columbia (Jacobsen *et al.* 1991, Joslin *et al.* 1988, Laurence *et al.* 1989, Schulze 1989, Deans *et al.* undated, Adams *et al.* 1985, Hornbeck *et al.* 1988, Fernandez and Lawrence undated).

4.0 CONCLUSIONS

The baseline dataset presented here indicates some anomalous values, and some interesting preliminary trends in sulphur contents. However, the purpose of describing this dataset is to provide a means of comparison to future data analysis. Repeated measures from similar locations and where possible, the same trees, will be the most useful tool in determining the possible impacts of long range transport of sulphur compounds. The comparisons with values from the literature can only serve to assist in the interpretation of mineral contents in a general context.

The Coquitlam ARNEWS plots appear to be high in sulfur in comparison to other plots. Whether these values have changes from 1986 to the present should be examined using repeated measures analysis (Looney and Stanley 1989, Hand and Taylor 1989). The dataset for this paper is designed to accomodate a second measurement for each datum. The Quesnel and Penticton area ARNEWS plots appear to have low sulphur and high cation contents in foliage. The comparison of these samples with samples from effected areas in Prince George and Quesnel would be useful for future reference, so that adequate definition of extent of damage (should it occur) can be achieved and viable comparisons can be made between forested ecosystems of variable value. As stated earlier, precipitation monitoring in plots suspected of receiving impacts and comparisons to controls or manipulated (field spiked) samples may be necessary in some of ARNEWS plots.

Mapping of foliar sulphur contents of coniferous foliage should be a long-tern objective of any sulphur monitoring program. This is particularly relevant in the Vancouver area forests, which constitute some of the most productive of B.C. resource areas, and also the most vulnerable to acidic and metals deposition. The ARNEWS system can serve as a baseline for determining long-range transport, and would be made considerably more valid as a monitoring system if additional point samples could be taken at distances radiating east and north from the Fraser River drainage. The establishment of back-country controls adjacent to Coquitlam, Seymour and Capilano are recommended, if only to collect a single set of samples, with no formal plot establishment other than records of location, soils and vegetation characteristics. Models for this type of system are readily available in the literature. The additional sampling, if restricted to grab type and sulphur determinations, could be economical and certainly cost effective considering the resource value the system is designed to protect.

If acid precipitation is the main target for discovery and cost of sampling are an issue, managers may consider sampling only for sulphur contents, as the literature is uncertain about the reliability of foliar contents versus throughfall chemistry as an indication of cation loss. Sulphur determinations alone will not warn of heavy metal impacts however. Heavy metals are under-represented in the analysis of ARNEWS foliage. For example, lead, cadmium, mercury and others are absent from this analysis. The impact of acidic precipitation on succeptability to heavy metal toxicity (discussed above) warrants the inclusion of heavy metals in future sampling. This is true for the Vancouver area samples, particularly in light of the slightly elevated lead contents of epiphytes noted in transplanted materials from the Coquitlam ARNEWS plots (Enns 1991). Foliar metal contents have proven to be exact enough to be used as a guide for metals exploration (Warren *et al.* 1968).

Based of the work by Santerre (*et al.* 1990), the pathology of the stand has implications for the interpretation of foliar element concentrations. Further, the implications of stand nutrient status as reflected by foliar concentrations of elements requires that soils and foliar information be analyzed together. Perhaps the ARNEWS data should be examined from an holistic perspective, using parent materials and soils, pathology, cryptogamic biomonitoring and foliar biochemistry as an indication of how all these possibly confounding factors indicate long range transport impacts. A team approach is recommended. The use of the FNA program to evaluate forest nutrition status of the trees (Emanuel 1987) is also recommended.

Finally, the choice of species for sampling in the ARNEWS plots is a function of species importance in these ecosystems, and species availability. However, managers should consider sampling ponderosa pine in the Pentiction ARNEWS plot as this species is reported to be most susceptible to sulphate deposition, whereas Douglas-fir, the sampled species, is comparatively resistant. Although Douglas-fir is the economic imperative, ponderosa pine is a better early warning tool.

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ERRATUM

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Kimmins, J.P. 1974. Nutrient removal associated with whole-tree logging on two different sites in the Prince George forest district. Unpublished report to the Faculty of Forestry, University of British Columbia. 100 pages + appendices.

APPENDIX 1 Pacific Region ARNEWS plots (Van Sickle *pers. comm.* 1991). Davis (1989) study locations and tables from Beaton *et al.* (1965).

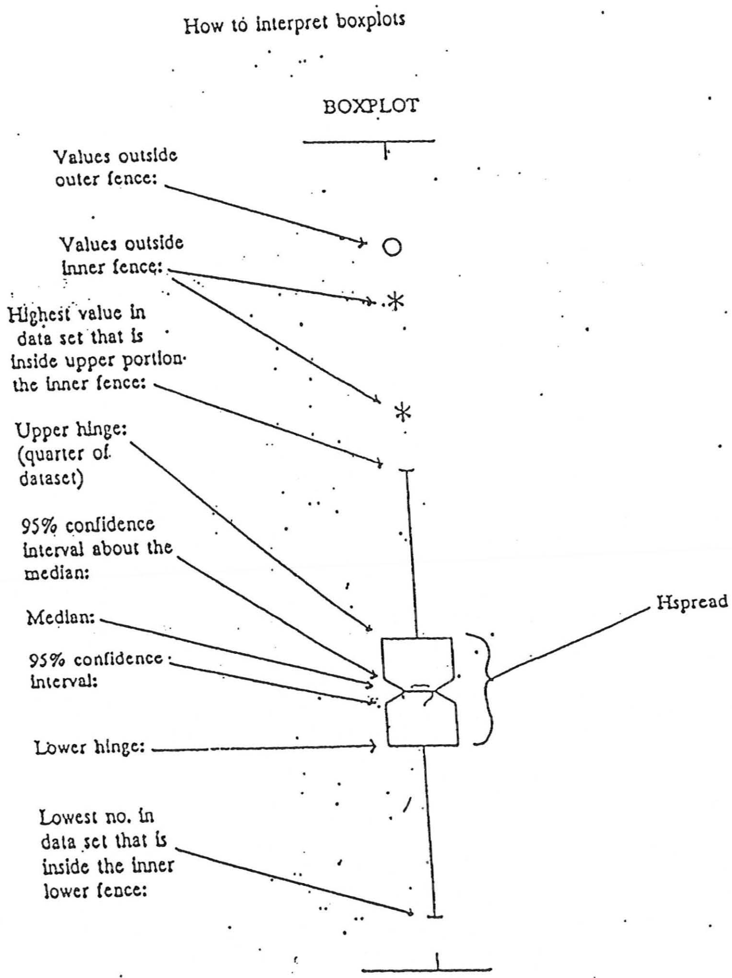
Table A1. ARNEWS plot vegetation and stand structure (*from* Van Sickle *pers. comm.* 1991).

ARNEWS PLOT	VEGETATION DESCRIPTION
901 Shawnigan Lake	Depauperate, probably subxeric*, salal dominated community under a mainly Douglas-fir canopy, with *Kindebergia oreganum*. Coastal Douglas-fir
902 Haney (UBC)	Mesic, moss dominated community under a mixed western red cedar and western hemlock dominated stand. Coastal Western Hemlock.
903 Salspring	Rich, possibly subhygric, moderately well developed vascular plant community under and open to moderately closed canopy Douglas-fir seral stage. Coastal Douglas-fir.
904 Campbell R.	Salal-dominated understory, with good light interception in an open, seral Douglas-fir stand. Possibly subxeric to mesic. Coastal Douglas fir
905 Castlegar	Herbaceous understory, possibly subhygric moisture regime under an open, (relatively) small-stemmed stand dominated by Engelmann spruce and subalpine fir. Upper Sub Boreal Spruce or lower Engelmann spruce - subalpine fir zone transition.
906	Pinegrass dominated, subxeric understory in selectively logged Douglas-fir.
Penticton	Interior Douglas-fir, but bordering the Ponderosa pine - Bunch grass zone.
907 Prince George	Well-developed, herbaceous understory, in an open, seral white spruce dominated stand. Probably subhygric. Sub-Boreal Spruce zone.
908 Terrace	Moss-low shrub co-dominated vegetation in a western hemlock dominated stand with considerable variation in canopy overlap. Probably mesic. In Coastal Western Hemlock.
909 Chilliwack	Moss dominated (?) understory occurring under a western hemlock dominated stand with one central opening in the canopy. Submesic(?). Coastal Western Hemlock.
910 Capilano	Moss dominated (?) understory occurring beneath a relatively closed, amabilis fir-dominated canopy. Submesic (?). Coastal Western Hemlock Zone.
911 Seymour	Moss and liverwort-dominated understory occurring beneath a single-layered Douglas-fir canopy. Probably subhygric to mesic. Coastal Western Hemlock Zone.

Table A1. Cont.	ARNEWS plot vegetation and stand structure (*from* Van Sickle *pers. comm.* 1991).
912 Seymour	Moss - liverwort dominated, relatively species-poor, rapidly growing early seral stage of mixed Douglas-fir and western hemlock. Probably hygric. Coastal Western Zone.
913 Coquitlam	Moss and liverwort dominated, species-poor understory developing under a dense overstory of mixed western hemlock and western red cedar. Probably subhygric. Coastal Western Hemlock.
914 Coquitlam	Moss and liverwort dominated species-poor understory developing under a dense overstory of mixed western hemlock and amabilis fir. Probably hygric; occurring on till but in a poorly drained area. Coastal Western Hemlock.
915 Quesnel	Mixed low light, dry to moist type vegetation indicating a somewhat complicated canopy development; early ingress by lodgepole pine followed by white spruce after a 30 year interval. Moisture regime unknown. Lower reaches of the Sub-boreal Spruce zone.

* NOTE: The moisture regime comments are not based on a on-site inspection of soils and vegetation, but on vegetation lists only.

APPENDIX 2 A labelled example of a notched boxplot (*adapted from* Wilkinson 1988).



A typical boxplot is shown above. A box plot illustrates the distribution of data for a given target species within the dataset for a given treatment. The box is divided by a horizontal line representing the median of the dataset. The outside edges of the box (the hspread) divides the two halves of data in half again. The tails of the data distribution are fit into "Lower and upper fences". These are not plotted on the boxplot but they are defined as:

Inner fences;

lower fence=lower hinge - (1.5Hspread)
upper fence=upper hinge + (1.5Hspread)

Outer fences;

lower fence=lower hinge - (3Hspread)
upper fence=upper hinge + (3Hspread)

The outer hinges or vertical t-lines above and below the box represent the highest and the lowest values in the data set that are inside the upper and lower inner fences.

The occurrence of a smaller lower half of the Hspread indicates more instances of data occur in the lower range of measurement. It also indicates the degree of skewness, or in this case positive skewness of the data.

The notch above and below the median represents 95% confidence interval about the median, such that the observer can be 95% sure that notch a (below) is significantly different from notch b;